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RESEARCH ARTICLE

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Circular supply chains in manufacturing—Quo vadis? Accomplishments, challenges and future opportunities

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Abstract

Circular approach in manufacturing supply chain (SC) operations yields multiple benefits through optimal utilisation and consumption of resources. This study maps the scope and structure of circularity in the manufacturing SC discipline and explores the evolution of the domain over time. We review 946 journal articles published between 2013 and September 2023. Our study identifies key drivers and barriers to circular economy (CE) deployment in manufacturing SC operations, bibliometric parameters, emerging research themes, decision support tools, theories and applications. Using the theory extension approach, we propose a strategic framework to fortify the deployment of circularity in SCs. This comprehensive study renders a methodological contribution through combined descriptive content analysis and bibliometric and network analyses to evaluate the circular manufacturing SC operations concepts, theories and applications. We posit that manufacturing firms require to deploy innovation-led approaches to embed the CE strategies in their SC operations. We find that the studies investigating green skill development and circularity-culture adoption can facilitate manufacturers to understand the efficacy of circularity in their SC operations. The findings of this study can facilitate the practitioners to identify the links between the CE approaches and their strategic implications and examine CE implementation at the strategic level.

KEYWORDS

circular economy; circular theories, strategies, applications; descriptive content analysis; manufacturing supply chain operations; network analysis

1 | INTRODUCTION

Over the last few years, manufacturers have been encouraged to maximise the value of their products and simultaneously eliminate disparate wastes in their supply chains (SCs) through circular economy (CE). The Ellen MacArthur Foundation (EMF, 2015) described CE as 'an industrial system that is restorative and regenerative by design'. CE emphasises a circular approach to materials and energy in SCs for yielding economic, environmental and social benefits through process and product innovations. CE has significant business implications in manufacturing SC operations (Andersen et al., 2022; Kazancoglu et al., 2018). To exemplify, the Carlsberg Group has recently developed a biodegradable 'paper' beer bottle made from recyclable fibres. The innovative packaging solution helps them reduce the carbon footprint in their SC, the majority of which arise from their packaging (Carlsberg Group, 2019). Some textile companies, including Levi Strauss, have contributed to process innovation and partnered with an intermediary enterprise for collecting clothing suitable for reuse and recycling (I:Collect GmbH, 2021). Adidas establishes circularity in their sneaker SC by recycling plastic collected from the ocean (Pugh, 2019). IKEA, a Swedish organisation, has recently launched a buy-back scheme for customers giving vouchers in exchange for the return of unwanted furniture and other items. They have adopted this step to fulfil their climate targets by 2030 (IKEA, 2023). General Electric (GE) adopts circular strategies for using rhenium in the aerospace industry, in particular in the production of jet engines. GE uses rhenium because of its wear-, heat- and corrosion-resistant properties. While GE's circular strategy relies on reclaiming the metal from end-of-life engines, they target to minimise and reduce the use of rhenium (GE Aviation, 2010). The government of Scotland has adopted a 'zero waste' policy. The underpinning of these policies lies in reducing environmental degradation and enhancing sustainable lifestyles through reusing and sharing resources. These policies fortify the grounds for achieving CE (Surminski, 2021).

CE in manufacturing SC operations is gaining momentum for providing a better alternative to the traditional linear 'take, make, use and dispose' model by minimizing environmental burdens and stimulating the economy (Bressanelli et al., 2022; Geissdoerfer et al., 2017). A transition from the linear to the circular approach brings economic, social and environmental benefits (Genovese et al., 2017). CE promotes the reduction of material and energy usage, waste reduction and reuse and recycling of resources to lessen negative environmental impacts and boost economic growth (Jabbour et al., 2019; Orji et al., 2022).

Although CE in manufacturing SC operations provides several competitive advantages (Genovese et al., 2017; Uhrenholt et al., 2022), studies on circular SCs in manufacturing are still at a nascent stage. The extant literature examines various perspectives on the nexus between circularity and manufacturing. The circular SC literature introduces many concepts and strategies integrating CE with manufacturing SC operations (Ahi & Searcy, 2015; Ciliberto et al., 2021), such as sustainable SC operations, green SCs, environmental SCs, low-carbon logistics, reverse logistics and closed-loop SCs (Gurtu et al., 2015; Howard et al., 2019). However, the extant literature on this domain is fragmented and spread across several associated functional areas, which pays limited attention to circular business model implementation in SCs (Lieder & Rashid, 2016). The literature reflects some strategic-level concepts of CE and concepts pivoting around some functional areas, such as design, procurement and production and so forth (Polotski et al., 2017; Unal & Shao, 2019). Circular utilisation of resources may be achieved through the long-lasting design of the product, effective maintenance, reusing, recycling, remanufacturing and refurbishing (Centobelli et al., 2020; Pan et al., 2015).

Studies explore the nexus between circularity and manufacturing SC by employing qualitative and quantitative methods (Bressanelli et al., 2022; Farooque et al., 2019). Recent literature emphasises a dearth of holistic approaches for examining the CE literature in the context of manufacturing SC operations (Azevedo et al., 2017; Thorley et al., 2022). The existing studies explore the trends and evolution of CE practices, policies and frameworks, but those do not focus on the strategies facilitating circular manufacturing SC operations.

Research gaps in the field of circularity in manufacturing SC operations necessitate further exploration. One significant gap is the absence of a comprehensive review encompassing the entire circularity landscape within the manufacturing SC, offering an opportunity to consolidate existing knowledge and identify research themes. While the extant literature covers the benefits, drivers and barriers of CE deployment, it lacks an in-depth examination of contextual factors influencing CE strategies across industries and regions.

CE practices aim to optimise resource efficiency and waste reduction through product and material reuse, recycling and remanufacturing. Process and technological innovation are crucial for achieving circular goals in supply chains, but there is a research gap in understanding the intersection of innovation and CE practices within SC operations.

Additionally, the relationship between circularity strategy adoption and its practical implications for manufacturers is unexplored in the literature. Investigating the effectiveness of these strategies in enhancing circularity within SC operations can offer valuable insights for businesses embracing CE principles. This study seeks to advance the understanding of circularity integration in manufacturing SC operations and its strategic implications.

Our study bridges these gaps by offering a unique methodology for conducting a systematic literature review. Through this study, we offer practitioners a strategic framework for implementing circularity in manufacturing SC operations. Driven by this background, we examine the spread of current studies in circular manufacturing SC operations. We answer the following research questions in our study:

a. How has the circularity in manufacturing supply chain evolved over the years?
b. What are the key strategies and research themes facilitating the manufacturing supply chains in achieving circularity?
c. How do the key strategies and research themes help evolve a strategic framework for CE implementation in manufacturing supply chains?

Our study complements the published reviews in the domain and provides a detailed research framework emanating from the key findings. The key objectives of our study are as follows:

i. to explore the evolutionary trend of the articles published between 2013 and September 2023,
ii. to identify the drivers and barriers to circular manufacturing supply chain operations,
iii. to explore the current research trends in the domain of circular manufacturing supply chain operations,
iv. to explore the emerging research themes and future research directions and
v. to design a strategic framework for adoption of circular manufacturing supply chain operations.

Our study complements the published reviews in the domain and provides a more detailed and robust research roadmap emanating from the key findings. The study renders a methodological contribution combining bibliometrics, network analysis and descriptive content analysis. Our analyses identify thematic research areas within the circular manufacturing SC operations literature and help to explore a strategic framework indicating future research directions. Our study deploys a hybrid approach using qualitative and quantitative tools to understand the evolutionary trend of the CE literature in manufacturing SC operations. The study develops a comprehensive framework on circularity that organises the fragmented literature into a rational structure for the domain. We synthesise research findings to uncover areas where more research is required, which is a critical component of creating theoretical frameworks and building conceptual models. The research themes identification process renders a systematic knowledge structure and a roadmap to fortify the current operational strategies.

We organise this article as follows. Section two explores the CE concept and its link to manufacturing SCs. This section also elucidates the state of the extant literature in the domain. Section three delineates the methodology, data analysis and review process. Section four analyses and synthesises the results obtained from the bibliometrics, network analysis and descriptive content analysis. Section five presents a strategic framework highlighting the importance of innovation-led lean approaches and resilient circular manufacturing SC operations. Section six discusses the pragmatic implications of the study. Finally, section seven concludes the study by elucidating the convergence of the research and future research directions.

2 | CIRCULAR ECONOMY AND MANUFACTURING SUPPLY CHAINS

This study renders a comprehensive and integrated view of CE in the context of manufacturing SC operations. Therefore, it would be appropriate to discuss the conceptual evolution of CE concepts and their relation to the manufacturing SCs.

2.1 | Evolution of circular economy

CE is regarded as a strategy that promotes economic growth through optimal utilisation and consumption of natural resources (Geissdoerfer et al., 2017; Genovese et al., 2017; Webster, 2013). The concept of CE evolves from rudimentary principles and strategies related to some broad-spectrum proposals of sustainability and economics, such as 'regenerative design' (Lyle, 1994), 'performance economy' (Stahel, 2008), 'cradle-to-cradle' (Braungart et al., 2007) and 'industrial ecology' (Erkman, 1997). In the last decade, the following studies conceived more comprehensive CE definitions, namely Guide et al. (2006), Sarkis et al. (2011), Kirchherr et al. (2017) and Korhonen et al. (2018). The United Nations Environment Program (2010) defines CE as '*an alternative economic model for exchange and production that seeks to decouple economic growth from material dependency*'. CE '*replaces the "end-of-life" concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models*' (EMF, 2015).

The CE concept originates in economics (Pearce & Turner, 1990), industrial ecology (Lifset & Boons, 2012) and management and corporate sustainability literature (Guide & Van Wassenhove, 2009). Although the concept of CE has been evolving in academia for the past few years, the underlying theories, mechanisms and strategies of CE require more attention (Antikainen & Valkokari, 2016). A Scopus search of the articles in the CE domain indicates an increase in the number of articles after 2015, which is likely due to the adoption of Sustainable Development Goals (SDGs).

CE is an integral part of the sustainability agenda and can contribute to several different SDGs. The SDGs constitute a set of plans of action for people, planet and prosperity. The 17 unified goals of SDG balance the economic, social and environmental dimensions of sustainable development (United Nations General Assembly, 2015). The premise of CE is a set of boundary conditions and principles that enables activities to contribute positively to people, planet and prosperity. Four SDGs, namely affordable and clean energy (SDG 7), sustainable cities and communities (SDG 11), responsible production and consumption (SDG 12) and climate action (SDG 13), describe the practice leading to CE environment (United Nations General Assembly, 2015).

We identify two phases of the CE literature, viz. pre-declaration (2010–2015) and post-declaration of the SDGs (2016 to present). The first phase of studies focusses on the concepts of eco-industrial parks (EIP), recycling networks and waste. The second phase primarily focusses on CE and various theories related to it. It appears that there is a shift from practice-oriented research to theory-based research.

In recent years, some studies examine the relationship of CE with emerging technologies such as Industry 4.0 (de Sousa Jabbour et al., 2018; Nascimento et al., 2019), additive manufacturing (Byard et al., 2019; Despeisse et al., 2017), blockchain (Ramchandani et al., 2021; Saberi et al., 2019), big data (Kristoffersen et al., 2021; Nobre & Tavares, 2017) and cloud-based technologies (Fisher et al., 2018) and so forth. The emergence of such novel technologies has enabled manufacturing organisations to implement the concept of circularity in their SC operations very effectively.

2.2 | Circular manufacturing supply chain operations

Circular manufacturing supply chain operations refer to a business model that aims to create a closed-loop system where materials are continuously reused or repurposed, thereby minimising waste and maximising resource efficiency (Acerbi et al., 2022; van Capelleveen et al., 2023). It involves various stages, such as designing products, sourcing sustainable materials, minimising waste during manufacturing, extending the life of products through repair and refurbishment and recovering materials at the end of their life for reuse or recycling (Chari et al., 2022; Saraji & Streimikiene, 2022).

Appropriate integration of CE with manufacturing SC operations renders several benefits to organisations like waste reduction, increased green consumption, effective energy management and sustainable development (de Angelis et al., 2018). CE, when infused in an SC, is termed a circular supply chain (CSC) (Genovese et al., 2017). In a CSC, enterprises collaborate and coordinate with other entities to maximise resource utilisation. While circularity in the manufacturing SCs guides SC managers to improve resource efficiency and profitability, it offers a mechanism to minimise the negative impacts of production operations (Merli et al., 2018; Rosa et al., 2020). Ideally, a CSC should trigger 'zero waste' as CE intends to systematically restore and regenerate the network resources (Andersen et al., 2022; Urbinati et al., 2017).

Although some studies discuss CSC operations (e.g. Batista et al., 2018; de Angelis et al., 2018), there has been a dearth of review articles providing comprehensive analyses of circular manufacturing SC operations. For example, Farooque et al. (2019) reviewed 261 articles relevant to CSCM. The study classified the terminologies of SC sustainability and conceptualised a unified definition of CSCM. We observe that review characteristics are classified as challenges in circular manufacturing SC operations, the SCs' emerging themes and success factors/trends. We found two types of review articles, namely systematic literature review (i.e. SLR) and review articles with bibliometric and/or network analyses. We perform descriptive content analysis, identify the key review articles in the domain and classify the articles based on their characteristics and the type of review (Table 1). Table 1 illustrates review articles published in the context of CE in the last 6 years. We find that the majority of the articles report content analysis and descriptive statistics. The focus of the existing review articles is on the growth of the domain and research gap identification by exploring some topical areas of research. We find that the array of literature examining circular manufacturing SC operations using bibliometric and network analyses is limited. Our article bridges this gap and presents one of the most comprehensive reviews in the circular manufacturing supply chain operations domain. The existing review articles with network analysis majorly use tools like VOSviewer, Pajek, HistCite and so forth, which have certain limitations in terms of the visual presentation of the literature. In our study, we use a more reliable tool, Gephi, for the network analysis to capture accomplishments, challenges and future opportunities in the domain.

2.3 | Research gaps

Although several studies have highlighted the potential benefits of implementing circularity in manufacturing supply chains, there is a lack of a comprehensive and systematic review that synthesises and evaluates the existing literature to identify the key challenges, success factors and best practices for circularity adoption in manufacturing SCs. Despite the growing emphasis on circular economy practices, there is a lack of literature integrating circular manufacturing and innovation strategy, hindering the realisation of a more sustainable and regenerative production system. The integration of innovation-led approaches and CE practices within supply chain operations remains underexplored in the literature that represents a promising avenue for resource optimisation and sustainability.

While there is a growing body of literature discussing the theoretical frameworks and benefits of CE, there is a limited understanding of the practical challenges and opportunities faced by specific sectors, such as electronics, textiles or food, and how these challenges vary across different global contexts. Our study, through bibliometrics, network analysis and descriptive content analysis, uncovers areas where circular business models have not been adequately explored, thereby highlighting opportunities for further research (Figure 1).

3 | RESEARCH METHODOLOGY

3.1 | Research philosophy

One of the principal objectives of reviewing the extant literature is to assess and evaluate the current body of knowledge highlighting and classifying the key contributions, existing knowledge gaps and limitations (Tranfield et al., 2003). We present a systematic review and identify empirical evidence to answer the research question. We use explicit methods and evidence to minimise bias and obtain reliable findings (Snyder, 2019). Table 2 illustrates the steps of the approach adopted in our study.

Our study is rooted in constructivist research philosophy meaning that multiple interpretations of a concept can co-exist in a real-world setting. Our research strategy for the descriptive data analysis part is based on typological analysis (Jakkola, 2020). The typological analysis differentiates and categorises the existing practices, theories and strategies and simultaneously articulates relationships among CE drivers and barriers to provide future research framework in circular manufacturing SC. Further, we adopt a theory extension approach drawing on Lukka and Vinnari (2014) and Hazen et al. (2021). Our study is based on the perspective of exploring circularity as a domain theory and manufacturing SC operations as a method theory. Through the theory extension approach, we propose a strategic framework for circular manufacturing SC operations. The inferences drawn from the outcomes of this study have their foundations in inductive reasoning based on the academic literature in the domain of CE and manufacturing SC operations.

3.2 | Review stages

We examine 946 articles and explore the state of research using bibliometric and network analyses. Our study adopts an amalgamation of a systematic and integrative approach (Snyder, 2019). It categorises the extant knowledge, identifies some key constructs and provides insights on emerging research areas indicating some meaningful relationships evolved from the existing theories, strategies and applications of circular manufacturing SC operations. Figure 2 elucidates the

TABLE 1 Comparison between some key literature review articles and our study.

Authors	Review characteristics						Type of review		No. of reviewed articles
	Challenges	Drivers	Decision support systems	CE models	Emerging themes	Success factors/ trends	SLR	Bibliometric/network analyses	
Geissdoerfer et al. (2017)	✓					✓		✓	290
Kirchherr et al. (2017)		✓		✓	✓		✓		114
Merli et al. (2018)					✓	✓	✓		601
Govindan and Hasanagic (2018)	✓					✓	✓		60
Homrich et al. (2018)	✓			✓	✓	✓	✓		327
Eiroa et al. (2019)					✓		✓		68
Farooque et al. (2019)					✓	✓	✓		219
Sassanelli et al. (2019)		✓		✓		✓	✓		60
Pieroni et al. (2019)	✓			✓			✓		94
Ferasso et al. (2020)				✓	✓			✓	253
Lahane et al. (2020)	✓					✓	✓		125
Türkeli et al. (2018)	✓				✓			✓	241
Metic and Pigosso (2022)					✓	✓	✓		63
de Lima et al. (2022)					✓	✓	✓		106
Calzolari et al. (2022)			✓	✓			✓		203
Ren et al. (2023)					✓			✓	673
This study	✓	✓	✓	✓	✓	✓	✓	✓	**946**

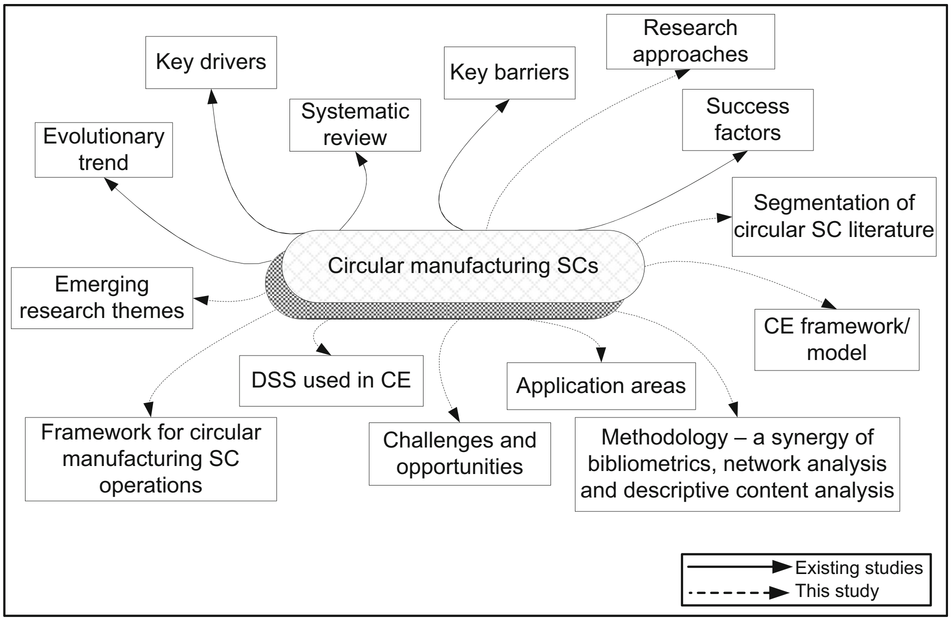

FIGURE 1 Research gaps and key contributions of this study to the circular manufacturing SC literature.

TABLE 2 The steps adopted in this study.

Approach	Description
Purpose of the study	To examine the extant literature and understand the evolutionary trends in the domain of circular manufacturing SCs.
Research question	How have the CE studies facilitated manufacturing SC operations in achieving circularity?
Search strategy	A search string is devised and used in Scopus database.
Search results	The review results in 946 articles including 145 review and 801 research articles.
Analysis and evaluation	A three-phase methodology was used consisting of bibliometrics, network analysis and content analysis.
Implementation strategies	Among others, we identify (i) the key drivers and barriers for implementing CE in manufacturing SC operations and (ii) research themes. We propose a strategic framework for policymakers and practitioners for implementing the operations strategies in circular manufacturing SCs.

stages and steps of the research approach adopted in our study. The next sections explain these stages and steps.

3.3 | Keywords and search string

We used the Scopus database for collecting data as it is the largest abstract and citation database containing over 25,000 peer-reviewed journals (Elsevier, 2023). Our research encompasses three elements, namely circularity, manufacturing and supply chain operations. The principle of circular economy involves the reduction, reuse, recycling and recovery of existing materials and products for as long as possible. Therefore, 'circular economy' was considered one of the keywords for developing the search string. To ensure the inclusion of all articles in this domain in the search result, we used equivalent keywords for the three elements. After thoroughly studying and understanding the contents of prominent studies in the domain, we identified the relevant keywords. We developed several search strings using Boolean operators and wildcard functions. After performing several iterative searches using these search strings, we found that the following search string is effective in identifying most of the articles in the domain:

> ("Circular economy" OR "Circularity" OR "Circular business model" OR "circular model") AND ("Manufacturing" OR "Production" OR "Remanufactur*" OR "Re-manufactur*") AND ("Supply *" OR "Logistics" OR "Value chain")

3.4 | Article screening process

We performed an initial search using the aforesaid string in Scopus in its 'title, abstract and keywords' field, which exhibited 3846 journal articles. We refined the search results further by applying exclusion criteria (Figure 2). We considered journal articles published in the English language between 2013 and September 2023. During a preliminary search, we observed that most of the CE-related articles on manufacturing SC operations were published in the subject areas of business, management and accounting, social sciences, decision

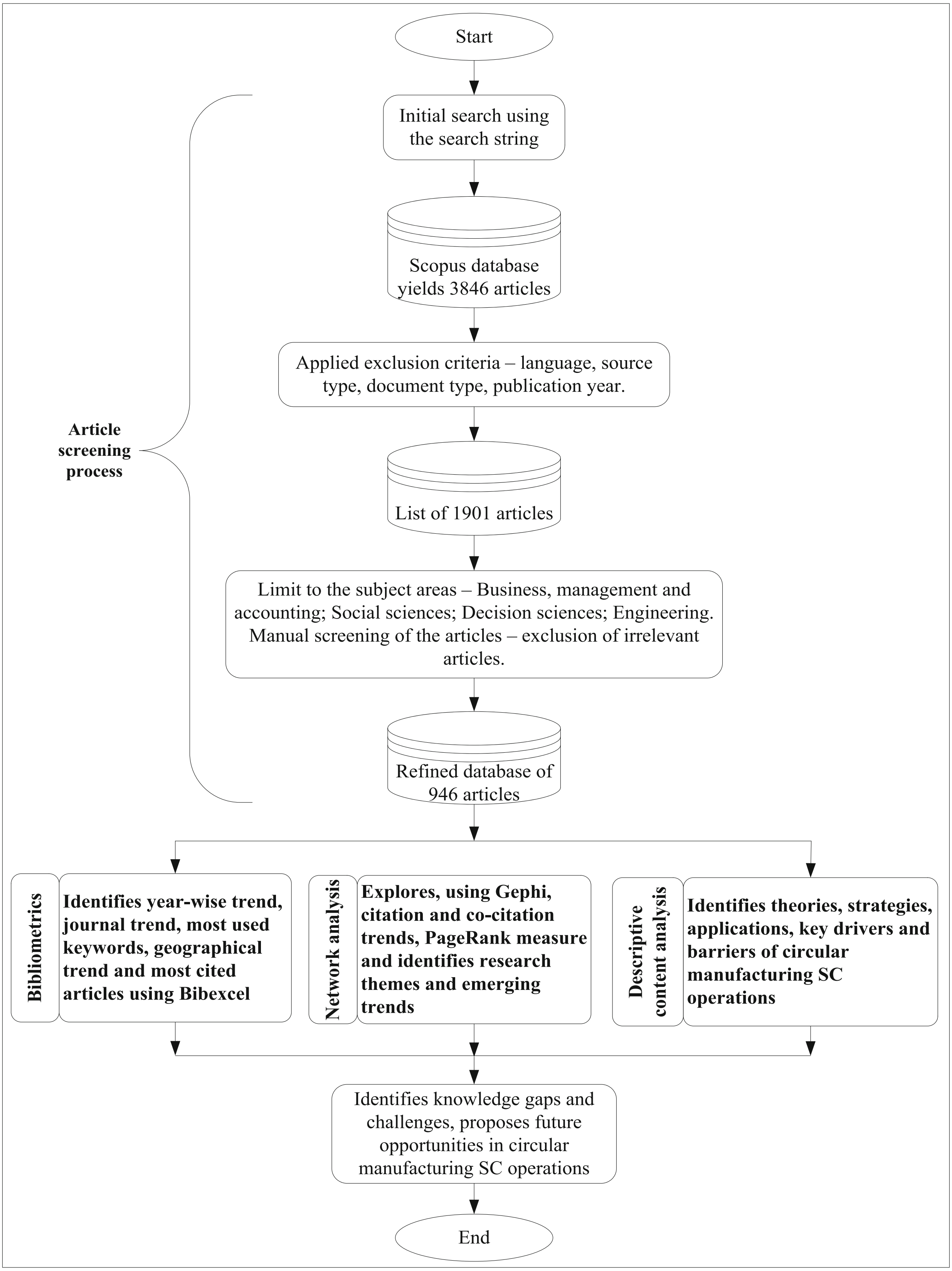

FIGURE 2 The research methodology.

sciences and engineering. Therefore, we limited our search to these subject areas. Figure 2 illustrates the four-stage process used in selecting the articles for the analysis.

3.5 | The review process

We performed data analysis in multiple stages (Figure 2). First, we conducted a bibliometric analysis using BibExcel (Persson et al., 2009) to identify the evolutionary publication trends. Second, we performed a network analysis through Gephi to analyse the articles' citations and classify them based on the contents of the articles. We chose Gephi as it is capable of accommodating different data formats, analysing data using integrated toolboxes, visualising data in different forms, providing easy access to network data, facilitating specialised data clustering and providing advanced data filtering capabilities (Gephi, 2013; Persson et al., 2009). We imported the details of 946 articles in Gephi and generated a random map. To spatialise a network, we used Gephi's 'ForceAtlas2' algorithm and created networks of co-cited articles. In the ForceAtlas2 layout, movement of the nodes and edges yielded a balanced state of the network that facilitated interpretation and visualisation of the data (Gephi, 2013). Gephi's default clustering tool is based on the modularity measure. Modularity measure determines the network strength and structure and also its value lies between −1 and +1 (Cherven, 2015). The articles frequently cited together are more likely to belong to the same thematic area or cluster (Hjorland, 2013).

Third, we performed a descriptive content analysis of the articles to identify associated theories, strategies, key drivers and barriers in circular manufacturing SC operations. Descriptive content analysis assists researchers in comprehending the reliability of the study (Basch et al., 2022). We used a directed approach to identify the prominent aspects of CE in manufacturing supply chains. The primary aim of the directed approach in descriptive content analysis is to extend or validate a theoretical framework (Assarroudi et al., 2018; Hsieh & Shannon, 2005). To perform the descriptive content analysis, we adopted the following steps in this study. We identified the articles and categorised those based on the types of research approaches used in the studies, key drivers and barriers, CE application areas in manufacturing supply chains and CE theories and strategies. We assessed the identified 946 articles based on these categories and reported and interpreted the results logically and scientifically.

4 | RESULTS AND ANALYSES

4.1 | Bibliometric analysis

The bibliometric analysis used 946 articles extracted from the Scopus database. The data contained all essential bibliographic information associated with the publications.

4.1.1 | Publication trend over the last 10 years

Figure 3 demonstrates the trend of the publications between 2013 and September 2023. This trend elucidates that the domain of study is evolving. There has been a growth in the number of articles after the adoption of the SDGs in 2015. The studies explore various pragmatic aspects of implementing circular SCs in the context of the manufacturing industry. A total of 262 journals have published these 946 articles. The 'Journal of Cleaner Production' has the highest publication count (191) followed by the 'Sustainability' (140) and 'Sustainable Production and Consumption' (40) journals, respectively. 'Business Strategy and Environment' (22) ranks fourth in this research domain.

A total of 92 countries contribute to circular manufacturing SCs literature. The European continent dominates in the publications related to the implementation of circular economy practices. The studies reported a global adoption of effective production and refurbishment techniques for the products and services due to growing consumer demand for environment-friendly products and services.

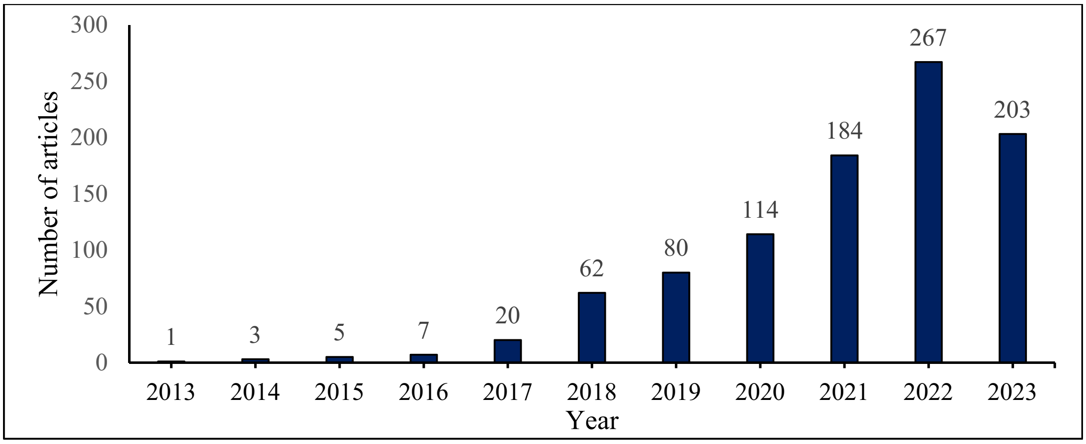

FIGURE 3 Year-wise publication trend.

4.1.2 | Popular keywords

The keywords statistics facilitate understanding the evolution of the discipline (Sidorova et al., 2008). We derived the idea of keywords' co-occurrence analysis from the bibliometric coupling and co-citation analyses. Using BibExcel, we identified the top keywords/phrases used in the titles and keyword lists. Table 3a illustrates the top 10 keywords in the titles and keyword lists drawn from 1034 keywords of 946 articles. Analysis of these two sets of keywords demonstrates a mostly consistent use of the keywords in the titles and keyword lists. We note that some of the popular keywords in Table 3b relate to the keywords used in the search string of this study.

4.2 | Network analysis

Network analysis was conducted using Gephi to classify the articles and perform a citation analysis of the articles. To facilitate a Gephi analysis, we reformatted the bibliographic data using BibExcel suiting the requirements of the graphical dataset. Citation analysis determines a publication's popularity. Our analysis revealed that 746 articles were cited in other articles in this 946-article network. Out of 262 journals, 88 journals had more than two papers. We thoroughly assessed each article and identified the contributions and limitations of the top 10 articles (Table 4).

The citation count reveals the popularity of an article. Brin and Page (1998) introduced the PageRank measure to determine the importance of web pages based on keyword searches in the Google search engine. Network analysis adopts this measure. We find the top 10 articles using the PageRank measure (Table 5). Comparing the top 10 articles in Table 4 and Table 5, we observe that only two articles, namely Govindan and Hasanagic (2018), Moktadir et al. (2018), appear in both lists of the top cited articles and top PageRank articles. The measure is influenced by the citations from other highly cited articles. Therefore, with the maturity of the domain, the measure would elucidate a better citation scenario.

Further, using Gephi, we identified research themes (i.e. research clusters) from 946 articles through network analysis. A cluster contains a group of well-connected articles within a research theme with comparatively limited connection to the articles in other clusters (Leydesdorff, 2011). A thorough examination and analysis of the articles belonging to a cluster facilitated the identification of the research theme associated with the cluster. We employed the Louvain algorithm in the 746-node network that created six major clusters (Figure 4). The modularity measure was 0.548, which indicated a strong relationship among the articles in each cluster. The next section explores the contents of identified themes through descriptive content analysis.

4.3 | Descriptive content analysis

We performed a descriptive content analysis to ascertain the key drivers and barriers used in the circular manufacturing SC operations along with diverse research approaches adopted, application areas, frameworks/models, decision support tools, strategies and underlying theories.

4.3.1 | Research approaches

The articles used various research approaches, including qualitative and quantitative studies (Mcleod, 2019). Based on the descriptive content analysis, we identify and list the approaches in Table 6. The approaches explore the nature of the research problems being addressed in the articles. As the circular manufacturing SC operations domain is still emerging, the list illustrates the conventional quantitative and qualitative research techniques, like surveys, focus groups, case studies and so forth.

4.3.2 | Key drivers and barriers

Drivers and barriers of circular manufacturing SC operations facilitate the formation of strategies. Studies exploring sector-specific drivers and barriers are limited in the literature (Farooque et al., 2019). After

TABLE 3 Top 10 keywords.

(a) Keywords used in the article titles		(b) Keywords used in the keyword lists	
Keywords	Frequency	Keywords	Frequency
Circular economy	588	Circular economy	655
Supply chain management	471	Supply chain management	561
Sustainable development	406	Recycling	431
Manufacturing	398	Sustainable development	418
Remanufacturing	365	Sustainability	387
Strategies	225	Life cycle assessment/LCA	348
Closed-loop supply chains	209	Waste management	319
Business models	176	Environmental impact	296
Waste management	143	Remanufacturing	241
Life cycle assessment	117	Manufacturing	239

TABLE 4 Contributions and limitations of top 10 publications.

Authors	Names of the journals	Citation count	Contributions	Limitations
Genovese et al. (2017)	Omega (United Kingdom)	763	Integrates sustainable SC management practices with the CE principles.	Does not consider the economic aspects of CE.
Govindan and Hasanagic (2018)	International Journal of Production Research	652	Reviews articles and identifies drivers, barriers and practices to circularity implementation.	60 reviewed articles limit the results.
de Sousa Jabbour et al. (2018)	Annals of Operations Research	596	Considers Industry 4.0 and builds a roadmap for CE strategies.	Limited implementation strategies for circularity.
Lüdeke-Freund et al. (2019)	Journal of Industrial Ecology	471	Identifies six dimensions through a morphological analysis of 26 circular business models.	The subjective method limits the generalisability of the results.
Nascimento et al. (2019)	Journal of Manufacturing Technology Management	443	Proposes a circular model and promotes reverse logistics to support CE practices.	Focus group-based study with low number of respondents increases bias in the results.
Pan et al. (2015)	Journal of Cleaner Production	396	Proposed eight key taskforces for effective execution of the strategies of waste-to-energy SCs to achieve circularity.	More policy-oriented framework was designed
Mangla et al. (2018)	Production Planning and Control	296	Assessed the barriers to adoption of circular supply chains	Data size was limited
Despeisse et al. (2017)	Technological Forecasting and Social Change	295	Designs a distributed manufacturing system to create a CE of materials.	The strategy focusses on limited aspects of the CE principles.
Hong et al. (2018)	Journal of Cleaner Production	263	Examines the impact of SC dynamic capability.	The measure of SC dynamic capability does not consider the SC processes of the organisation.
Moktadir et al. (2018)	Journal of Cleaner Production	254	Assesses, prioritises and ranks the drivers of sustainable manufacturing practices.	Limited sample size restricts generalisability of the results.
Nasir et al. (2017)	International Journal of Production Economics	251	Compares the strategies of traditional and circular production systems.	Impacts of land, water usage and ozone depletion are not considered.

exploring the contents of the articles, we consolidate the drivers and barriers of CE in manufacturing SC operations in Table 7.

4.3.3 | CE frameworks/models

We identified and listed 10 CE frameworks/models reported in the studies (Table 8). The CE frameworks/models create and capture the value that helps achieve an appropriate level of resource utilisation (Arruda et al., 2021; Vinante et al., 2021). The frameworks/models also facilitate in reduction of waste and consumption (Lüdeke-Freund et al., 2019).

4.3.4 | Decision support in circular manufacturing supply chains

The goal of the circular economy mechanisms is to reduce waste, decrease the use of new resources and decrease the environmental impact of manufacturing. Decision support tools play a critical role in helping manufacturing firms implement CE principles and achieve sustainability goals in their supply chain operations (Khan & Ali, 2022; Kristoffersen et al., 2021). The decision support tools help in tracking and analysing resource usage, identifying areas for improvement and generating recommendations for more sustainable practices (dos Santos Gonçalves & Campos, 2022; van Loon et al., 2018;). We explore in Table 9 some decision support tools used in implementing CE mechanisms in manufacturing SC operations.

4.3.5 | Strategies and theories of circular manufacturing SC operations

CE strategies, such as recycling, remanufacturing, refurbishing, reuse, reverse logistics, dematerialisation, lean principles and waste management practices, evolve enterprises' complex decision-making processes embedded in some organisational theories. The theories explain and augment the theoretical foundation of the links between circular SC strategies and organisational behaviours. Literature reveals that some CE theories emerge from the sustainable SC literature (Liu

TABLE 5 Top 10 articles by PageRank measure.

Authors (year)	PageRank measure	Global citation numbers	Local citation numbers
Borrello et al. (2017)	0.06875	219	60
Despeisse et al. (2017)	0.05997	243	45
Franco (2017)	0.05431	178	39
Moktadir et al. (2018)	0.04514	254	52
Govindan and Hasanagic (2018)	0.04291	652	220
van Loon et al. (2018)	0.04002	85	28
Chen et al. (2022)	0.03213	24	21
Zore et al. (2018)	0.03019	35	30
Nascimento et al. (2019)	0.02108	443	48
de Angelis et al. (2018)	0.01152	247	39

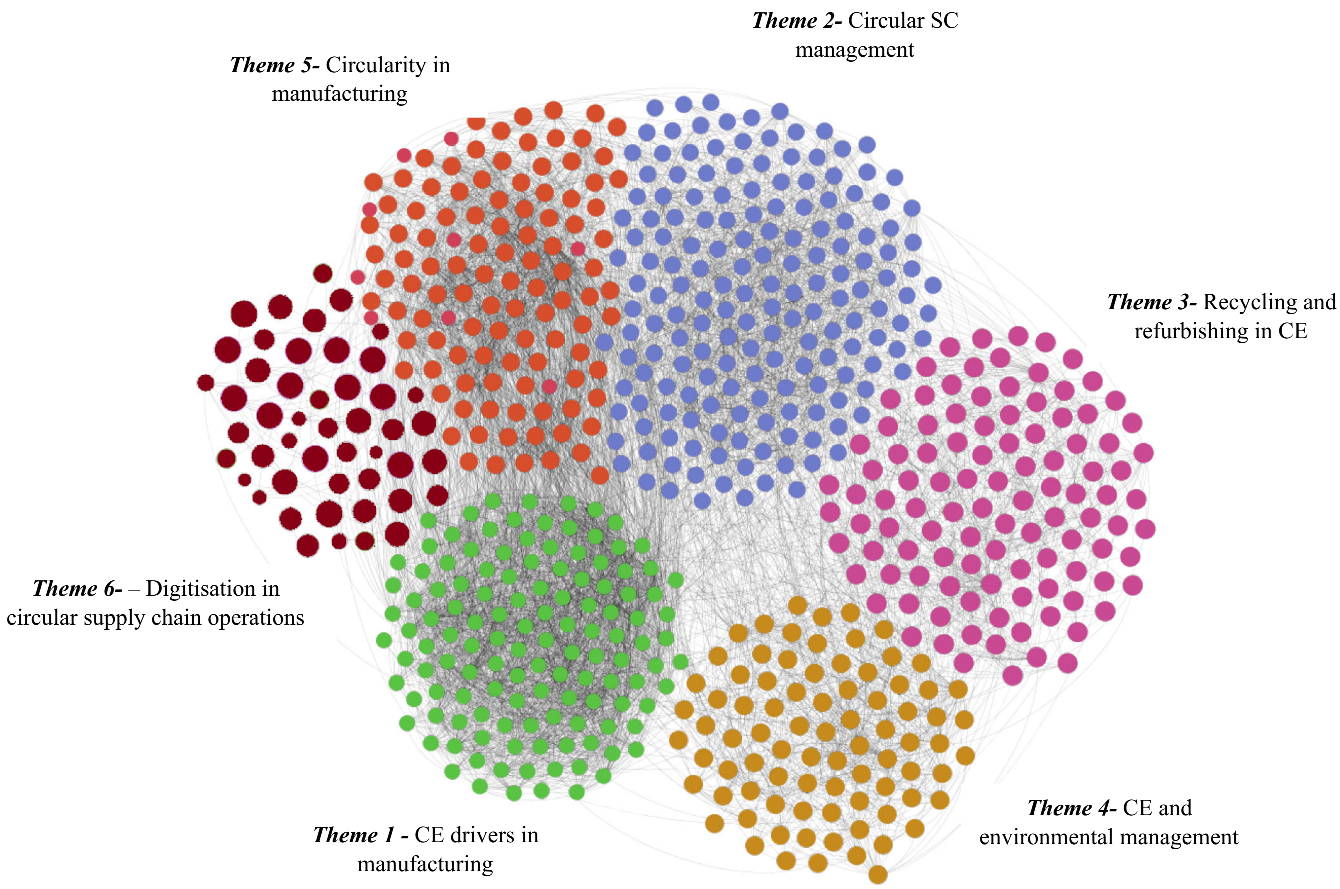

FIGURE 4 The six research themes.

et al., 2018). Studies examine the CE practices and implementation using theoretical lenses like resource-based view, industrial ecology, institutional theory, stakeholder theory, resource dependence theory, social network theory and diffusion of innovation theory (Liu et al., 2018).

The descriptive content analysis of the articles exhibited the diffusion of some of the aforesaid theories in the circular manufacturing SC literature. The articles reviewed in this study addressed disparate functional dimensions of the stakeholders. Table 10 exhibits the functional dimensions of these articles. Based on the functional dimensions and theoretical perspectives, we segmented the circular SC articles and placed those under relational, organisational, technological and regulatory categories. The key stakeholders were suppliers, manufacturers, distributors, retailers, end-users, policymakers and regulatory bodies. We considered the stakeholders as functional dimensions and categorised them in the relational segmentation level of the CSC literature. These stakeholders develop business models and policies for enabling circular SCs within their enterprises. These functional

TABLE 6 Research approaches adopted in the articles.

Qualitative methods	No. of articles	References	Quantitative methods	No. of articles	References
Case study	133	Feng and Gong (2020); Casson et al. (2020); Jaeger and Upadhyay (2020)	Survey	212	Dominish et al. (2018); Yang et al. (2019); Abadías Llamas et al. (2020)
Observational method	34	Wei et al. (2014); Testa et al. (2017); Kurilova-Palisaitiene et al. (2018)	Experiments	56	Ali et al. (2019); Vimal et al. (2019); Lapko et al. (2019)
One-on-one interview	76	Galati and Bigliardi (2019); Salvador et al. (2021)	Correlational method	21	Cooper et al. (2017); García-Bustamante et al. (2018); Cezarino et al. (2021)
Focus group	68	De Marchi and Di Maria (2019); Tsiliyannis (2020); Sivanandhini et al. (2021)			
Text analysis	55	Bigano et al. (2017); Prosperi et al. (2018); Rizvi et al. (2021)	Multi-criteria decision-making tools	94	Yadav et al. (2020); Ethirajan et al. (2021); Kazancoglu et al. (2021)
Review	145	Türkeli et al. (2018); Lahane et al. (2020); Mhatre et al. (2021)	Causal-comparative research	21	Deviatkin et al. (2016); Lin et al. (2019); Lange et al. (2021); de Vasconcelos et al. (2021)
Exploratory study	31	Walker et al. (2018); Xue et al. (2018); Koumoulos et al. (2019)			

dimensions appear under the organisational segment of the literature. Technological advancements play a pivotal role in achieving circularity in manufacturing supply chain operations. We found articles on predictive analytics, Internet of Things (IoT), blockchain, RFID, artificial intelligence, cloud computing and Industry 4.0. These functional dimensions act as enablers to circularity in manufacturing SC operations. We placed these articles within the technological segmentation level. We classified the articles falling in these functional dimensions as the regulatory segment.

We carefully examined the contents of the research themes of the articles explored through the network analysis (Figure 4) and identified the research focus of each cluster. While the articles demonstrated a general description of the clusters, the identification of cluster-wise contributing journals facilitated the determination of the most relevant research themes. The topical literature classification elucidates that the studies tend to provide conceptual, theoretical and empirical findings facilitating the investigation of the feasibility of economic and environmental performance enhancement of circularity in manufacturing SC operations. To identify the areas of research focus in each research theme, we analysed the contents of the top 10 publications from each cluster (Table 11).

4.3.6 | Applications

The applications of CE in manufacturing SC operations are growing. The content analysis reveals that 710 articles out of 946 relate to specific manufacturing industries. Increased consumer awareness about environment-friendly products has facilitated major manufacturing firms' transition towards circular practices (Tukker, 2015). Articles report that the electronics, automotive and food processing industries have adopted circular practices in their SC operations. These articles explore the re-design and modification of product–service systems, refurbishing and recycling strategies, reverse logistics operations and collaborative consumption.

Industries like textiles with high water consumption have implemented practices to reduce and reuse wastewater (Holkar et al., 2016). Small-scale industries have adopted circular concepts in their internal SC operations to attain sustainable production methods. SMEs in the automotive, textiles and plastics SC networks have been implementing circular SC strategies to adapt to the dynamism of the market.

5 | CHALLENGES AND OPPORTUNITIES

The findings of this study reveal several challenges and ample opportunities for development in this domain. We performed an in-depth analysis of the six research themes (Table 11). We find that some operations strategies can effectively tackle the challenges (Table 7) emanating from the circular manufacturing SC operations. Based on the review of the articles, we propose a framework for future research. The framework dispenses a set of recommendations to guarantee a more integrative and non-myopic research framework in this domain.

We find effective mitigation strategies for the key challenges to deploying circularity in manufacturing SC operations at different functional dimensions. The mitigation strategies include innovation-led lean approaches, reconfigurability of the SCs for shock absorption, the symmetric flow of information for improved communication, forecasting and increased visibility, greater degree of integration to mitigate channel uncertainties, collaboration and synchronisation for enhanced

TABLE 7 Key drivers and barriers for implementing CE in manufacturing SC operations.

Drivers	Publications	Barriers	Publications
Technological integration	Genovese et al. (2017); Maqbool et al. (2020); Bauer et al. (2020); Andersen et al. (2022); Rehman Khan et al. (2022).	Lack of information systems	Ghisellini et al. (2016); Govindan and Hasanagic (2018); Huang et al. (2019); Caldera et al. (2019); Gupta et al. (2021); Ayati et al. (2022).
Accessibility to green finance	Masi et al. (2018); Kumar et al. (2022); Andersson et al. (2023)	Lack of adequate environmental laws and regulations	Pan et al. (2015); Franco (2017); Kirchherr et al. (2018); Piyathanavong et al. (2019); Ghisellini and Ulgiati (2020); Gerassimidou et al. (2022).
Technical know-how and expertise	Winkler (2011); Gaustad et al. (2018); Yadav et al. (2020); Vence and Pereira (2019); Kazancoglu et al. (2021); Cheng et al. (2022).	Lack of acceptance of new business models	Heyes et al. (2018): Huang et al. (2019); Peng et al. (2020); Xia and Ruan (2020); Tseng et al. (2021); Xin et al. (2022).
Developing carbon pricing mechanisms	Kondo et al. (2019); Alkhayyal (2019); Naims (2020); Bonsu (2020); Wang et al. (2020)	Lack of availability for recyclable materials	Franco (2017); Huang et al. (2019); Centobelli et al. (2020); Alexandre de Lima et al. (2021); Ayati et al. (2022)
Reverse logistics and remanufacturing practice	Ranta et al. (2018); Moktadir et al. (2018); Vence and Pereira (2019); Andersen et al. (2022); Rehman Khan et al. (2022).	Lack of incentives for greener activities	Kirchherr et al. (2018); Caldera et al. (2019); Peng et al. (2020); Xin et al. (2022)
Resource recovery and recycling infrastructure for waste management	Genovese et al. (2017); Lieder and Rashid (2016); Moktadir et al. (2018); Gusmerotti et al. (2019); Cheng et al. (2022).	Lack of effective planning and adoption of circular practices	Lacy and Rutqvist (2015); Lieder and Rashid (2016); Huang et al. (2019); Zheng et al. (2021); Alexandre de Lima et al. (2021); Gerassimidou et al. (2022).
Legal and regulatory policies	Winkler (2011); Govindan and Hasanagic (2018); Ranta et al. (2018); Yadav et al. (2020); Rehman Khan et al. (2022).	Design challenges to reused and recovered products	Ranta et al. (2018); Govindan and Hasanagic (2018); Piyathanavong et al. (2019); Ghisellini and Ulgiati (2020); Andersen et al. (2022).
Managing carbon emission	Low et al. (2016); Jia et al. (2018); Xia et al. (2020); Naims (2020); Bonsu (2020)	Lack of skilled employees	Govindan and Hasanagic (2018); Centobelli et al. (2020); van Keulen and Kirchherr (2021)
Coordination and collaboration across SC	Heyes et al. (2018); Yadav et al. (2020); Vence and Pereira (2019); Maqbool et al. (2020); Rehman Khan et al. (2022).	Lack of consumer awareness	Lieder and Rashid (2016); Centobelli et al. (2020); Peng et al. (2020); Tseng et al. (2021); Ayati et al. (2022).
Employee empowerment and motivation	Govindan and Hasnagic (2018); Kirchherr et al. (2017); Gusmerotti et al. (2019); Yadav et al. (2020); van Keulen and Kirchherr (2021).	Lack of cost-effective recycling technologies	Shahbazi et al. (2016); Tura et al. (2019); Ghisellini and Ulgiati (2020); Alexandre de Lima et al. (2021).

product and service visibility and enhanced coordination. These strategies facilitate the adoption of some of the CE frameworks/models (Table 7) and simultaneously mitigate the challenges to CE implementation. Based on these strategies we propose a framework (Figure 5) featuring the inclusion of effective mitigation strategies in achieving the CE goals in manufacturing SCs. The framework also identifies the unexplored areas of the literature in the domain.

Technologies, CE-oriented business models and process innovations play crucial roles in overcoming some of the challenges to circularity adoption in manufacturing SC operations (Bhattacharya & Dey, 2020). The findings of our study suggest that the literature requires more emphasis in this domain to understand the connection between the implementation and execution of circular SC operations in manufacturing. Thus, as illustrated in Figure 5, future opportunities in the domain include the innovation diffusion strategy in achieving CE goals in manufacturing SC operations.

In manufacturing SCs, process innovations leading toward lean operations trigger sustainability (Bhattacharya & Dey, 2020).

TABLE 8 Ten CE frameworks/models reported in the circular manufacturing SC operations studies.

Circular economy framework/model	Focus	References
4R	Reduction, reuse, recycling and recovery	Allwood et al. (2011)
5R	Reduction, reuse, refurbish, repair and recycle	Lacy and Rutqvist (2015)
9R	Refuse, rethink, redefine, reuse, reform, remanufacture, redefine, recycle and recover	Van Buren et al. (2016)
10R	Refuse, rethink, reduce, reuse, repair, reform, remanufacture, redefine, recycle and reclaim	Kirchherr et al. (2017)
RESOLVE	Regenerate, share, optimise, loop, virtualise and exchange	EMF (2015)
Extended product lifecycle	Empowers the organisation to create opportunities for product extension and lifecycle management	Aboulamer (2018)
Resource recovery	Reduces material leakage and make best use of the economic value of product return flows	Geissdoerfer et al. (2017)
Waste regeneration systems	Waste materials are reprocessed into products, materials or substances either for the original or other purpose.	Bocken et al. (2014)
Cradle-to-cradle	Waste is seen as an eternal resource based on the concept 'waste = food', meaning that what is considered waste can become food in a new product cycle.	Braungart et al. (2007)
Closed-loop production	Businesses reuse the same materials to create new products.	Winkler (2011)

TABLE 9 Decision support tools used in CE.

CE mechanisms	Definition	Decision support approaches	Author(s)
Design for longevity	Designing products with the intention of keeping them in use for as long as possible	System dynamics, material flow analysis, game theoretic approaches and TOPSIS	Sabaghi et al. (2016); Franco (2017); Li et al. (2020)
Leasing and renting	Renting or leasing products, rather than buying them outright, to keep them in use longer	Life cycle assessment, material flow analysis and network optimisation	Deviatkin et al. (2016); Vidergar et al. (2021)
Product-as-a-service	Providing products as a service, rather than selling them outright, to keep them in use longer	Machine learning, IoT, geographic information systems and MULTIMOORA	Kjaer et al. (2019); Yang et al. (2018), Stankevičienė et al. (2020).
Remanufacturing and refurbishing	Taking used products and restoring them to like-new condition	Life cycle assessment; carbon footprint; multi-criteria decision-making methods; game theory; fuzzy logic, VIKOR and AHP	Zhao et al. (2017); Gaspari et al. (2017); Fofou et al. (2021).
Recovery and recycling	Recovering materials from used products to use in new products	MCDM-integrated multi-objective mixed-integer non-linear programming; material flow analysis; life cycle assessment and GISWASTE tool	Liao et al. (2020); Yazan et al. (2022); Feng et al. (2021).
Collaborative consumption	Sharing or swapping products among individuals or groups to keep them in use longer	Multi-criteria decision-making methods, game theoretic approaches and multi-attribute value theory	Tan and Guo (2019); Mayer (2020); Slorach et al. (2020).

Therefore, considering the aspects of the 'diffusion of innovation' theory, Figure 5 envisages that an innovation-led lean operations strategy can augment the implementation of circularity in manufacturing SC operations.

An in-depth analysis of the literature reveals that the introduction of circularity in the channel compounds complexity in the SC operations. Further, increased focus on circularity may ignore the resiliency and responsiveness dimensions of the SC network (de Arquer et al., 2022), which may pose a threat to the SC networks. Global logistics networks are vulnerable to frequent SC disruptions. Some nodes and links of the networks may become vulnerable to the impacts of disruption shocks, which make the networks less resilient. Thus, as illustrated in Figure 5, it is imperative to embed strategies involving the networks' reconfigurable capability for shock absorption enabling a business continuity plan (BCP) (Bhattacharya et al., 2013). The proposed reconfigurability of the networks would enable the circular manufacturing SCs to operate at enhanced capability in responding to the disruption events. Further, if some operations of the SC entities are

TABLE 10 Segmentation of the circular SC literature.

Segmentation levels	Functional dimensions	Description	References
Relational	Suppliers, manufacturers, distributers, retailers, end-users.	Circular thinking is to be implemented at all stages of the SC network. Effective SC integration and collaboration within the SC entities enable the network to achieve efficient material flow, risk preparedness, symmetric information flow, forecasting and benefit sharing.	Sawe et al. (2021); Bressanelli et al. (2022)
Organisational	Business models, for example forward and reverse logistics, waste management, dematerialisation, environmental management, refurbishment practices.	Reverse logistics is essential to the implementation of the CE principles in SCs. Adoption of lean operations and waste reduction mechanism enhance CE business models considering the social, environmental and business requirements.	van Loon et al. (2018); Franco (2019); Nazmul Islam et al. (2021); Andersen et al. (2022)
Technological	Predictive analysis, IoT, blockchain, RFID, artificial intelligence, cloud computing, Industry 4.0, additive manufacturing.	Effective alignment with technologies aids SC networks in achieving process synchronisation, functional integration and visibility through symmetric information flow across the networks thereby facilitating waste reduction from various corners of the network. Industry 4.0, such as blockchain, additive manufacturing, IoT, cloud computing, simulation, augmented reality and cyber security, can facilitate efficient circular operations and add value to the networks.	Kazancoglu et al. (2021); Uhrenholt et al. (2022); Despeisse et al. (2017).
Regulatory	Political, social, regional, legal and economic environment.	Territorial legislations and national economies are the part of enablers to CE in manufacturing enterprises. Further, societal parameters facilitate to determine the level of social CE. Therefore, involvement of legislators, governmental and inter-governmental organisations expedite policy design at national and regional levels for effective implementation of CE in SC operations.	Kazancoglu et al. (2021); Bag and Rahman (2023).

not appropriately synchronised (Salmela & Huiskonen, 2019), the benefits of circularity may not be available to the end-users and society. To ensure effective manufacturing circular SC operations, the future opportunities lie in exploring the deployment of the CE framework, as illustrated in Figure 5, and aligning those with the relevant functional dimensions and strategies of the SC entities.

6 | KEY IMPLICATIONS

This study provides significant insights for the practitioners and policymakers facilitating strategy building in boosting the circularity in manufacturing supply chains. Based on the features of the framework (Figure 5), we present some meaningful implications for the stakeholders, namely, scholars, managers and policymakers.

6.1 | Theoretical implications

Our study provides a comprehensive account of CE for the researchers/scholars in a manufacturing context through the framework. The study facilitates the examination and mapping of the CE practices of supply chain operations producing different products. Further, our study identifies possible challenges to CE adoption in

TABLE 11 Identified research themes.

Research themes	Focus of the themes	Top 10 articles (ranked based on PageRank measure)
Theme 1—CE drivers in manufacturing	Focus is on the key drivers and set the foundation to implement circularity in the manufacturing SCs.	Bressanelli et al. (2022); Farooque et al. (2019); Franco (2019); Gupta et al. (2021); Liu et al. (2018); Moktadir et al. (2018); Banguera et al. (2018); Witjes and Lozano (2016); Gusmerotti et al. (2019); Yadav et al. (2020).
Theme 2—Circular SC management	Articles emphasise the emergence of reverse logistics and remanufacturing practices to attain sustainability.	García and Ferat (2017); Ada et al. (2021); Howard et al. (2019); Khan et al. (2021); Choi et al. (2019); de Angelis et al. (2018); Genovese et al. (2017); Lüdeke-Freund et al. (2019); Roy et al. (2022); Balugani et al. (2022).
Theme 3—Recycling and refurbishing in CE	Articles elucidate the tools and techniques for managing and reducing waste to achieve a reduce–reuse–recycle framework.	Cesur et al. (2022); Peng et al. (2020); Kamble and Gunasekaran (2023); Tan and Guo (2019); Kalmykova et al. (2018); Dominish et al. (2018); Testa et al. (2017); Dominguez et al. (2021); Turner et al. (2019); Baralla et al. (2023).
Theme 4—CE and environmental management	Articles address environmental policies and legislations like carbon emission reduction practices, sustainable packaging measures, wastewater management and green practices.	Chen et al. (2021); Ersoy et al. (2022); Alavi et al. (2021); Coderoni and Perito (2020); González-Sánchez et al. (2020); Solís-Quinteros et al. (2020); Adams et al. (2021); Chaudhary et al. (2022); Gambino et al. (2020); Dominguez et al. (2021).
Theme 5—Circularity in manufacturing	Articles emphasise life cycle assessment, regulatory requirements, zero waste manufacturing and circularity in social responsibility.	Liao et al. (2020); Ralph (2021); Govindan (2022); Chiaraluce et al. (2021); Alkhayyal (2019); Lieder et al. (2020); Kerdlap et al. (2019); Teigiserova et al. (2020); Mukherjee et al. (2022); Nikkhah et al. (2021).
Theme 6—Digitalisation in circular supply chain operations	Articles represent emerging technologies like blockchain and Industry 4.0 etc. to co-create value during the implementation stage.	Centobelli et al. (2022); Rehman et al. (2022); Apalkova et al. (2021); Nayal et al. (2022); Karayılan et al. (2021); Alvarez and Ruiz-Puente (2017); Bag and Pretorius (2020); Nascimento et al. (2019); Ruiz et al. (2022); Ciliberto et al. (2021).

manufacturing supply chain operations and suggests strategic solutions. The study can help explore the CE adoption process across different geographies. For example, Mazur-Wierzbicka (2021) conducted a cross-country mapping of the CE implementation indicators. They proposed an IDCE (i.e. index for development of circular economy) framework. Their study was limited to the indicators related to waste management across the European Union. In our study, we offer a comprehensive understanding of the CE adoption strategies focusing on manufacturing supply chains. The strategies conceive ideas of process and technological innovations from the diffusion of innovation theory at relational, organisational, regulatory and technological levels (Zheng et al., 2021) (refer to Figure 5). The application of the natural resource-based view (NRBV) theory facilitates organisations in redesigning their operations to manage innovations from a sustainable outlook (Mishra et al., 2021). NRBV is a theoretical framework to understand the drivers of sustainable practices (Ouro-Salim & Guarnieri, 2023). CE practices can be explored at the organisational level through the NRBV and resource dependence theory (Liu et al., 2018). The literature indicates that the social network theory contributes to CE practices enabling enterprises to form conceptual models for industrial synergies at relational and organisational levels of Table 10 (Ghali et al., 2016).

SCs derive circularity in operations from the principles of industrial ecology (IE) (Bressanelli et al., 2019; Gaustad et al., 2018). IE aims to reduce waste by investigating material and energy flows in industrial systems (Lowe & Evans, 1995). The institutional theory (Di Maggio & Powell, 1983) enables manufacturers to identify policies and drivers external to their organisations for implementing CE practices (Geissdoerfer et al., 2017).

The social contributions of the enterprises may get neglected during the implementation of some of the CE strategies. It is due to a paradox between the CE strategies and SDGs 5 (i.e. “gender equality”), 8 (i.e. “decent work and economic growth”) and 10 (i.e. “reduced inequalities”). To address this paradox and affirm the development of social contributions in CE, the social circular economy (Robinson, 2017) evolved from the social capital and social exchange theories and SDGs 5, 8 and 10.

6.2 | Managerial implications

The findings of this study can facilitate practitioners identify the links between the CE approaches and their strategic implications. For example, H&M believes in adopting circular strategies by maximising the value derived from the resources. Their supply chain keeps products in circulation and supports circular production processes and material flows (H&M, 2022). Experiences in the eco-design process may facilitate an improved product design (McDowall et al., 2017;

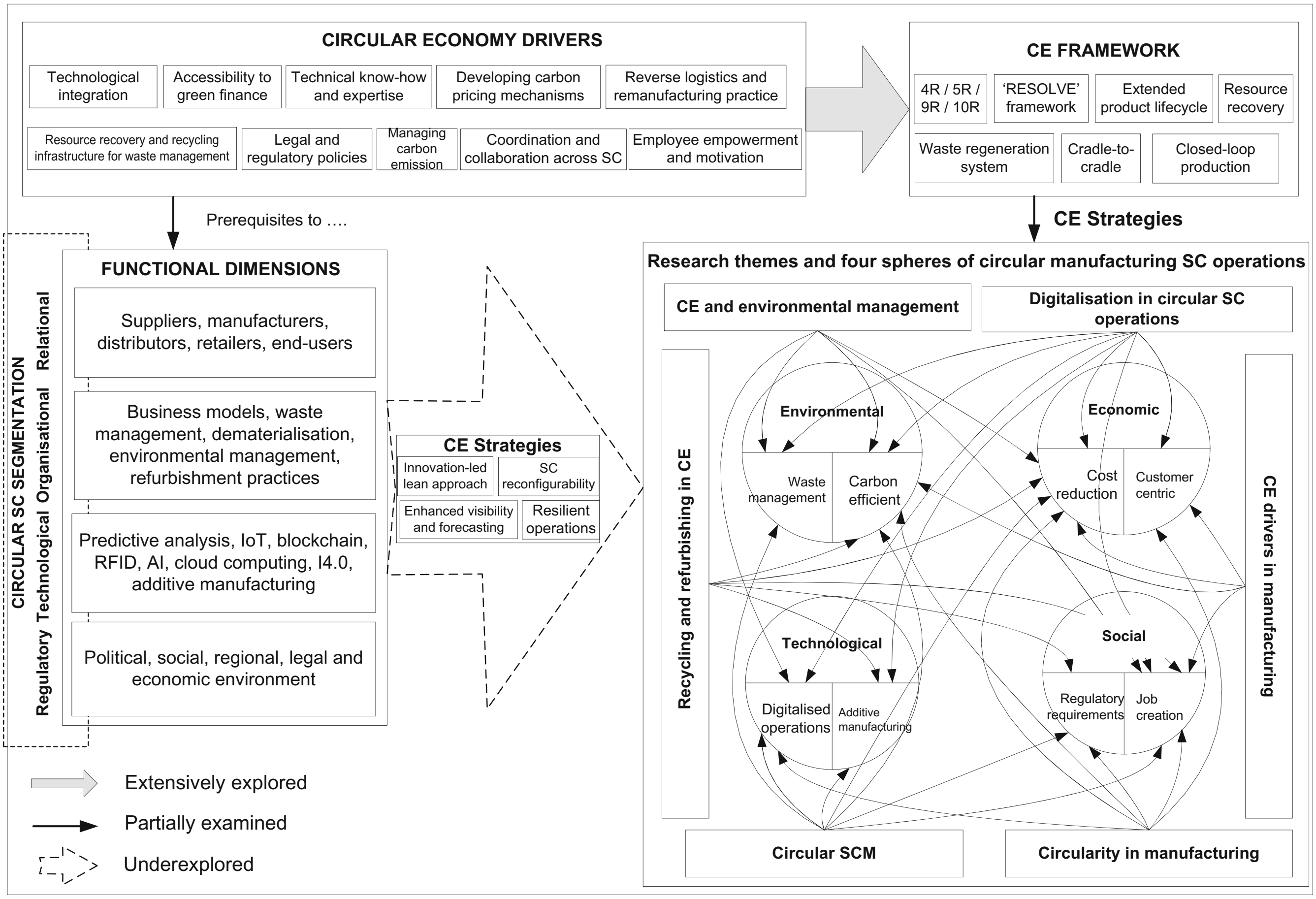

FIGURE 5 A framework for circular manufacturing SC operations and future opportunities.

Silva et al., 2019). Our study helps the practitioners examine CE implementation at the strategic level. The proposed framework suggests the adoption of innovative strategies for CE.

The policymakers, including national governments, local authorities and non-governmental agencies, can benefit from our study. The Resource Efficient and Cleaner Production (RECP) program of UNIDO (United Nations Industrial Development Organization, 2017) supports CE through preventive environmental strategies to processes, products and services to increase efficiency and reduce risks to humans and the environment. In the same context, Serbia has launched a Chemical leasing initiative, where chemicals are leased rather than purchased through cooperation between chemical producers, suppliers and users. Through this policy they reduce the use of chemicals, leading to economic and environmental benefits (United Nations Industrial Development Organization, 2017). This is an innovative strategy aiming toward achieving CE. With the findings of our study, policymakers can design more transparent circularity policies making supply chain operations economically viable for the manufacturing sector. They can create industrial and infrastructural policies ensuring circularity benefits. Additionally, our study helps policymakers initiate awareness programs for enhancing the circular agenda.

The study suggests the adoption of innovation-led practices in implementing circular manufacturing supply chain operations. The adoption requires sustained policy efforts to embed innovation-led frameworks in supply chain operations and encourage consumers to adopt innovative and sustainable consumption patterns (Azcárate-Aguerre et al., 2018). Thus, this study maps some significant aspects of the extant literature concerning circular manufacturing supply chain operations that serve as a point of departure for future research directions.

Within manufacturing SC operations, CE drivers (Table 7) play a pivotal role in shaping the practices related to CE adoption and implementation (Gusmerotti et al., 2019). Despite some existing studies, there remains a dearth of comprehensive CE frameworks that can effectively align with CE goals, strategies and performance across supplier, manufacturer and buyer levels (i.e. relational level of Figure 5). Many SC networks face challenges when implementing circularity in manufacturing SC operations at various functional dimensions. Thus, identifying efficient mitigation strategies becomes essential. The mitigation strategies include an innovation-led lean approach, reconfigurability of the SCs for shock absorption, the symmetric flow of information for improved communication, forecasting and visibility, channel uncertainties and a greater degree of integration, collaboration and synchronisation for enhanced product and service visibility and coordination. These strategies facilitate the adoption of some of various CE frameworks/models (Table 8) by overcoming the challenges. To bring these strategies into a cohesive plan, our framework (Figure 5) offering effective mitigation strategies can advance the achievement of CE objectives within manufacturing SCs.

6.3 | The way forward—Transitioning towards net zero

The net zero target refers to commitment to become carbon neutral. The identified drivers of the circular economy approach can act as a catalyst towards transitioning to a net-zero economy, thereby offering economic resilience and growth. The transition would foster green innovation and job creation through circular business models and sustainable technologies. This shift will spawn new industries, promoting economic diversification and global competitiveness. Simultaneously, the presented framework in Figure 5 would facilitate transitioning towards net-zero thereby reducing resource dependencies, ensuring robustness against raw material price fluctuations and enhancing energy security. Social equity and inclusivity would benefit vulnerable communities through clean energy, green jobs and sustainable products (Bonsu, 2020; Demartini et al., 2023). International collaboration, agreements and partnerships accelerating the transition are crucial. In conclusion, the transition towards net zero through the presented circular manufacturing SC framework would address climate crises, foster economic growth and enhance social equity, leading to a sustainable and resilient future.

7 | CONCLUSIONS AND FUTURE RESEARCH AGENDA

Our study employs bibliometric, network and descriptive content analyses to systematically address the three research questions. Firstly, we investigate how CE studies support circular operations within manufacturing SCs. Our analysis reveals a substantial growth in CE adoption from 2013 to September 2023, particularly influenced by the declaration of the SDGs. We identify influential articles, geographical distribution, frequently used keywords and emerging research themes tracing the evolution of circularity in manufacturing SCs over the years.

Secondly, we perform a descriptive content analysis to uncover research approaches, major theories, applications, key drivers, barriers, CE mechanisms and strategies in manufacturing SCs. These findings provide insights into the various facets of CE's role in SCs, answering our second question. Building upon the findings of the first two research questions, we propose a strategic roadmap focused on fostering innovation-led resilient circular manufacturing SC networks. We find that the rigour of the domain started to grow with some influential articles published in the middle of the last decade. We find that additional longitudinal analysis in the domain would facilitate the design of some pragmatic strategies and frameworks for CE implementation in manufacturing SCs, which answers the third research question.

In conclusion, our study underscores the rapid evolution of CE as a pragmatic strategy harmonising environmental preservation and economic growth within manufacturing SCs. It emphasises the need for collaborative efforts among researchers, policymakers, practitioners and stakeholders to implement strategies aimed at addressing the associated challenges (Silva et al., 2019). This comprehensive analysis lays the foundation for the future development of pragmatic CE strategies and frameworks for successful implementation in manufacturing SCs.

7.1 | Future research directions

This study lays the foundation for comprehensive research into circular manufacturing SC operations, setting the stage for future investigations. Future studies may investigate topics like green skill development, circularity culture development within organisations and circularity in the interplay between Industry 4.0 and sustainability. By employing topic modelling, future studies can explore the strategic implications of recent 'zero waste' and 'net zero' policies on circular manufacturing SC operations. Furthermore, future reviews can explore the role of SMEs within this context using the proposed methodology. In addition, future research should focus on the strategic implications of digitalised circular manufacturing SC operations. The findings underscore the need for more quantitative research to establish causal relationships between CE strategies and circularity drivers and barriers thereby advocating for extensive primary surveys and interviews. A sharing economy can support CE as the foundation of both concepts lies in the efficient use of resources during the production and consumption process (Henry et al., 2021). Therefore, the concept of a circular-shared economy, aligning with CE principles, emerges as another promising avenue for future investigation. Circular SCs can influence product design concerning competition and fairness (Li et al., 2020). Further, consumers are reluctant to return the end-of-use products (Singhal et al., 2019; Mostaghel & Chirumalla, 2021). These suggest potential research into designing more appealing circular products and strategies to change consumer behaviours in support of circularity. Additionally, there is an opportunity to advance the field through formal modelling, guiding SC participants toward embracing circularity in manufacturing SC operations and reducing waste.

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CONFLICT OF INTEREST STATEMENT

The authors report there are no competing interests to declare.

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