



# Insights from circular supply chain implementation prospects employing industry 4.0 technologies: a study based on applied methodologies of SLR and content analysis

Rita Nagwal<sup>1</sup> · Kumar Rohit<sup>2</sup> · Ravindra Pathak<sup>1</sup>

Received: 4 April 2023 / Revised: 26 February 2024 / Accepted: 2 May 2024

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## Abstract

This research emphasized on the applicability of Industry 4.0 technologies in the domain of supply chain network exploring the relevance to circular economy. A study was conducted to portray integrated impact of two different domains: circular supply chain (CSC) and Industry 4.0 (I4.0) underlining their effects on the circular economy. The outline of this research is to determine the linkage between CSC and I4.0 to address the barriers to CSC implementation in small medium enterprises (SMEs). This research specifically focused to explore synergies, conflicts, or dependencies between CSC principles and the implementation of I4.0 technologies within SMEs citing the impact on circular economy (CE). To extract vital and conclusive insights from this research, a systematic literature review (SLR) was conducted followed by incorporating content analysis. A systematic procedure was adopted focused on identification of anticipated keywords/and themes having relevance to CSC linking with I4.0 applicability inferring to their core concepts and their overall impact on the circular economy. The existence of specific keywords, topics, or key concepts in a given set of qualitative data (i.e. text) having linkage with the integrated impact of CSC and I4.0 was explored employing this systematic procedure based on PACEF framework. This procedure to validate this research encompasses six different steps – research convention (defining the study's parameters), search (identifying search terms and database types), evaluation (consistent standards for the inclusion and rejection of literature as well as for evaluating the quality), amalgam (extrapolating and classifying data), scanning (describing outcome before coming to a decision), and finally reporting the results (describing the process used and releasing the outcome to the communal), entire procedure being abbreviated as CSEASR. This research yielded significant inferences on the combined effects of CSC and I4.0 on the circular economy that will aid eradicate barriers to CSC deployment with the usage of I4.0 technologies for SMEs.

**Keywords** Circular supply chain · Industry 4.0 · Circular economy · Systematic literature review · Content analysis · CSEASR

## 1 Introduction

A new approach has been developed in the field of supply chain management which is also known as “Circular Supply Chain Management System” (Ayati et al. 2022). The flow of supply chain is reversed in case customer rejects any product, in order to deal with the loss of material and money and put a full stop of on excessively increasing waste generation. There are so many barriers to implement the CSC in SMEs. Here the primary purpose of this article is to find out the fourth industrial revolution solution to overcome the barriers of CSC (Gupta et al. 2020). The circular supply chain (CSC) is a term used to describe how the circular economy (CE) concept is integrated into the supply chain. The CE is intended to support industrial businesses in their efforts

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✉ Kumar Rohit  
rohitkumar.mechy@gmail.com

Rita Nagwal  
enggrita@gmail.com

Ravindra Pathak  
ravindra13479@gmail.com

<sup>1</sup> Department of Mechanical Engineering, Medi-Caps University, Indore 453331, Madhya Pradesh, India

<sup>2</sup> Department of Industrial and Production Engineering (IPE), Shri. G.S. Institute of Technology and Science (SGSITS), Indore 452003, Madhya Pradesh, India

to establish a sustainable economy in partnership with a socially just society (Ayati et al. 2022). Fourth industrial revolution technologies are cited as essential ingredients for the circular economy's productively growth. A framework (Rosa et al. 2020) that connects the CE to I4.0 examined how a particular industry 4.0 technology (blockchain) affected the shift to a CE. While minimizing estimated cost of transaction, enhancing conveying medium of supply chain, and lowering carbon footprint, industry 4.0 practices including the use of block chain technology improved the performance of the circular economy (Kouhizadeh et al. 2019; Gupta et al. 2021). The implementation of CSC practices enhanced the societal value conforming to the ecological balance by avoiding hazardous working situations (Van Buren et al. 2016). The adoption of CSC procedures also contributed towards waste reduction, maximization of resource efficiency, minimization of energy use, and reduction in pollution levels (Gupta et al. 2019; Ghisellini et al. 2016). Protection against climate change (Stewart and Niero 2018), having ethical manufacturing practices throughout the supply chain, developing eco-design, optimizing the production of renewable energy, digesting trash into useful resources for increased value, and remanufacturing, recycling and repair (3R) (Jabbour et al. 2020; Lehmann et al. 2014) are just a few of the factors that contribute towards sustainable development while adopting the CSC procedures. Based on the adoption of digital transformation by contemporary civilizations, I4.0 is the fourth industrial revolution wherein some of these civilizations exhibit signs that they are moving in the direction of ecological transition, or environmental conservation considering the overall sustainability (Belaud et al. 2019). In contrast to traditional record reviews, systematic literature reviews (SLR) employ a reproducible, scientific, and open production method. To fully point out specific previous finding issues, it is helpful to finalize all applicable task and research papers that match our pre-settled insertion basis as identifying the barriers to CSC implementation in SMEs. It makes use of explicit and systematic approaches to lessen the possibility of bias during the search, evaluation, amalgam, scanning, report, and final report of studies. When the step by step method is followed precisely with the fewest possible errors, the research can yield trustworthy discovery and conclusions that could be useful to decision-makers and scientists to take the necessary steps and find out the best solutions (Oxman and Guyatt 1993; Tranfield et al. 2003). It can assist in producing more accurate estimations for the subject being studied (Moher et al. 2015). Primary attributes of SLR and the auxiliary plan of action, content estimation or analysis, are (i) defining fact finding issues that the study would address, (ii) having a expressed objective with straightforward and reproducible procedure, (iii) conducting a search string that contains every relevant study that would satisfy the competence scale, and (iv) assessing the standard/

sustainable of the sort out check out (Moher et al. 2015; del Amo et al. 2018). So, the goal of this example SLR work is to improve our comprehension of the scientific information and study on CSC and I4.0, the barriers to implement CSC in SMEs and I4.0 solutions to overcome the barriers. The SMEs taken into consideration while performing this study majorly fall under the category of small or medium scale manufacturing units in the domain of automotive OEMs, fast-moving consumer goods (FMCG), fast-moving consumer durables (FMCD), spare parts and consumables, pharmaceutical, and chemical-based sectors. Most of these industry sectors strive to either deploy the best practices of I4.0 technologies or CE principles or even integrated framework of both of these two, I4.0 applications as well as CE systems so as to sustain not only in terms of their operations but also considering the firms' overall growth at all levels. The research questions (RQs) to be addressed in this conceptual review-based study are highlighted herein accordingly;

- RQ1: How specific keywords, topics, or key concepts in a given set of qualitative data (i.e. text) having linkage with the integrated impact of CSC and I 4.0 can be derived while performing the systematic literature review (SLR)?
- RQ2: What are the key inferences that can be extracted from this conceptual review-based research pinpointing the combined effects of CSC and I 4.0 on the circular economy?

## 2 Challenges and issues behind CSC adoption employing I4.0 solutions

There are severe challenges or issues experienced by the SMEs while deploying CSC practices in their organizations providing the I4.0 solutions. These challenges affecting the CSC implementation prospects employing I4.0 technologies based on real practices have been thoroughly reviewed to have a clarity on this said research domain and are addressed accordingly;

- Scarcity of Consciousness: Benefits are unclear, knowledge is poor, the organization has a bad vision, and there is little consciousness of farmers or sustainable raw materials. This necessitates to comprehend the significance of I4.0 towards successful adoption of CSC practices in SMEs (Long et al. 2016; Sharma et al. 2019).
- Scarcity of Generalized Structure: There are no universally accepted global standards, protocols, or integrated systems, and due to the lack of internationally recognized processes, organizations are having severe issues to implement I4.0 effectively. For SMEs, the lack of a validated paradigm has become a serious concern (Rajput and Singh 2019; Yadav et al. 2020).

- **Scarcity of Proficient Workforce and Digital Environment:** Being conforming to proficient workforce, language obstacles, digitalization of processes, and digital culture, there have not been enough technical experts in the workforce to operate and comprehend the most cutting-edge technological platforms to deploy CSC practices applying the state-of-the-art I4.0 technologies (Long et al. 2016; Lezoche et al. 2020).
- **Scarcity of Physical and IT Infrastructure:** Taking into account the integration of sensors, standardization of infrastructure, interface platforms, and compatibility problems, there is no adequate infrastructure for the physical and digital worlds to connect (Rajput and Singh 2019; Lezoche et al. 2020).
- **Scarcity of Adeptness and Inspiration:** There is no rivalry in the market for environmental performance pinpointing the issues concerned with ability, capability, and lower priority for CSC practices. Scarcity of incentives for greater sustainability programmes and skill advancement results in less inspiration (Luthra and Mangla 2018; Mangla et al. 2020).
- **Scarcity of Government Support:** These issues are concerned with the law, problems with teamwork, a lack of financial backing, and the low cost of virgin materials. There are no government subsidies, financial incentives, or training programmes as well as no standard policies or protocols to help offset the expense of adoption of CSC practices employing I4.0 solutions (Kirchherr et al. 2018; Kumar et al. 2019).
- **Scarcity of Effective Code and Convention:** The critical issues arising from semantic interoperability or with reference to a policy or code that encourages the transition to CSC, monitoring, sustainability standards and regulations are required to be appropriately emphasized. The entrepreneur's ability to invest and create business possibilities is limited by absence of aligned policies linked to CSC adoption in SMEs (Sehnm et al. 2019; Yadav et al. 2020).
- **Scarcity of Circular Design Aspect:** With reference to eco-efficient technology, eco-innovation, and eco-design, due to outdated technology and lack of digitalization efforts, possibly higher degree of variations or abnormalities might be prevalent in product designing. This requires to incorporate different aspects of redesigning, remanufacturing, regeneration, and restoration towards the creation of successful and effective CSC business models (Rajput and Singh 2019; Kirchherr et al. 2018).
- **Scarcity of Acceptance:** High investment costs, adoption costs for sustainability, security concerns, anxiety related to company losses throughout the transformation period, and trust issues severely lowers the diffusion or adoption rates. The issues related to financial viability, and security concerns with new technologies obstruct the adoption of CSC practices based on deploying I4.0 solutions (Kumar et al. 2019; Liboni et al. 2018).

### 3 Linkage between CSC adoption and I4.0 solutions

The association between adoption of CSC practices and I4.0 applications with reference to CE formed the baseline for research question to be pondered in this study as per this stated subject domain that could be addressed employing some standardized procedure for SLR. A crucial component of every subject domain conducted a review of the relevant literature assessment (Hart 2018). Diverse researches highlighted the integrated impact of CSC practices and I4.0 solutions on the CE. Under the impact of cutting-edge digital technology facilitating the sustainability activities, the I4.0 technologies and applications set the path for substantial growth of circular economy (CE). The sustainable performance, flexibility, and interoperability of CE-oriented supply chains witnessed significant improvements with the aid of I4.0 technologies (Hettiarachchi et al. 2022). The integration of CSC practices and I4.0 technologies contributed significantly to CE principles while fostering sustainability and resource efficiency, and adopting closed-loop practices with the supply chain network. Based on the summarization of these above discussions, the crucial CE principles taken into consideration are characterized by the integration of CSC systems and I4.0 applications to support the sustainable growth of SMEs. Diverse CE principles are adopted by different SMEs depending on their nature of adaptability and conforming to CSC performance measures facilitated by adoption of I4.0 technologies (Ayati et al. 2022; Kouhizadeh and Zhu, Qingyun, Sarkis 2019). These CE principles comprehensively encompassed resource efficiency, waste management/waste reduction and recycling, collaboration and ecosystem thinking, customization and flexibility, continuous innovation and learning, and many other aspects signifying this integration of CSC practices and I4.0 technologies (Rosa et al. 2020; Gupta et al. 2021). The complexity and dynamic nature of different attributes raised the level of uncertainty in supply chains as such, solutions from the fourth industrial revolution sector have been devised to restructure such supply chains creating their digital networks to address the challenges associated with supply chain uncertainty (Atzori et al. 2010; Giusto 2010). From an I4.0 perspective, the sustainability issues in the shipbuilding supply chain have been identified providing the linkage between four different supply chain applications – lean CSC, agile CSC, resilience CSC, and green CSC along with major supporting technologies like internet of things (IoT), artificial intelligence (AI), big data, autonomous robots, and last cybersecurity, among others, in terms of significant outcomes (Rosa et al. 2020). The best practices in CSC and IoT-enabled supply chain solutions collectively for the food industry have the potential towards cost curtailment resulting in affordable prices and reduced

emissions leading to environmental sustainability along with having a positive social impact while enabling sustainability throughout conforming to supply chain and firm-level sustainability (Papetti et al. 2019; Mastos et al. 2020). The German industries brought the I4.0 revolution in 2011 to experience significant transformations in their manufacturing operations in terms of overall sustainability (Roblek et al. 2016). ICT-enabled digital manufacturing and conventional production models both indicated substantial compatibility with the I4.0 approaches (Kang et al. 2016). I4.0 solutions assist the businesses in managing their wide range of product offerings and escalating competitiveness on a global basis while facilitating communication between organizations and their customers targeting the customer satisfaction level (Shrouf et al. 2014). The linkage between CSC practices and I4.0 technologies can be validated based on the support from performing the SLR and content analysis of the previous as well as extant literatures conforming to this research domain. This will aid in outlining the current body of knowledge and locating any gaps in between CSC adoption and I4.0 solutions with reference to specific issues having concern with the CE and this will facilitate to broaden the knowledge base with respect to this stated research domain. The combined impact of CSC practices and I4.0 technologies can bring about significant synergies, particularly in the context of small and medium enterprises (SMEs) while addressing various barriers and unlocking new opportunities to sustainable and efficient manufacturing operations. In summary, the integration of CSC practices and I4.0 technologies would form the baseline to create a formidable framework for SMEs to navigate the challenges of resource scarcity, environmental concerns, and the need for operational efficiency. This combined approach would allow SMEs to not only address barriers but also to capitalize on the opportunities characterized by a circular and digitally connected business ecosystem.

### 3.1 Methodological approach to CSEASR towards SLR

The CSEASR methodological approach encompasses six (6) phases aimed at investigations of both previous and extant literatures towards SLR conforming to facilitate the content analysis. SLR is conceptualized as “a methodical, transparent, and notable procedure for locating, estimating, and combining the modest body of completed and registered work reduced by scholar, practitioners, and researchers (del Amo et al. 2018). The majority of scientific research (del Amo et al. 2018; Grant and Gabor 2009; Mengist and Soromessa 2020) used this methodological technique to lower the danger of publication bias and to improve the acceptance of the work. Based on Grant and Gabor (2009), the structure of search, evaluation, amalgam, along with scanning which is a basic steps to identify the exploration conventions that the SLR ought to adhere. It ensures comprehensibility,

exhaustiveness, systematization, and methodological precision. As a result, the majority of reviews adhered to the framework of Search, evaluation, aggregation, and Scanning (Grant and Gabor 2009) and the Recommended Reporting Elements for Content investigation along with Systematic Reviews (Page et al. 2021) for conducting literature searches. The authors of this paper developed the CSEASR framework by drawing on those common review method types and connecting convention and result interpretation to the search, evaluation, amalgam, and scanning frameworks. Hence, six steps were used in this CSEASR framework for SLR work, with summaries of each step provided in Table 1. The next subsections provide a detailed explanation of each step of the SLR method and its outcomes using the SLR performed by Mengist et al. (Mengist and Soromessa 2020). To address this research, an analysis-based framework employing applied methodologies of SLR and content analysis had been incorporated to derive crucial insights (refer to Table 1).

- (I) Convention: It establishes study scope for review of the literatures.
- (II) Search: It describes the explore plan wherein numerous data from the literatures are the prerequisites and these data are identified through this second step ‘search’ towards performing the content analysis.
- (III) Evaluation: Applying the outcomes of results obtained through the second step ‘search’, insertion and extraction criteria are identified in this third step as such;

The literature selection conforming to SLR with reference to ‘insertion’ has been specified pointedly:

**Regarding insertion – 1 (when the title, keywords, or abstract portion of the paper contain all or nearly all of the chosen keywords)** On the basis of this domain (conforming to title/abstract/keywords), total 197 articles in number fulfilled the insertion criteria which included 95 Scopus, 72 Sciondirect/Elsevier, 20 Web of Science, and 13 Google Scholar databases and 45 articles got excluded from this research study.

**Regarding insertion – 2 (the article that underwent peer review and was published in a scholarly journal)** The article that underwent peer review and was published in a scholarly journal has been included in this research in conformance to CSC implementation.

**Regarding insertion – 3 (research paper should be written in the English language)** Language should be standard and easily understandable; research paper should be written in clearly defined ‘English’ language.



**Table 1** An Analysis-based Framework employing Applied Methodologies; Source: (Mengist and Soromessa 2020; del Amo et al. 2018) with Modifications

Phases for Investigations employing both SLR and Content Analysis	CSEASR Structure	
	Results	Technique
Convention	Established study scope	Only the CSC system and I4.0 applications
Search	Describe the explore plan	Exploring strings
	Explore studies	Explore bibliography
Evaluation	Choosing studies	Defining insertion and extraction criteria
	Computation of the research' standard	quality standards
Amalgam	Take data out	Arrangement for extraction
	Classify the facts	Sort the fact according to the repetitive articles to prepare it as additional evaluation.
Scanning	Fact evaluation	Quantitative classifications, illustration, and history analysis of the assembled facts
	Conclusion along with conversation	Show the patterns, detect gaps, and compare the results based on the analysis.
	Conclusion	Developing a verdict and a suggestion
Report	Writing reviews(statement 2010)	PRISMA methodology
	Operation Management Research Journal	Providing a public summary of the review findings

**Regarding insertion – 4 (studies providing vital data for identifying CSC obstacles and I4.0 solutions)** Research articles that provided relevant databases and information for identifying the CSC obstacles and regarding I4.0 solutions to provide resolution to CSC barriers were considered.

**Regarding insertion – 5 (when at least one I4.0 solution is discussed in the papers)** In those research articles that provided challenges towards I4.0 adoption in CE, in which at least one of the I4.0 solutions was detailed is discussed in the research papers.

The literature selection based on SLR incorporating ‘extraction’ has been detailed pointedly:

**Regarding extraction – 1 (copied documents within conclusive research paper)** All the copied and repetitive documents have been excluded within the conclusive research.

**Regarding extraction – 2 (Papers, review articles, and meta-data that are available)** The papers, review articles, and meta-data being available are considered.

**Regarding extraction – 3 (research papers that are fake or not primary)** The research papers those are fake or not primary fall under such criteria.

**Regarding extraction – 4 (Papers published prior to 2012)** This research has taken into consideration those research articles which have been published during the last

decade (10 years) linked to two different theories, CSC practices and I4.0 solutions but integrated as one.

- (IV) Amalgam: In this step of CSEASR approach, the facts are classified or sorted in accordance with the repetitive articles to prepare it as an additional evaluation.
- (V) Scanning: This step encompasses quantitative classifications, illustration and history analysis of the assembled facts, conclusion along with conversation, pattern(s)’ recognition, gap(s)’ identification, and comparison of the results based on the analysis.
- (VI) Report: The explanation and presentation of the methods employed as well as the conclusions from the finally selected literatures are reported accordingly as per this step of CSEASR.

### 3.1.1 ‘Coding’ Process for SLR

Almost any instance or basis of informative language, such as interviews, unrestricted inquisitions, area or subject research notes, dialogues, and open-ended questions can be used as a source of facts. A single research might look at a variety of textual genres to analyze them. In order to study a text using content analysis, it must be coded or broken into manageable code categories. After the text has been processed into code categories, the codes can then be further separated into “code categories” towards further categorization of the data.

**Table 2** PACEF Framework defining the Research Objective and SLR Research Scope; Source: (Mengist and Soromessa 2020; del Amo et al. 2018) with Modifications

Abstraction	Resolution according to Booth et al. (2016)	SLR approach
Population	Allocating with overcoming the barriers of CSC using I4.0 techniques in SMEs.	Scientific research work on CSC performance measures and I4.0 solutions in SMEs.
Arbitration	Techniques currently in use to solve the identified problem	Identifying the gaps that require additional research work, such as developing a suitable methodology for improving CSC performance and overcoming implementation barriers using I4.0 applications, linked research with human well-being, to examine SMEs in different sectors to uncovered barriers that affect CSC performance and unresearched problems, less-researched variables affecting CSC performance metrics, etc.
Collation	Techniques to contrast the the CSC performance measure against each other	Differences between the numerous approaches used to assess, value, and map distinct SMEs
End Results	Expected outcome of this research will be focused on improving the CSC performance measures (Circular performance, Economic performance, Environmental performance and Social performance) with the help of I4.0 solution.	Current knowledge on CSC barriers such as the most/least studied hurdles and I4.0 solutions to overcome the barriers, classifications of SMEs such as the methodologies along with model address employed, data kinds, objective and the volume of research. Note the following gaps: high-tech restrictions, modelling issues, poor fact attribute along with poor research on CSC barriers and I4.0 solutions.
Factors	The specific scenarios classify the critical barriers to CSC adoption according to their impact	The obstacles and limitations in CSC and I4.0 research, the trends in CSC and I4.0 research, the topographical circulation of current research based on types of SMEs analysed, and the existing knowledge in CSC and I4.0 studies

Source: (Mengist and Soromessa 2020; del Amo et al. 2018) with Modifications

### 3.2 SLR approach – 1: convention

A research convention for systematic literature reviews is necessary since transparency, transferability, and replicability are components that constitute a literature assessment systematic (Sohrabi et al. 2021; Booth et al. 2016). It helps to lessen prejudice by managing thorough literature searches. The big and current challenging issue at the moment is defining the opportunity of research. By creating exploration questions and study boundaries, it is easy to select the ideal research methodology after the parameters of the study are determined (refer to Table2).

By employing CSEASR methodology, this study would respond to these research questions (Sohrabi et al. 2021).

### 3.3 SLR approach – 2: search

This step also included the search's execution and approach. In order to gather relevant documents, the search strategy assists in defining appropriate search keywords and locating relevant databases (del Amo et al. 2018). The subject matter has a major impact on the number of databases available for SLR searches, even though the number may be limited or defined (Papaioannou et al. 2010). Therefore, the search string specification should be based on the idiom for the population in the SLR technique of PACEF framework (as depicted in the Table2). The core conceptualization of PACEF (Population, Arbitration,

Collation, End Results, Factors) framework towards performing the systematic literature review (SLR) has been elucidated herein;

- Population: This refers to finalize the population (research papers) allocating the I4.0 approaches in SMEs to get beyond CSC obstacles.
- Arbitration: The applied mediation techniques have to be employed as per current scenario to solve the identified problem that will aid to identify the gap requiring additional research work.
- Collation: In this step of PACEF framework to compare the CSC performance measures against each other, comparison techniques were applied to assess, signify, and map the distinct SMEs.
- End Results: The goal of this research's anticipated outcomes is basically focused on pinpointing the improvement in CSC performance measures.
- Factors: The specific contexts form the basis for categorization of significant obstacles to CSC adoption considering their impact on CE.”

“Using this SLR-based technique based on the PACEF framework, the existence of particular keywords, subjects, or key concepts having linkage with the integrated impact of CSC practices and I4.0 applications on the CE principles would investigate in a given set of qualitative data (i.e. text). As such, with reference to this context, the

**Table 3** Details for Total Number of Published Articles and Usage of Search Terms for Each Database; Source: (Mengist and Soromessa 2020; del Amo et al. 2018) with Modifications

Databases	String used to Search	Terms for searches	No. of Research Articles	Date of Acquisition
Scopus	Primary search terms using the document Title, abstract and keywords		92	25/03/2023
		Circular supply chain, Industry 4.0, and supply chain	50	24/03/2023
	Secondary searching terms	Barriers and circular economy	25	18/03/2023
		Industry 4.0 solutions	50	18/03/2023
		Industry 4.0, the circular supply chain, and gaps	60	18/03/2023
		Circular economy and Sustainable supply chain management	54	18/03/2023
		Industry 4.0 and circular supply chain	44	18/03/2023
Science Direct	Primary searching terms	Circular supply chain, Industry 4.0 and Gaps	72	14/03/2023
		Circular supply chain barriers and Industry 4.0 applications	65	14/03/2023
	Secondary searching terms	Supply chain, Circular supply chain, Industry 4.0,	55	14/03/2023
		Circular economy, Performance improvement	50	14/03/2023
		Circular supply chain, Linkage and Industry 4.0	44	24/03/2023
		Circular supply chain, Barriers and Gaps	50	10/03/2023
Google Scholar	Main searching terms- where all is found in the title of the articles	Supply chain, Circular supply chain, I4.0	13	10/03/2023
		Circular supply chain, I4.0 and Gaps	11	19/03/2023
	Secondary searching terms	Circular supply chain and challenges to implementations	10	28/02/2023
		Circular economy, Performance improvement	13	28/02/2023
		Circular supply chain, I4.0 and Gaps	12	18/02/2023
		Performance measurement, Circular supply chain management	10	18/02/2023
		Circular supply chain barriers and I4.0 applications	10	18/02/2023
Web of science	Primary searching terms	Barriers to circular supply chain	20	15/02/2023
		Supply chain, Circular supply chain, Industry 4.0	15	15/02/2023
	Secondary searching terms	Circular economy, Performance improvement	12	15/02/2023
		Circular supply chain, Industry 4.0 and Gaps	10	15/02/2023
		Circular supply chain and challenges to implementations	14	15/02/2023

relevance of PACEF framework towards SLR methodological approach got validated in this conceptual review-based study. The key phrase focuses on the “barriers to deployment of CSC practices in SMEs and I4.0 applications to overcome this”, being highlighted in Table 3. The syntax used was as follows: TITLE- ABS-KEY is an additional search engine that can be used in conjunction with the aforementioned keywords to find results for phrases like “Circular supply chains,” “Circular economy,” “Sustainable supply chain,” “Circular supply chain, Industry 4.0 and Gaps,” “Circular supply chain, Linkage with Industry 4.0,” and “Performance measurement, Circular supply chain management.” Single search terms or several amalgam

that took the demands into mind or restrictions utilized the relevant facts. Papers from these facts were destroyed as they couldn’t be recovered for more thorough investigation.

For this inquiry, the search databases examined were Google Scholar, Science Direct, and Scopus. On March 10, 2023, the literature searches were completed. The relevant information from publications was gathered by searching a variety of well-known, internationally renowned databases. Science Direct is a database of published scientific research that is also an online academic citation index, sponsored by publisher Elsevier (Gonçalves et al. 2018). Scopus is a global database of peer-reviewed articles from all across the world.

N.B. The information presented here comprises original and reviewed publications in every language.

Information includes, but is not limited to, publisher lists, journal lists, journal kinds, information about the publication period or refereed status of records, etc. Nonetheless, using Google Scholar's sophisticated search engine is helpful for covering citations that are not included in other databases (Yang and Meho 2006). Each database should be searched using the search phrase, and the number of articles found as well as the date of publication should be recorded. In the search delivery stage, the selected databases are contacted using the search term to acquire a selection of papers from related literature (del Amo et al. 2018). Using the search string in the finalized facts yielded the quantity of works that might be found, as validated by the explored output displayed in Table 3. The amount of publications with the closing study, Yet, was influenced by the researcher's search parameters and the goal that was intended to be achieved (Martinez-Harms et al. 2015). Moreover, the sample proportion of the analysis may be impacted by the proportion and database types used to look for pertinent papers (Mengist and Soromessa 2019). A pilot literature search should be carried out before the actual systematic review search to fine-tune the search keywords to fit the targeted study objectives (Howe et al. 2014). Before selecting the search engine, a pilot search should be carried out to further specify the search terms. For instance, it appears that many articles are connected based on the vast number of results from the three databases we examined during our pilot search. This came about as a result of the extensive time period, the usage of broader searching strings, and the distinct outcomes from one and all facts.

From final output, the article search only included publications that were published between 1998 and 2020.

### 3.4 SLR approach – 3: evaluation

This stage involved evaluating the chosen articles in light of the goal of the review activity. The research selection process involved screening the chosen literature in order to

discover suitable papers for the review task. The two key stages are the selection of research using insertion basis and standard estimation.

### 3.5 Selection of relevant literature studies

When using insertion along with extraction standard, publications which satisfy insertion standard were picked for next analysis along with content evaluations. The planned literature insertion and extraction standards applied are highlighted in Table 4 to conclude our thorough review of literature. Gray literature, lengthy abstracts, keynote addresses, speeches, review articles, and works published in languages other than English were primarily excluded. Certain publications or papers may not have had the phrase "barriers to deploy the CSC in SMEs" in the title, keywords, or abstract. Because they went beyond the review of the work being done, which is defining the status of application of I4.0 to remove barriers to CSC deployment, these types of papers were removed from the review.

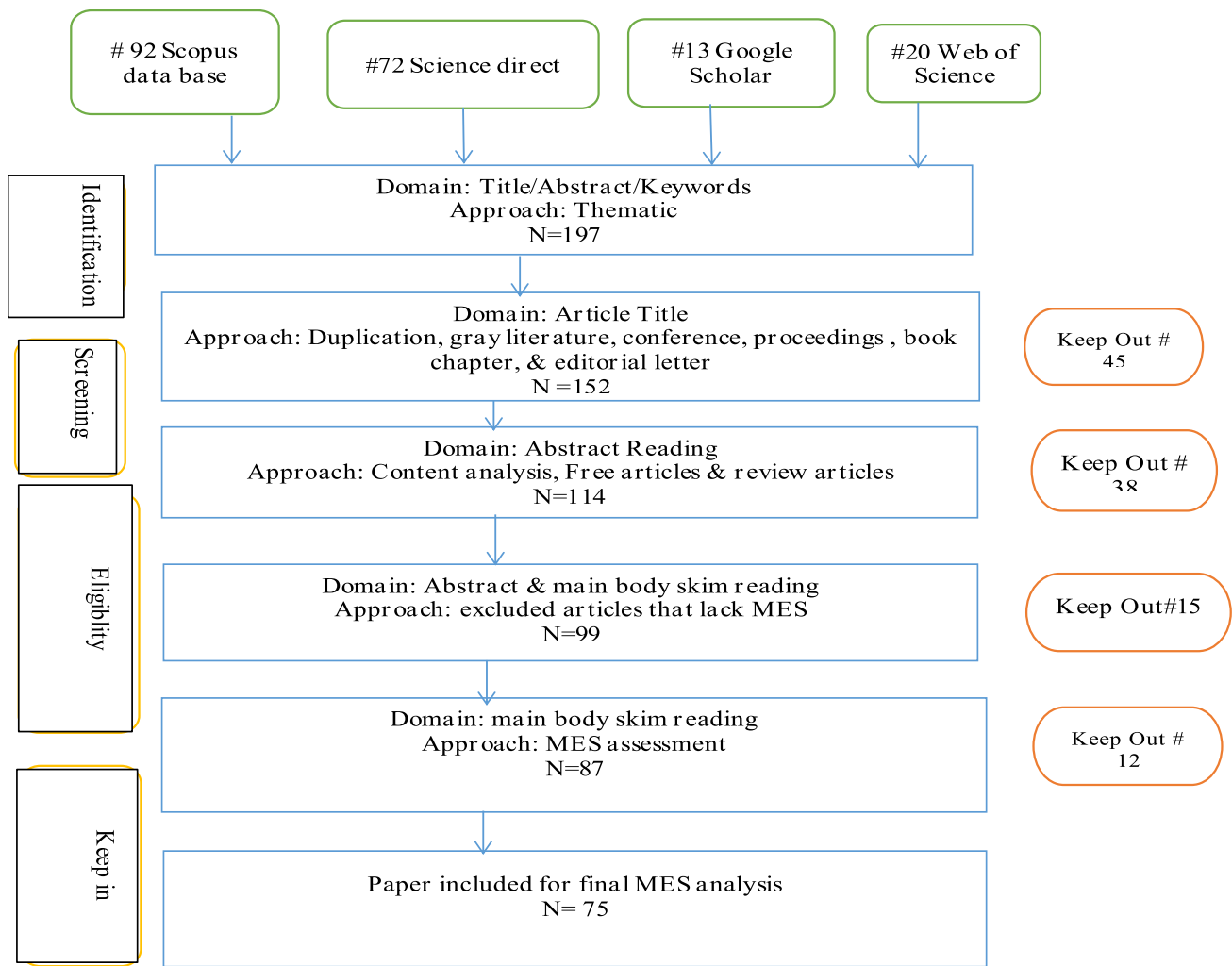
Figure 1 displayed the general screening procedures and the order of picking pertinent material. An initial search turned up 197 records in total (92 from Scopus database, 72 from Sciencedirect, 13 from Google Scholar, and 20 from Web of Science). After removing literary works like grey English language papers and inaccessible publications, the number of literary works was reduced to 152 articles retained for future title reading. Only 114 more publications were eligible for further abstract reading after that. After reading the article abstracts, there were only 99 articles remaining to read. These articles were retrieved for additional screening procedures after 87 of them had their CSC and I4.0 scores analysed. During reading of the main body, duplicate papers and those lacking exact ecosystem service evaluation methods were manually removed. In the end, 75 publications were left that met every requirement for inclusion in SLR effort (refer to the Fig. 1).

For additional study, complete collection of relevant papers was obtained. 6.5% of the original articles in the databases made up the articles used for additional research.

**Table 4** Literature Selection based on SLR incorporating Insertion and Extraction Criteria; Source: (Mengist and Soromessa 2020; del Amo et al. 2018) with Modifications

Literature Selection based on SLR incorporating Insertion and Extraction Criteria	
Standard	Conclusion
When the title, keywords, or abstract portion of the paper contain all or nearly all of the chosen keywords	Insertion
The article that underwent peer review and was published in a scholarly journal	Insertion
Research paper should be written in the English language	Insertion
Studies providing vital data for identifying the CSC obstacles and I4.0 solutions	Insertion
When at least one I4.0 solution is discussed in the papers.	Insertion
Copied documents within conclusive research paper	Extraction
Papers, review articles, and meta-data that are available	Extraction
Research papers that are fake or not primary	Extraction
Papers published prior to 2012	Extraction





**Fig. 1** Flowchart depicting SLR based on Paper Searches in Databases; Source: (Mengist and Soromessa 2020; del Amo et al. 2018) with Modifications

Thus, a larger sample size was chosen in this review investigation (Yang et al. 2018) that used 0.6% and 1.8% of the real number of research papers in the facts, appropriately. Still, the searching standard and the aim of the review was achieved identifying the number of articles in the sample for said analysis (Martinez-Harms et al. 2015). Also, the sample size for analysis depends on the quantity and kinds of databases used for publishing searches. Also, the majority of investigating articles on the issue were not open sources, which reduced the total number of published articles included for next analysis.

#### 4 Quality evaluation

The following criteria, which are based on four quality assessment questions, were used to each SLR evaluation:

- Q.1. Are the criteria for Insertion and extraction for the review well specified and appropriate?
- Q.2 Is the validity and calibre of the work evaluated by blind reviewers in the selected publication?
- Q.3. Is it likely that all relevant studies on the issue were covered in the literature review?
- Q.4. Was description of the types of I4.0 applications and obstacles to CSC in the publication accurate?

#### 5 SLR Approach – 4: amalgam

In order to produce knowledge and conclusions, the amalgam process involves both the extraction and classification of pertinent information from certain sources. The data extraction procedure involved locating and removing pertinent material from the chosen publications. There is coding

for SLR and content analysis studies, much like in survey research. The coder uses the predetermined criteria to extract the information from the chosen publications (Shelby and Vaske 2008; Duriiau et al. 2007).

The basic classification of the published articles along with particular metrics used to examine, estimate, and map the barriers to CSC adoption in SMEs in order to meet the SLR objectives. The extensive knowledge in the articles includes publication time in years, examination types (quantitative, qualitative, and mixed), research kind along with sizes, and number of barriers that affect the CSC and I4.0 solutions to overcome the barriers. As a result, the research work included variables of interest (10), which were listed along with characterized in 5th Tabular result. Information pertaining to one and all finalized publication was lastly removed and entered for data processing in Excel spreadsheet. The data retrieval procedure involves classifying along with step by step information to prepare it for further analysis (Mengist and Soromessa 2020).

### 5.1 SLR Approach – 5: scanning

Synthesis data evaluation and relevant data extraction, along with the examination of the selected publications were all added in the scanning phase. By this stage, the research questions would have been answered. It also incorporates both the qualitative and quantitative interpretation and narrative of the data, as well as suggestions for potential future routes for research projects and conclusions. The data from the final selected publications can be synthesized using Statistical methods that are descriptive or fundamentally inferential (Shelby and Vaske 2008).

This research, were used descriptive statistics to determine publication trends, evaluate the CSC and I4.0 indicator elements, and examine the date of publication, spatial size, kind of evaluations, and ecosystem that had barriers to CSC adoption in SMEs. An outline of the data, lack of knowledge, along with implications for alternative maintenance were provided based on the 10 criteria that were chosen for this study. The systematic review also identifies the several categories of scientific study that will be conducted in the future across a range of disciplines that are interested in doing so and have the resources to do so, additionally, the effects of the current condition of the findings for the development and execution of policy. The studies that were chosen were categorized based on the publication year, the countries in which they were done, and the spatial scale they employed (patch, local, regional, national, or global). Information was also retrieved about the goal of the study, the categories of barriers and I4.0 applications studied, and other topics.

However, Shelby and Vaske (Shelby and Vaske 2008) argue that the subjective assessments of the analyst,

researcher's standard of research comprehension, and this research goals all affect the analysis and result presentation. Depending on the kind of studies, the use of statistical analytic research mechanism in SLR along with content-analysis is essential and required to convey final output fairly and assure consumers of the end results. The study made use of the Voyant tool, an open-source text mining and analysis tool for the web that makes it easier for scholars to view and analyse the texts from the selected articles (<https://voyant-tools.org/>). Also, it might be used to examine the keyword frequency information from all finalized published research work (Xu et al. 2018).

### 5.2 SLR Approach – 6: report

SLR article process added the explanation and presentation of the methods employed as well as the conclusions from the finally selected literature. According to del Amo et al. (2018), the report phase consists of two processes: (i) description of the main technique used, as specified in Table 5, and (ii) population release of the results in the form of a journal paper. A journal publication was the product of the final stage of SLR, which adds to the body of work needed for scientific applications.

### 5.3 Key insights from this study and discussion

Small and medium-sized enterprises (SMEs) are under intense pressure to make their manufacturing operations ethical and sustainable in the I4.0 and CE era. In the contemporary era of I4.0 and CE, companies that function on ethical business practices and consider the environmental responsibility are in high demand. This has been pointed out that deploying I4.0 technologies could support to achieve the objectives of ethical and sustainable business practices. Feasible studies or researches addressing the practical implications in reality linked to the applicability of I4.0 technologies in SMEs for socially and ecologically conscious job practices are scarce as per this scenario, despite substantial research being conducted in connection to larger enterprises. Based on the core outcomes of this research, this research will create a benchmark for the manufacturing sectors involving practitioners and policymakers deploying the integrated framework of CSC practices and I4.0 solutions to excel at the global basis getting the competitive advantage for these firms in terms of overall sustainability. Small and medium-sized enterprises (SMEs) are under intense pressure to make their manufacturing operations ethical and sustainable in the I4.0 and CE era. In the contemporary era of I4.0 and CE, companies that function on ethical business practices and consider the environmental responsibility are in high demand. This has been pointed out that deploying I4.0 technologies could support to achieve the objectives

**Table 5** Criteria incorporated for extracting Data from Shortlisted Articles

S.No.	No	Criteria Categories	Consideration of the Facts	Justification
1		Publishing year	Between 2013-22	Studies conducted prior to 2013 were disregarded.
2		Name of journal		To describe how the work was distributed
3		Several sources of data Data	Primary fact	Generated from field sampling (e.g., field data, surveys, or interviews or census data)
	Secondary fact		Data categories that weren't field-verified and were drawn from widely available sources of information	
	Mixed fact		Database (e.g. automotive parts), bibliography, modeling, surveys, and field data.	
4		Method	Look-up tables	Use of existing barriers classification criteria from the literature
	Expert knowledge		Experts are invited to rank barriers types based on their potential to provide specific knowledge about all obstacles and solutions	
5		Mode of assessment	Qualification	Expressing the barriers to CSC with critical factors.
	Quantification		Classify the barriers according to there impact	
	Economic valuation		Publications analyzed monetary barriers to implementation to CSC in SMEs	
	Mapping and modeling mixed		Studies showing the prioritization of barriers The article made use of multiple of the aforementioned evaluations.	
6		Classification of CSC performance measures Assessment (Bals 2019)	Roundabout performance	The circular strategies, such as reuse, repair, refurbish, re-manufacture, and recycling, result in both concrete and intangible advantages.
	Financial performance		Aim is to increase economic value and ensure the CSC's financial stability (e.g., costs, profits)	
	Environmental performance		Services provided by ecosystems that control the environmental circumstances under which people live. (For instance, reducing climate change).	
	Social performance		Aim is to improve human social circumstances (e.g., workplace conditions that are safer and better, employeebenefits).	
7		Reasons behind publication	Increased site-specific information	Studies presenting the relationship between CSC and I4.0 in terms of money and/or biology
	Methodological implementation		Create a latest method or assess existing technique for CSC implementation success.	
	Management option Policy Implementation		To make management suggestions for effective resource usage The article analyzed potential future policy challenges connected to barriers and used existing policies to remove obstacles to CSC implementation utilizing I4.0 solutions frame.	

of ethical and sustainable business practices. Feasible studies or researches addressing the practical implications in reality linked to the applicability of I4.0 technologies in SMEs for socially and ecologically conscious job practices are scarce as per this scenario, despite substantial research being conducted in connection to larger enterprises. Being interpreted from this research, topic-specific knowledge, trends, gaps, and vital inferences having significant relevance to CSC implementation prospects applying the core technologies of I4.0 can be imparted to the scientific community and policy makers towards sustainable growth of the firms indicating major impact on the CE. This will take into account to design and develop a comprehensive framework

considering the key factors facilitating SMEs as well as large enterprises overcome the obstacles to CSC adoption employing I4.0 technologies so as to bring crucial transformations in the CE.

#### 5.4 Limitations of this SLR-based study

An excessive dependence on search restrictions can make the SLR procedure less transparent. One of the limitations of this research is concerned with an oversimplification of the study issue, which could result in faulty or incomplete SLR conclusive outcomes (Papaioannou et al. 2010). Limits may decrease the sensitivity of the search leaving out cer-

tain relevant studies and reducing the completeness of SLR approaches. If too many restricting commands are applied, bias may be introduced towards the category of particular study types (Higgins 2019; Kugley et al. 2016).

## 5.5 Concluding remarks and future directions of research

This research explored the existing knowledge, trends, and gaps conforming to the integrated effects of CSC and I 4.0 while considering the overall impact on circular economy. From this study, crucial insights were derived to infer to the integrated impact of CSC and I 4.0 while affecting the circular economy that will aid to pinpoint the barriers to CSC implementation deploying I 4.0 technologies for SMEs, getting validated by previous researches (Dongfang et al. 2022; Hettiarachchi et al. 2022). The core essence of this research was focused on to investigate the linkage between CSC and I 4.0 addressing their overall effects on circular economy through performing a systematic literature review (SLR), and later on incorporating the content analysis. Such techniques incorporating CSEASR analysis method will form the form the baseline to determine the obstacles to CSC implementation employing the core I4.0 technologies in SMEs. “The outcomes of this research strived to put a strong emphasis on identification and categorization of crucial obstacles to the effective implementation of CSC practices targeting the improvement in CSC performance metrics whether in terms of social, economic, or environmental factors employing the I4.0 solution approaches. The futuristic advancements in this research can be facilitated towards further analysis –via- a thorough survey employing ISM-MICMAC analysis, Fuzzy-MICMAC (FMICMAC) approach, fuzzy approaches to multi-criteria decision-making (MCDM) methods that of AHP, TOPSIS, PROMETHEE, VIKOR and DEMATEL. Such analyses can also be facilitated employing Grey relational analysis (GRA), and statistical modelling approaches like structural equation modelling (SEM) using PLS, AMOS and its cran-R programming package named as simulated-SEM (SIMSEM) aimed at classification and determination of linkages or associations between the vital barriers to CSC deployment and applicability of I4.0 technologies for SMEs conforming to future directions of research. This research can be further extended to address CSC implementation aspects employing Industry 5.0 (I5.0) technologies leveraging with smart technologies, robotics applications, and big data analytics while deploying for SMEs as well as large-sized enterprises. The forthcoming researches in this domain will enable the operations managers to develop an integrated framework considering the major aspects to overcome the barriers to CSC implementation with the deployment of I4.0 technologies not only for SMEs but also for large-sized manufacturing set-ups. Such researches from the perspective of manufacturing operations will ascertain a substantial standard

for manufacturing organizations adopting CSC practices with the aid of I4.0 technologies to thrive not only in India but also at a global basis, giving these manufacturing set-ups a fair competitive advantage as they rigorously strive to outperform conforming to overall sustainability.”

## Declarations

**Competing interests** The authors have no relevant financial or non-financial interests to disclose. The authors have no competing interests to declare that are relevant to the content of this article. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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