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Circular supply chains in the era of industry 4.0: A systematic literature review

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ABSTRACT

The literature already discussed about how the synergic implementation of Circular Economy (CE) and Industry 4.0 (I4.0) paradigms in industrial contexts could enable improvements in Supply Chain (SC) efficiency and competitiveness. However, the experts concentrated on a single topic of circular supply chain (CSC), CE, and I4.0, lacking a systemic approach to the integrated context. To this aim, the paper proposes a systematic literature review investigating and systematizing the knowledge around the circular SC domain enabled by CE and I4.0 and, simultaneously, highlighting the major trends. Starting from six dimensions of analysis (Type of contribution, LC phases, I4.0 technologies, Triple Bottom Line (TBL) layers, CE strategies, and SC typologies), CSC-related articles have been classified basing on five thematic categories (I4.0 enabling technologies, Performance tools and indicators, Challenges and barriers, Business models and strategies, Best practices). Results allowed to provide some peculiarities of each category. From a sustainability side, they confirmed a predominance of economic and environmental aspects over social ones, together with a life cycle perspective. From an I4.0 side, they shown a prevalence and a synergic implementation of internet of things, big data analytics, and cloud technologies. From a CE strategy side, reuse-recycle-remanufacturing, waste management, material and energy efficiency have been identified as prevalent topics. The paper contributes in building an integrated knowledge of the threefold CE, CSC and I4.0 research context. In addition, it proposes a theoretical framework useful to gradually guide practitioners in approaching the CSC transition. Depending on different CSC aspects, managers could easily raise their knowledge about practices, methodologies, and technological solutions helpful to support their CSC activities.

1. Introduction

Technological growth rates, resources constraints, environmental issues, and directives have started to warn Supply Chain (SC) actors to rethink materials and energy consumption (Rosa et al., 2019). In this sense, CSC plays a fundamental role since it promotes the transformation from a linear to a circular paradigm characterized by return processes. To achieve this, upward and downward linkages in the different SC processes and activities are established (González-Sánchez et al., 2020). Waste reduction through self-sustaining production systems can thus be achieved (Genovese et al., 2017).

Circular Economy (CE) and Industry 4.0 (I4.0) represent the two most important industrial patterns in recent years. Their synergic implementation in an industrial context provides improvements in SC efficiency and competitiveness (Rosa et al., 2020).

This paper replies to the urgent need to shift the restricted focus of Industry 4.0 on the firms, to a more extended and systemic view that considers governments perspective, macroeconomic aspects, public dimensions and social development. A more extended focus along the SC and society will enable the exploration of the full disruptive impact of Industry 4.0 technologies from a Circular Economy perspective to a more extended context, contributing to provide the needs of current and future generations. Indeed, I4.0 technologies have been scarcely assessed from the CE perspective across the entire SC (Walker et al., 2021). Several contributions have concentrated on the individual topics of Circular Supply Chain (CSC), CE, and I4.0, yet a scarcity of attention devoted to the integrated context and its synergic impact has been detected.

Beside the lack of systematicity in the studying approach of the domain, the literature context appeared deficient of approaches to cross-analyze different aspects and topics. Contributions able to detect trends

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Nomenclature

Acronyms

3DP	3D Printing
3Rs	Reuse-Recycle-Remanufacturing
AI	Artificial Intelligence
AM	Additive Manufacturing
BDA	Big Data Analytics
BM	Business Model
BoL	Beginning of Life
CBM	Circular Business Model
CE	Circular Economy
CLSC	Closed-Loop Supply Chain
CPS	Cyber Physical System
CRM	Customer Relationship Management
CSC	Circular Supply Chain
CSCM	Circular Supply Chain Management
CSF	Critical Success Factor
EoL	End of Life
I4.0	Industry 4.0
ICT	Information and Communications Technology
IoT	Internet of Things
IT	Information Technology
KPI	Key Performance Indicator
LC	Life Cycle
LCA	Life Cycle Assessment
M&EE	Material and Energy Efficiency
ML	Machine Learning
MoL	Middle of Life
PSS	Product-Service System
RFID	Radio Frequency Identification
SC	Supply Chain
SDGs	Sustainable Development Goals
SME	Small and Medium Enterprises
SSC	Sustainable Supply Chain
SSCM	Sustainable Supply Chain Management
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TBL	Triple Bottom Line
UAV	Unmanned Aerial Vehicle
V&HSI	Vertical and Horizontal System Integration
WEEE	Waste from Electrical and Electronic Equipment

and successful relations among the research domains of SC, CE and I4.0 could not be found in the extant literature. The final purpose of this research is, indeed, to investigate and systematize the knowledge around this threefold research domain through an analysis able to systematically integrate the three domains and identify trends to provide research directions for researchers and guidelines for practitioners coping with the CSC transition.

In particular, in the discussion section, a framework to successfully guide managers and raise their awareness in the CSC domain has been provided.

The paper is structured as follows. Section 2 presents the research context. Section 3 displays the adopted research methodology. Section 4 provides the main findings. Section 5 discusses the results and raises the implications of the work. Section 6 argues conclusive considerations while debating limitations and future research trends.

2. Research context

This section introduces the main concepts of this research (i.e., Circular Economy, Circular Supply Chain and Industry 4.0) to clarify what is meant per each of them and pave the way to their joint analysis.

2.1. Circular Economy

A commonly agreed definition of the CE was proposed by the Ellen MacArthur Foundation (EMF, 2015): "A circular economy is one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles".

The CE is defined as an economic model overcoming the linear (take, make, dispose) one and minimizing the consumption of finite resources thanks to innovative materials, products, and systems.

However, only in the last few years the relevance of the CE has been amplified worldwide. Progressively, closed-loop patterns, completely focused on balancing economic, environmental, and societal impacts, have substituted old industrial practices (Rosa et al., 2020).

The diffused CE strategies have been exhibited in the paper by Acerbi & Taisch (2020), including cleaner production, Circular Business Models (CBMs), waste management, disassembly, remanufacturing, reuse, recycle (3Rs), servitization, industrial symbiosis and eco-industrial parks, Material and Energy Efficiency (M&EE) and circular design practices.

2.2. Circular Supply Chain

CSCs promote the transformation from a linear to a circular model by involving return processes that capture additional value and further integrate the SC activities.

Various terms, such as reverse, closed-loop or open-loop and green SC, have been interchangeably used in the literature to talk about CE paradigm applications.

The reverse SC includes activities, dealing with product design, operations and End of Life (EoL) management, which maximize the value creation over the entire Life Cycle (LC) through the value recovery of after-use products either by the original product manufacturer or by a third party. Reverse SCs are either open-loop or closed-loop (Genovese et al., 2017).

Open-loop SCs involve materials recovered by parties other than the original producers who are capable of reusing them.

Closed-Loop Supply Chains (CLSCs) deal with the returning of products to the original manufacturer for the recovery of added value. The latter expanding on reverse logistics, include remanufacturing, reuse, repair, refurbishment and recycling (Hussain & Malik, 2020).

Green supply chains engage suppliers and customers to foster an environmental cooperation resulting in gains associated with both environmental and economic performance (Masi et al., 2017). "Green supply chain management is characterized by greenness in product design, selection and purchase of raw materials, production, distribution and after sale services" (Y. Kazancoglu et al., 2018).

2.3. Industry 4.0

I4.0 is referred to as a wide range of concepts related to advanced digital technologies (Rosa et al., 2020). In particular, the Boston Consulting Group identifies 9 technologies as building blocks of I4.0: Big data and analytics, Autonomous robots, Additive manufacturing, Simulation, Augmented reality, Horizontal and vertical system integration, the Internet of Things, Cloud and Cyber-security (Russmann et al., 2015). These connected systems (Cyber Physical Systems - CPS) are able to gather and analyze data across machines through fast, flexible, and efficient processes thanks to standard internet-based protocols. Therefore, I4.0 enables to gather and analyze data across machines

through a fast, flexible and efficient process. The use of such technologies contributes to information exchanges between actors and organizations fostering CBMs.

3. Research methodology

To optimally present the contribution of this paper in enlarging and systematizing the Circular Supply Chain (CSC) domain, the research methodology consists of a systematic literature review composed of three main phases (search criteria, article search and article content analysis) according to the guidelines provided by (Denyer & Tranfield, 2009; Rosa et al., 2020; Smart et al., 2017). In the first one, the investigation dimensions were chosen according to the aim of the research. Specifically, Industry 4.0 (I4.0) technologies, Circular Economy (CE) strategies, and Supply Chain (SC) typologies represent the three main themes addressed by the analysis.

A documents search was performed in this threefold research context through a set of queries on scientific database. Scientific articles published from 2010 up to the first quarter of 2021 were gathered from the Scopus® scientific database (being it the most diffused one for industrial engineering and having a broader coverage (Ren et al., 2019)) to investigate about a decade from the initial digital technologies diffusion. The term I4.0 was firstly introduced by Henning Kagermann, during the Hannover Fair of 2011 (Kagermann et al., 2011). Without considering any field content limitation, to search for contributions, four queries were used on titles, abstracts, and keywords. Fig. 1 shows the research strategy used in the systematic literature review (Smart et al., 2017). The first research related to the query “Supply Chain” AND “Industry 4.0″ AND ”Circular Economy” being the main and broader field of analysis, was limited to journal articles and conference papers (23%). Alternatively, the other three searches were limited only to journal articles; this choice was driven by the willingness to shrink the search to a restricted number of documents representing finalized and valuable contributions in very wide research contexts. As a result, the combination, after discarding redundancies, led to a total number of 333 articles.

Then, on the identified sample of papers, the first selection was conducted by reviewing titles, abstracts, and keywords, and the second screening was performed by analyzing the entire manuscript. The selection was conducted based on the relevance of documents, taking into account only those contributions proposing approaches and related guidelines to foster the CE paradigm adoption through CSC solutions thanks to the use of I4.0 technologies. By applying these refining criteria, the set of documents found was reduced to 198 selected articles identifying the major trends in the field.

Finally, the contributions selected have been progressively sorted, labeled, integrated and then prioritized (using the SLIP method proposed by (Maeda, 2006) adopted also in (Sassanelli et al., 2020)) according to their content in five main categories, presented in Section 4.2. Then, they were analyzed through six dimensions: type of contribution proposed (framework, approach, guidelines, model, methodology, tool), LC phase covered (Beginning of Life (BoL), Middle of Life (MoL), EoL, whole), I4.0 technologies adopted (according to the nine pillars described in Section 2), Triple Bottom Line (TBL) layers addressed (economic, environmental, social), CE strategies embraced (presented in Section 2), and SC typologies involved (green, sustainable, circular, reverse, open-loop, and closed-loop). Among these six dimensions, type of contribution proposed, LC phases covered, and TBL layers enclosed, have been selected and considered since they have already demonstrated their effectiveness in this kind of analysis, due to their recurrent use in previous systematic literature reviews investigating different facets of the CE paradigm (e.g. in (Rosa et al., 2019; Sassanelli et al., 2020)). The three remaining dimensions (SC typology, I4.0 technologies and CE strategies) have been included in the analysis due to their relevance for the definition and characterization of the threefold research context investigated in this study.

4. Main findings

4.1. Descriptive analysis

Fig. 2, presenting the publications’ chronological distribution, shows a growing trend from 2016, with a peak reached in 2020 (94 articles). This can be explained by the gradual shift of researchers interest related to CE and I4.0 from the company dimension to a wider one, exactly the CSC. Indeed, the need to move the restricted focus of Industry 4.0 from the firm dimension to a more extended and systemic focus along the SC and society enables the exploration of the full disruptive impact of Industry 4.0 technologies from a Circular Economy perspective to a more

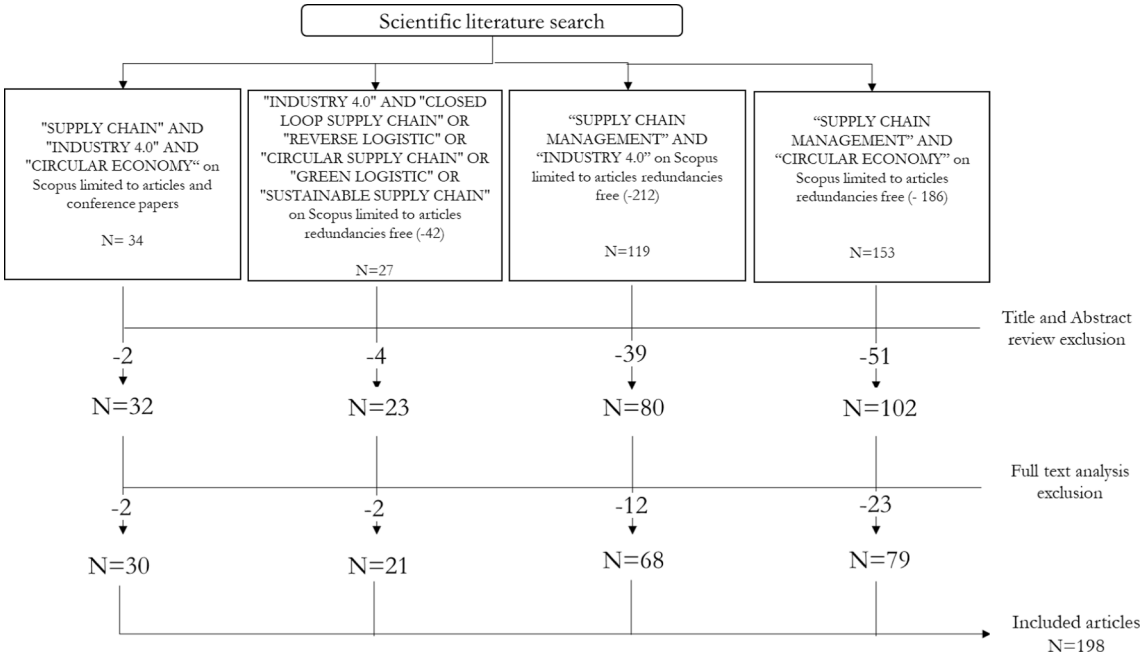


Fig. 1. Systematic literature review approach.

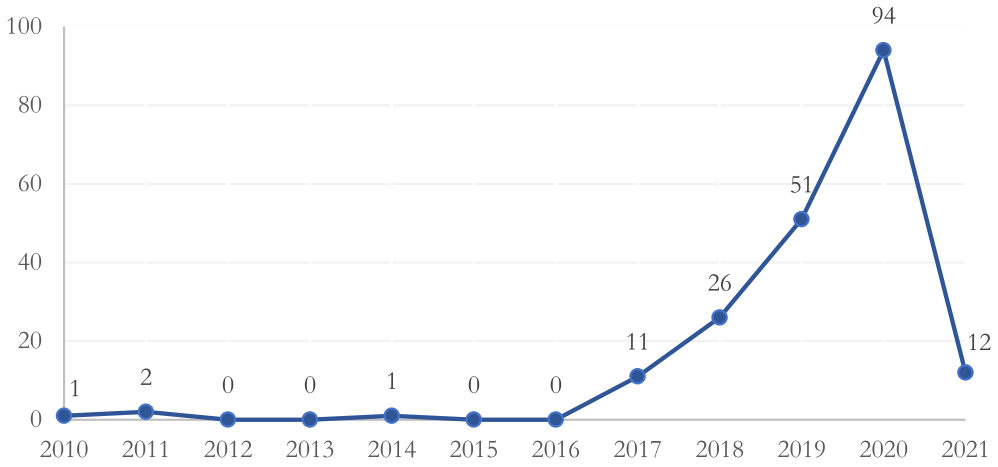


Fig. 2. Historical publication trend by year.

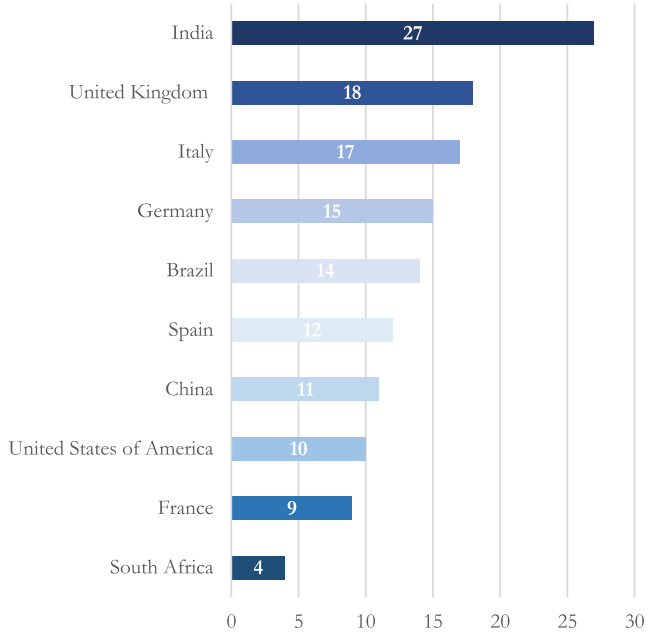


Fig. 3. Top 10 countries.

extended context, contributing to provide the needs of current and future generations. The degradation trend in 2021 can be explained by the fact that only the data related to the first quarter were used.

A further analysis, to detect geographical trends in the literature, has been performed. Figs. 3 and 4 show the top 10 countries and 5 schools that emerged from the 198 selected articles according to the first author provenance. Fig. 3 displays that a large number of papers come from European authors, in particular United Kingdom (18), Italy (17), Germany (15), Spain (12) and France (9). In this regard, the French Montpellier Business school has been reported as the most diffused one, since 4 first authors are affiliated to this school. The Italian university of Politecnico di Milano and the British university of Warwick are both referred to 3 papers. Indian authors have proven to be the most numerous in terms of articles (27) with the Nation Institute of Industrial Engineering as the reference school. Others very populated countries have shown a strong commitment to the research domain, as the case of Brazil (14), China (11) and United States of America (10). Lastly, the University of Johannesburg in South Africa has collected 3 papers.

The principal publishing location is the Journal of Cleaner Production (20 publications), followed by Sustainability (18) and Resources Conservation and Recycling (15). Fig. 5 presents the distribution of the selected documents according to the top 10 relevant journals.

Fig. 6 shows that there are many different industries contributing to the development of the literature on the application of Circular Supply

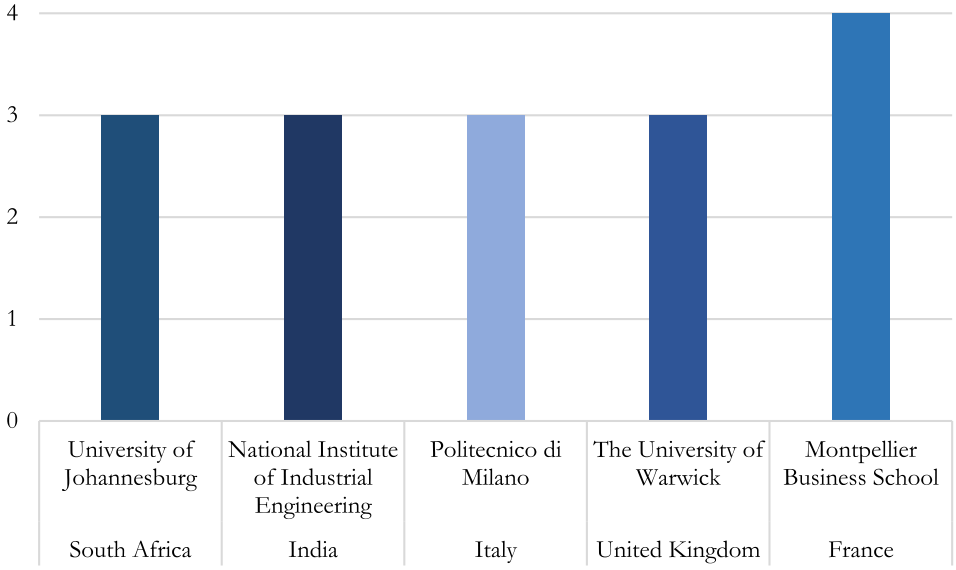


Fig. 4. Top 5 schools.

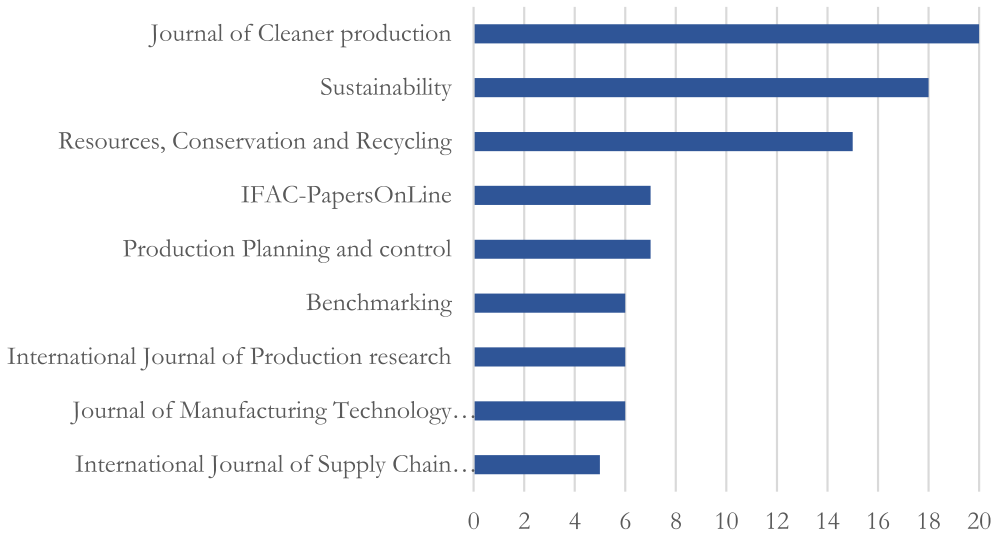


Fig. 5. Top 10 journals.

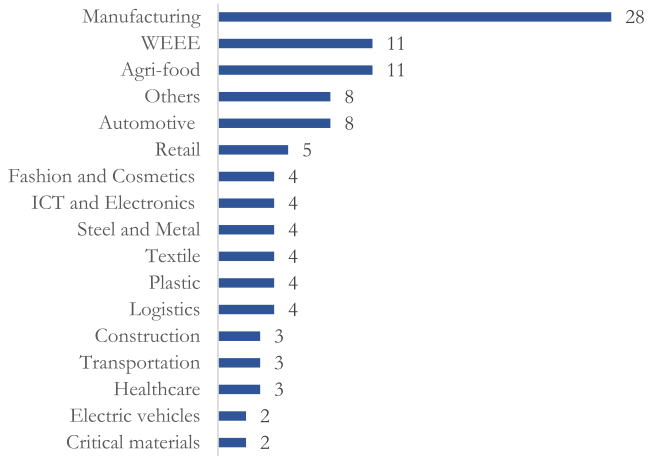


Fig. 6. Addressed Industries.

Chain (CSC) through Industry 4.0 (I4.0) technologies. As would be expected, the most addressed industry is manufacturing, being able to exploit in its production processes the applications and opportunities offered by I4.0 technologies. However, numerous contributions come even from the agri-food, Waste from Electrical and Electronic Equipment (WEEE), and automotive industries, where the search for SC circularity has been deeply stressed in the last years.

4.2. CSC thematic classification analysis

This section presents the results of the analysis of the detailed macro topics concerning CSC detected in the literature. To structure the investigation, articles have been progressively grouped, leading to the detection of the following five main categories composing the CSC domain:

- *CSC I4.0 enabling technologies,* focusing on the role of I4.0 technologies in the CSC adoption;
- *CSC performance tools and indicators,* offering guidelines and practical tools to achieve relevant assessment and performance measurement;
- *CSC challenges and barriers,* about problematic and challenging issues that may occur in the development of a CSC;
- *CSC business models and strategies,* presenting managerial and organization models proven to be efficient;
- *CSC best practices,* clustering successful case studies and practices in implementing the transition.

The articles' distribution among the categories has been performed manually and is illustrated in Fig. 7.

Five tables (Tables 1, 2, 3, 4, 5) have been built for each category with the aim of characterizing the contributions according to the LC phases, I4.0 technologies, Triple Bottom Line (TBL) layers, Circular Economy (CE) strategies, and Supply Chain (SC) typologies.

4.2.1. CSC I4.0 enabling technologies category

Concerning the proposition types, five papers present an innovative methodology, such as the work by Fernández-Caramés et al. (2019), in which the design and evaluation of an Unmanned Aerial Vehicle (UAV)-based system is presented. Findings show that UAVs, together with big data analytics, help industries in automating inventory tasks and traceability, ensuring SC efficiency and effectiveness. Alternatively, four contributions proposed a model. For instance, Tripathi and Gupta (2020) re-designed a procurement framework leveraging on I4.0 technologies. Several documents focused on informing managers of the I4.0

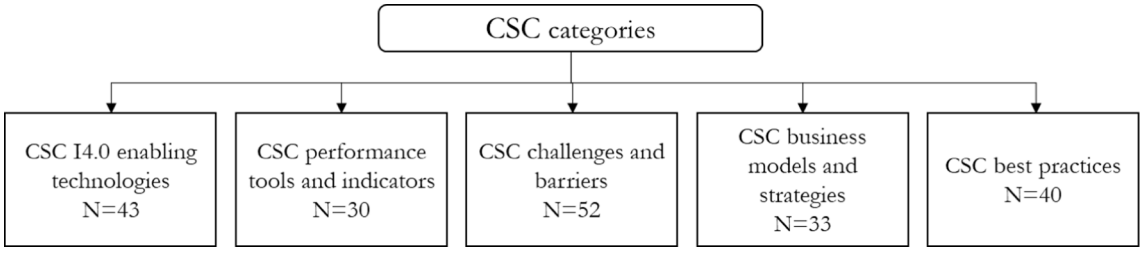


Fig. 7. CSC categories' distribution.

Table 1
CSC I4.0-enabling technologies category analysis.

AUTHORS	Life cycle phase				I4.0 technologies										Triple bottom line		
	BoL	MoL	EoL	Whole LC	IoT	Big Data Analytics	Additive Manufacturing	Cloud	Autonomous Robots	Simulation	V&HSI	Augmented Reality	Cyber-Security	General	Economic	Environmental	Social
(Chiappetta Jabbour et al., 2020)					x	x									x	x	x
(Cwiklicki & Wojnarowska, 2020)				x	x	x	x	x	x								
(Rizvi et al., 2020)				x	x	x	x								x	x	x
(Rejikumar et al., 2019)					x	x	x	x	x		x				x	x	x
(Nascimento et al., 2019)				x			x								x	x	x
(Borregan-Alvarado et al., 2020)					x	x	x	x							x	x	x
(Sung et al., 2020)			x		x											x	
(González Rodríguez et al., 2020)														x			
(R. Sharma et al., 2020)				x	x	x	x	x							x	x	x
(Zheng et al., 2021)				x	x	x	x	x	x	x	x	x			x	x	x
(Van Lopik et al., 2020)												x					
(Takhar & Liyanage, 2020)						x											
(Franco et al., 2020)							x								x	x	
(Núñez-Merino et al., 2020)					x	x	x	x	x			x			x	x	
(Ramirez-Peña et al., 2020)					x	x	x	x	x	x	x	x	x		x	x	x
(J. Sharma et al., 2020) (Danjou et al., 2020)					x	x				x					x	x	x
(Raut et al., 2020)					x	x		x									
(Patrucco et al., 2020)					x	x		x	x			x					
(Taboada & Shee, 2020)					x	x	x	x	x								
(Dhamija, 2020)					x	x			x								
(Abdirad & Krishnan, 2020)					x	x		x	x								
(Zekhnini et al., 2020)					x	x	x	x	x				x		x	x	x
(Rejeb et al., 2020)					x	x						x					
(Tiwari, 2020)					x			x	x		x				x	x	x
(Moldabekova et al., 2020)					x	x		x					x				
(De Vass et al., 2020)					x	x									x	x	x
(Tripathi & Gupta, 2020)					x	x	x	x	x				x				
(Chauhan & Singh, 2019)														x	x		x
(H. Gupta et al., 2020)					x	x									x	x	
(Oncioiu et al., 2019)					x	x									x	x	x
(Fernández-caramés et al., 2019)					x	x			x		x	x	x				
(Ardito et al., 2019)					x	x		x					x				
(Ben-Daya et al., 2019)					x			x									
(Jermsittiparsert & Boonratanakittiphumi, 2019b)							x										
(Barata et al., 2018)					x	x	x	x									
(Ivanov et al., 2018)								x									
(Ciccullo et al., 2021)						x									x	x	x
(Safiullin et al., 2020)					x										x	x	x
(Garrido-Hidalgo et al., 2020)			x		x										x	x	x
(Del Giudice et al., 2020)					x	x		x							x	x	x
(Hazen, Russo, & Confente, 2020)				x	x	x	x	x	x			x			x	x	x
(S. Gupta et al., 2019)						x		x							x	x	x
TOTAL	**0**	**0**	**2**	**6**	**32**	**30**	**16**	**22**	**14**	**3**	**5**	**8**	**6**	**2**	**23**	**23**	**20**

paradigm in Supply Chain Management (SCM) (Dhamija, 2020), showing both potentialities and difficulties (Rejikumar et al., 2019). Moreover, R. Sharma et al. (2020) proposed a I4.0 discussion highlighting the benefits in favor of the sustainability dimension.

I4.0 has been defined through a set of important improvements in digitalization, data exchange, processes automation, and system productivity (Abdirad & Krishnan, 2020). Raut et al. (2020) evaluated the implementation of I4.0-enabling technologies in the manufacturing context.

Among the nine technologies defined by Russmann et al. (2015), some are more diffused and adopted than others. In particular, Internet of Things (IoT) is addressed in 74% of the selected articles, as shown in Table 1. IoT is a technology based on connected smart devices able to strengthen the internal and external SC integration (de Vass et al., 2020). Ben-Daya et al. (2019) explored the IoT impact on SCM and found a scarcity of empirical studies and analytical models.

Others have concentrated on the big data analytics technology. For instance, Chiappetta Jabbour et al. (2020) stated that developing big data analytics capabilities are able to effectively build competitive Sustainable Supply Chains (SSCs). Oncioiu et al. (2019) studied big data analytics potentialities for SC improvements in experience, strategies, and professional capabilities.

Augmented reality in SCM and logistics was examined by Rejeb et al. (2020) and van Lopik et al. (2020) as a potential solution to enhance operational efficiencies, business processes, and competitiveness.

Jermsittiparsert and Boonratanakittiphumi (2019) examined the role of Additive Manufacturing (AM), showing the relationship between SC management, flexibility, and performance. Franco et al. (2020) explored AM adoption effects on businesses. A circular model reusing scrap electronic devices and integrating CE practices, reverse logistics, and additive manufacturing was recommended by Nascimento et al. (2019).

Some scholars have assessed all the proposed nine technologies, such as in the case of the review about I4.0 technologies' applications in the business processes of manufacturing companies (Zheng et al., 2021). Ramirez-Peña et al. (2020) conducted a study of the key enabling I4.0 technologies aimed at obtaining a general overview. Cwiklicki and Wojnarowska (2020) identified the relationships between the CE and I4.0, demonstrating the importance of recycle and reuse strategies for SSCs, while Taboada and Shee (2020) explored, through a systematic literature review, the role of 5G.

Several contributions are committed to presenting innovative efforts in sustaining SCM (Ardito et al., 2019). In this regard, Hazen et al.

CE strategy											SC typology					
Recycle	Reuse	Remanufacturing	Disassembly	Waste Management	M&EE	CBM	Circular Design	Servitization	Cleaner Production	Industrial Symbiosis	Green SC	Sustainable SC	Circular SC	Reverse SC	Closed-loop SC	Open-loop SC
												x				
x	x	x			x										x	
x	x	x		x	x		x	x						x		
x	x	x			x	x	x					x		x	x	
											x	x				
x				x										x		
	x														x	
x	x	x			x		x	x			x			x	x	
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x	x	x													x	
14	**12**	**6**		**1**	**8**	**6**	**1**	**5**	**5**	**0**	**0**	**2**	**4**	**1**	**8**	**7**	**1**

(2020) presented CE applications in the plastics industry adopting a SCM perspective. Zekhnini et al. (2020) evaluated the SCM and digital technologies relationship. Chauhan and Singh (2019) assessed the I4.0 theme in the context of SCM, highlighting the need for practical models to guide the implementation. Gupta et al. (2020) identified "big data science skills," the "tracking and localization of products," and the "adoption of Big Data Analytics (BDA) technologies and techniques" as the top three Information Technology (IT) enablers to improve SC performances. Barata et al. (2018) discussed mobile SCM in the advent of I4.0, presenting the gaps raised in the domain, while Núñez-Merino et al. (2020) assessed the research context of lean SCM by including recommendations for policy makers and industrial managers.

Concerning the LC, two articles about the End-of-Life (EoL) phase were reported. Unsurprisingly, they are part of the WEEE sector; indeed, the industry operates in the recovery of wastes' inner value, focusing, in particular, on the last phases. In this regard, Garrido-Hidalgo et al. (2020) proposed an EoL management framework aimed at satisfying the information infrastructure requirements for the recovery of electrical vehicle batteries.

Regarding the TBL, 19 articles reported on all the three layers. Among others, S. Gupta et al. (2019) argued that mutual support and coordination, coupled with holistic SC information processing, can effectively create a basis for achieving TBL sustainability. Ciccullo et al. (2021), in contrast, stated that food systems are afflicted by the sustainability issue of food waste from economic, environmental, and social points of view.

Several scholars have addressed the CE strategies, including waste management, Material & Energy Efficiency (M&EE), circular design, and servitization. However, the majority (6 articles) implemented the Reuse-Recycle-Remanufacturing (3Rs) strategy. For instance, Sharma et al. (2020) explained food SCs and their linkages in the Indian system. Tiwari (2020) explored the relationship between I4.0 and SC integration, providing directions to practitioners. Safiullin et al. (2020) created a mechanism to minimize the negative effects produced by industrial activities.

Regarding the SC typologies, the majority of the gathered contributions presented reverse (8 articles) or closed-loop (7 articles) SCs. Respectively, Rizvi et al. (2020) sought an answer to the research question of "has the CE and reversed SC logistics nexus changed significantly under the impact of the IT tools and their applications?'. Sung et al. (2020) focused on the strength of using sensor data and IoT technology in the collection phase of reverse logistics. González

Table 2
CSC performance tools and indicators category analysis.

AUTHORS	Life cycle phase				I4.0 technologies										Triple bottom line		
	BoL	**MoL**	**EoL**	**Whole LC**	**IoT**	**Big Data Analytics**	**Additive Manufacturing**	**Cloud**	**Autonomous Robots**	**Simulation**	**V&HSI**	**Augmented Reality**	**Cyber-Security**	**General**	**Economic**	**Environmental**	**Social**
(Morella et al., 2020)	x				x			x							x	x	
(Hoffa-Dabrowska & Grzybowska, 2020)				x											x	x	x
(Ivascu, 2020)				x	x	x		x	x	x		x	x		x	x	x
(Bhagawati et al., 2019)					x										x	x	
(Gružauskas et al., 2018)					x	x		x	x						x	x	
(Fatorachian & Kazemi, 2020)					x	x		x	x						x	x	
(Xie et al., 2020)					x	x		x							x	x	
(De Giovanni & Cariola, 2020)					x				x						x	x	
(Ehie & Ferreira, 2019)					x	x	x	x		x							
(Singh et al., 2019)					x	x		x				x					
(Ante et al., 2018)														x			
(Tjahjono et al., 2017)					x	x	x	x	x		x		x		x		x
(Walker et al., 2021)															x	x	x
(Luo et al., 2021)						x									x	x	x
(Alkhuzaim et al., 2021)															x	x	x
(Shoaib-Ul-Hasan Et Al., 2021)				x													
(Vegter et al., 2020)			x												x	x	x
(Tahu et al., 2020)															x	x	x
(Inoue et al., 2020)			x		x										x	x	
(Isernia et al., 2019)			x												x	x	x
(Doni et al., 2019)															x	x	
(Jain et al., 2018)															x	x	x
(Y. Kazancoglu et al., 2018)															x	x	x
(Braun et al., 2018)															x	x	
(Larsen et al., 2018)															x	x	
(Genovese et al., 2017)															x	x	x
(Zhu et al., 2011)															x	x	
(Nasir et al., 2017)															x	x	
(Wei et al., 2014)															x	x	
(Halstenberg et al., 2017)																	
TOTAL	**1**	**0**	**3**	**3**	**11**	**8**	**2**	**8**	**5**	**2**	**1**	**2**	**2**	**1**	**25**	**24**	**12**

Rodríguez et al. (2020), on the contrary, addressed a methodology to overcome Closed-Loop Supply Chain (CLSC) management problems through a decision-making system built on Machine Learning (ML).

However, several scholars focused on the circular SC, such as the paper by Del Giudice et al. (2020) exploring the moderating role of big data analytics in SC relationships. Takhar and Liyanage (2020), instead, proposed the adoption of an open loop manufacturing system through CE. Finally, Borregan-Alvarado et al. (2020) discussed I4.0 and additive manufacturing tendencies in the context of SSCs.

Several contributions focused on the construction sector. For instance, Danjou et al. (2020) explored the I4.0 technological applications in the construction industry. In the same sector, Patrucco et al. (2020) discussed how process re-engineering can be supported by I4.0 technologies.

Finally, the logistics sector has been addressed on different occasions. Moldabekova et al. (2020) provided a review of the role of Information and Communications Technology (ICT) in logistics services. Ivanov et al. (2018), alternatively, stated that a cooperation between SC experts and technical operators may improve the performance in production and logistics systems.

4.2.2. CSC performance tools and indicators category

Only four out of the 30 articles explicitly proposed a tool. Among them, just two defined a new Key Performance Indicator (KPI) (Ante et al., 2018; Morella et al., 2020). In particular, Morella et al. (2020) developed a new KPI to measure the impact of energy consumption on Nakajima's six big losses (breakdowns, setups, minor stoppages, speed loss, quality defects, and start-ups). A three-pronged structure of KPIs describing the performance measurement system of a lean production system was proposed by Ante et al. (2018). Singh et al. (2019) determined an index able to quantify SC coordination performance in the I4.0 era. Wei et al. (2014), instead, presented an evaluation system for green SCM in the manufacturing industry.

The TBL dimension raises a second deficiency as 60% of the selected documents did not focus on social aspects. A partial analysis of the TBL line is stressed by several scholars; Walker et al. (2021), for instance, highlighted that the social dimension is the least assessed and that when it is included, the analysis is frequently superficial.

Luo et al. (2021) proposed a framework to examine food loss and waste issues within food SC operations. Alkhuzaim et al. (2021) discussed CE performance measurement and Sustainable Supply Chain Management (SSCM). Lastly, Genovese et al. (2017) compared, across a range of indicators, the performances of both traditional and innovative circular production systems. The articles by Larsen et al. (2018) and Zhu et al. (2011) examined, respectively, the role of environmental SC cooperation practices and how reverse SCs contribute to the financial performance.

Concerning the LC phase, three documents state their commitment to the entire LC, such as the SSC model proposition by Hoffa-Dabrowska and Grzybowska (2020) and the Life Cycle Assessment (LCA) considerations of Shoaib-ul-Hasan et al. (2021).

Ivascu (2020) proposed a hierarchical framework that integrates the

CE strategy											SC typology					
Recycle	**Reuse**	**Remanufacturing**	**Disassembly**	**Waste Management**	**M&EE**	**CBM**	**Circular Design**	**Servitization**	**Cleaner Production**	**Industrial Symbiosis**	**Green SC**	**Sustainable SC**	**Circular SC**	**Reverse SC**	**Closed-loop SC**	**Open-loop SC**
x	x				x						x					
												x			x	
x	x	x		x			x							x		
												x				
												x				
x	x															
	x			x	x						x					
x	x			x									x	x		
				x												
x	x			x			x			x	x					
x	x	x					x									
x	x	x		x	x								x	x		
x	x			x	x	x										
	x	x		x												
x	x	x		x										x		
x	x	x			x			x			x					
x	x	x		x		x	x	x		x	x		x	x	x	
x	x	x		x	x				x		x				x	
x		x		x	x	x								x		
	x				x									x		
	x	x				x			x			x		x	x	x
x	x						x		x							
x	x	x		x	x						x	x			x	
x				x	x						x					
x	x	x		x	x					x						
17	**19**	**12**	**0**	**15**	**11**	**4**	**5**	**2**	**3**	**3**	**8**	**5**	**3**	**8**	**5**	**1**

goals for sustainable development and those of I4.0 by considering the whole LC through reverse SCs, taking into account several CE strategies and the technologies of IoT, big data analytics, the cloud, and autonomous robots. Ehie and Ferreira (2019) developed a conceptual framework describing the relationship between SC digitalization and performance. Tjahjono et al. (2017) and Fatorachian and Kazemi (2020) analyzed and explored the impact of I4.0 on the SC. An indicator to monitor SC performance was proposed by Xie et al. (2020). Lastly, Gružauskas et al. (2018) highlighted how the adoption of these technologies (IoT, big data analytics, the cloud, and autonomous robots) is fostering the competitiveness advantage in the long run, limiting trade-offs between sustainability and cost-effective performances. Similar results in terms of cost reduction and competitive advantage opportunities were described by Jain et al. (2018), using a Circular Supply Chain Management (CSCM) performance matrix.

Further documents focused on CE strategies. For instance, the servitization theme and its opportunities were profoundly discussed by Doni et al. (2019), assessing the potential impact on sustainability through a sample of 208 European listed manufacturing companies. Halstenberg et al. (2017) presented industrial symbiosis as a promising approach to foster the transformation toward CE.

The numerical recurrence of IoT technology in the selected documents represents more than one-third of the total, as displayed in Table 2.

IoT fosters SC digitalization and optimization, as highlighted by Bhagawati et al. (2019) and De Giovanni and Cariola (2020). Inoue et al. (2020) stated that companies monitoring product usage through IoT are able to suggest and implement appropriate life cycle options, such as reuse and remanufacturing, leading to customer retention.

Concerning the LC phase, three documents focus their attention exclusively on the EoL (Inoue et al., 2020; Isernia et al., 2019; Vegter et al., 2020), two of which (Isernia et al., 2019; Vegter et al., 2020), regarding the WEEE sector. Morella et al. (2020) concentrated on the BoL phase, developing a KPI to measure the impact of energy consumption and, thus, to adjust and improve the design of machine tools.

Several contributions have implemented the synergic use of waste management and M&EE since the material efficiency potential is assessed through the waste recovery by CE activities along the SC (Braun et al., 2018). A new green SCM performance assessment framework was proposed in detail by Y. Kazancoglu et al. (2018). Tahu et al. (2020) analyzed how CE, SCM innovation, and sustainability impact on organizational performance. Lastly, Nasir et al. (2017) demonstrated the environmental gains (carbon emissions) achieved through CE strategies in the context of sustainable, green, and CLSC.

4.2.3. CSC challenges and barriers category

This category represents the most numerous in terms of selected articles (52). As stated by Ozkan-Ozen et al. (2020), in fact, the industry is facing a transition from Industry 3.0 to the I4.0. Therefore, in the 3.5 stage, barriers to synchronized CSC and I4.0 need to be taken into consideration.

This category is mainly composed of framework and methodology

Table 3
CSC challenges and barriers category analysis.

AUTHORS	Life cycle phase				I4.0 technologies										Triple bottom line		
	BoL	**MoL**	**EoL**	**Whole LC**	**IoT**	**Big Data Analytics**	**Additive Manufacturing**	**Cloud**	**Autonomous Robots**	**Simulation**	**V&HSI**	**Augmented Reality**	**Cyber-Security**	**General**	**Economic**	**Environmental**	**Social**
(Kumar et al., 2021)				x	x		x	x							x	x	x
(Ozkan-Ozen et al., 2020)				x	x								x		x	x	x
(G. Yadav et al., 2020)				x													
(Bag & Pretorius, 2020)				x	x	x		x	x						x	x	x
(Philip et al., 2020)				x	x	x				x					x	x	
(Rajput & Singh, 2019)				x	x	x		x							x	x	x
(Cezarino et al., 2019)				x	x	x		x	x		x	x			x	x	x
(Cañas et al., 2020)				x	x	x					x	x			x	x	x
(Panetto et al., 2019)				x	x	x	x		x			x			x	x	x
(Luthra & Mangla, 2018)					x	x		x	x						x	x	x
(Acharya et al., 2019)					x	x		x	x								
(M. Sharma et al., 2020)					x	x	x	x	x			x			x	x	x
(Bag et al., 2020)					x	x	x	x	x		x						
(Princes, 2020a)					x	x			x						x	x	x
(Princes, 2020b)																	
(Luthra et al., 2020)					x	x		x	x						x	x	x
(Pandey et al., 2020)					x			x					x				
(Pessot et al., 2020)					x	x	x	x	x	x					x	x	x
(Veile et al., 2020)					x	x		x			x						
(S. Yadav et al., 2020)					x	x		x	x						x	x	
(Ogbuke et al., 2020)					x	x		x							x	x	x
(Horváth & Szabó, 2019)					x	x						x	x		x	x	x
(Ivanov et al., 2019)					x	x							x				
(Krykavskyy et al., 2019)					x	x		x							x	x	x
(Kaczmarek, 2019)																	
(Liboni et al., 2019)					x	x			x								x
(Jermsittiparsert & Boonratanakittiphumi, 2019a)							x										
(Bienhaus & Haddud, 2018)					x	x	x	x					x		x		x
(J. M. Müller & Voigt, 2018)					x												
(Majeed & Rupasinghe, 2017)					x	x		x									
(I. Kazancoglu et al., 2021)															x	x	x
(Ethirajan et al., 2021)															x	x	x
(Ibn-Mohammed et al., 2021)					x	x		x	x						x	x	x
(I. Kazancoglu et al., 2020)				x											x	x	x
(Dey et al., 2020)														x	x	x	x
(Frei et al., 2020)															x	x	x
(Xia & Ruan, 2020)															x	x	x
(Jia et al., 2020)				x											x	x	x
(Khandelwal & Barua, 2020)			x												x	x	x
(Zhang et al., 2019)					x	x		x							x	x	x
(Paes et al., 2019)															x	x	x
(Sehnem et al., 2019)															x	x	x
(Farooque et al., 2019)					x	x									x	x	x
(Piyathanavong et al., 2019)															x	x	
(Y. K. Sharma et al., 2019)															x	x	x
(Lapko et al., 2019)			x														
(Braz et al., 2018)															x	x	
(Mangla et al., 2018)															x	x	
(Mishra et al., 2018)															x	x	x
(Zeng et al., 2017)															x	x	x
(Masi et al., 2017)															x	x	x
(Park et al., 2010)			x												x	x	x
TOTAL	**0**	**0**	**3**	**11**	**29**	**25**	**7**	**19**	**13**	**2**	**4**	**5**	**5**	**1**	**39**	**38**	**35**

propositions thanks to the use of these instruments in the search, analysis, and prioritization of barriers. An example is provided by Rajput and Singh (2019), which identified 26 significant enabling and 15 challenging factors in the context of CE and I4.0.

Concerning the LC phase, several contributions have focused on the whole LC (Jia et al., 2020; I. Kazancoglu et al., 2020; G. Yadav et al., 2020), while others have concentrated on the EoL phase, all acting in the waste treatment sphere and the recycling approach (Khandelwal & Barua, 2020; Lapko et al., 2019; Park et al., 2010).

A total of 40% of the collected documents, most of which address the manufacturing, automotive, and agri-food sectors, referred to the use of IoT and big data analytics with the cloud or autonomous robots.

The central role of big data analytics was stressed by many scholars. Bag and Pretorius (2020) stated that sustainable manufacturing, strongly influenced by the adoption of big data analytics powered with Artificial Intelligence (AI), is the enabler for the CE transition. Moreover, Ogbuke et al. (2020) discussed the potential of big data analytics to support more responsive generations of global companies operating in an increasingly challenging and uncertain environment. S. Yadav et al. (2020) identified the critical challenges of IoT adoption in agriculture SCs. The software issues, security issues, technical issues, congestion, and overload issues of the IoT network were identified as four of the main challenges. Majeed and Rupasinghe (2017) focused on the use of Radio-Frequency Identification (RFID) technology to improve operations in the fashion industry. Sharma et al. (2020) assessed how I4.0 advancements foster SSC initiatives aimed at reducing environmental

CE strategy											SC typology					
Recycle	**Reuse**	**Remanufacturing**	**Disassembly**	**Waste Management**	**M&EE**	**CBM**	**Circular Design**	**Servitization**	**Cleaner Production**	**Industrial Symbiosis**	**Green SC**	**Sustainable SC**	**Circular SC**	**Reverse SC**	**Closed-loop SC**	**Open-loop SC**
x	x			x	x		x	x		x	x			x	x	
x	x	x				x	x								x	
x	x	x												x		
x	x	x		x	x			x	x		x			x	x	
x	x										x					
x	x			x			x	x							x	
x	x	x			x		x								x	
				x	x						x				x	
															x	
								x				x				
x		x		x	x							x				
x	x	x					x				x			x		
				x	x							x				
					x											
x																
x	x	x		x	x	x	x							x		
x	x			x											x	
	x			x	x	x	x							x	x	
x	x	x		x		x	x					x		x	x	
x				x	x					x			x			
x		x		x	x	x								x		
x				x		x										
x	x	x		x	x					x				x	x	
x	x			x			x									
x	x	x		x				x								
x				x			x			x					x	
x				x			x			x		x			x	
x	x	x		x					x	x	x					
x	x			x	x				x					x		
x	x			x		x	x									
x					x									x	x	
x	x	x												x	x	
x	x	x		x		x		x	x	x			x			
x	x	x				x		x						x	x	
x	x									x		x		x	x	
x	x	x		x					x	x	x				x	
x				x	x		x		x	x	x			x		
31	**25**	**16**	**0**	**24**	**15**	**9**	**14**	**7**	**6**	**10**	**8**	**6**	**2**	**16**	**19**	**0**

impacts, maximizing economic gains, and contributing to social development.

The moderating goal of additive manufacturing in the relationship between knowledge management capability and firm performance was addressed by Jermsittiparsert and Boonratanakittiphumi (2019).

Lastly, Ethirajan et al. (2021) identified the risks of circular SC initiatives aimed at minimizing the environmental impact in the manufacturing industry. The results have showed that "branding" is the least significant risk, while a "transparent process" is the most prominent one.

Pandey et al. (2020) examined 16 cyber-security risks, divided into supply, operational, and demand, in globalized SCs for improving performance. Ivanov et al. (2018) analyzed analytical risks in cyber SCs.

Pessot et al. (2020) studied the transformation of European manufacturing companies by encompassing the technological, strategic, managerial, and organizational perspectives. Similar concepts were addressed by Panetto et al. (2019) through their vision of the challenges facing the so-called "industry of the future." Their conclusion highlighted the need for modular models and systems to support the modification and self-adaptation of organizational structures.

Concerning the TBL, the *CSC challenges and barriers* category collects several approaches that understand the importance of considering a holistic meaning of sustainability. Indeed, 65% of the selected contributions reported the entire TBL, and 67% addressed social issues, as reported in Table 3. Although in the I4.0 and CE literature environmental aspects are predominant over the social ones, as stated by Cañas

Table 4
CSC business models and strategies category analysis.

AUTHORS	Life cycle phase				I4.0 technologies										Triple bottom line		
	BoL	**MoL**	**EoL**	**Whole LC**	**IoT**	**Big Data Analytics**	**Additive Manufacturing**	**Cloud**	**Autonomous Robots**	**Simulation**	**V&HSI**	**Augmented Reality**	**Cyber-Security**	**General**	**Economic**	**Environmental**	**Social**
(Sun et al., 2020)				x			x									x	
(Lu et al., 2020)					x	x		x	x						x	x	x
(Dev, Shankar, & Qaiser, 2020)				x	x		x	x							x	x	x
(Garcia-Muiña et al., 2018)				x	x	x	x	x	x						x	x	x
(Lopes De Sousa Jabbour Et Al., 2018)				x	x		x	x							x	x	
(Dev, Shankar, & Swami, 2020)			x		x			x							x	x	
(Tozanli et al., 2020)			x		x				x						x	x	x
(Manavalan & Jayakrishna, 2019a)					x	x		x					x		x	x	x
(Tombido et al., 2018)			x		x			x									
(Victor et al., 2020)			x		x												
(Mboli et al., 2020)				x	x		x	x								x	
(Ghosh et al., 2020b)					x	x	x	x	x				x		x	x	
(Hahn, 2020)					x	x	x		x								
(Zangiacomi et al., 2020)					x	x		x									
(Facchini et al., 2020)					x	x			x						x	x	x
(Preindl et al., 2020)					x	x		x									
(Mihardjo et al., 2020)						x											
(Garay-Rondero et al., 2019)					x	x		x		x		x			x	x	x
(Pekarcíková et al., 2019)																	
(Sundarakani et al., 2019)					x	x		x	x								
(Omar et al., 2019)					x	x		x							x	x	x
(Asdecker & Felch, 2018)					x												
(Hussain & Malik, 2020)					x	x									x	x	x
(González-Sánchez et al., 2020)					x	x	x	x	x			x	x		x	x	x
(Pohlmann et al., 2020)					x										x	x	x
(Hazen, Russo, Confente, et al., 2020)					x		x								x	x	x
(Dubey et al., 2019)															x	x	x
(Ünal et al., 2019)															x	x	x
(Cardoso De Oliveira et al., 2019)															x	x	
(Lüdeke-Freund et al., 2019)							x								x	x	x
(Geissdoerfer et al., 2018)															x	x	x
(Xiao & Zeng, 2017)															x	x	x
(Winkler, 2011)															x	x	
TOTAL	**0**	**0**	**4**	**5**	**23**	**14**	**10**	**15**	**8**	**1**	**0**	**2**	**3**	**0**	**22**	**24**	**17**

et al. (2020) and Sassanelli et al. (2019), the presented category seems to oppose this trend. For instance, Acharya et al. (2019) identified challenging factors such as the increasing autonomy in consumer choice and the retirement and turn-over of skilled workers. Liboni et al. (2019) concentrated on I4.0′s impacts on human resource management, focusing on employment, job profile and qualification, and skill requirements. Horváth and Szabó (2019) stated that the introduction of I4.0 technologies might be hindered by employee and management resistance. Moreover, consumer-related aspects were crucial in the analysis. Philip et al.'s (2020) research paper aimed at comprehending how fast fashion is indulged in consumers. Princes (2020), instead, highlighted that the customer experience will become the brand differentiator of the future.

Several contributions have identified and prioritized barriers.

Regarding the automotive sector, Kumar et al. (2021) identified ineffective strategies for the integration of I4.0 with sustainable measures combined with a lack of funds for I4.0 initiatives as major barriers. Managerial, organizational, and economic challenges emerged as the most critical to SSCM according to G. Yadav et al. (2020). Alternatively, the level of firm readiness regarding the adoption of I4.0 technologies was defined as the major concern by Krykavskyy et al. (2019).

In relation to the textile sector, Kazancoglu et al. (2021) identified several barriers, the majority of which are related to institutions, such as the lack of legislation for efficient CE and government support for environmental-friendly policies. The same authors classified 25 barriers under nine categories, including lack of knowledge and awareness, lack of integration and collaboration, and costs (I. Kazancoglu et al., 2020).

Regarding Small and Medium Enterprises (SMEs), Dey et al. (2020) derived the issues, challenges, and strategies in the implementation of CE in SMEs. Princes (2020b) developed nine steps to integrate ambidextrous capabilities in SMEs, with clear deadlines and goals, to gain a competitive advantage in the context of the modern manufacturing era of I4.0.

Moreover, numerous contributions have focused on emerging countries. Among others, Sehnem et al. (2019) stressed this duality by analyzing the Critical Success Factors (CSFs) for the adoption of the CE

CE strategy											SC typology					
Recycle	**Reuse**	**Remanufacturing**	**Disassembly**	**Waste Management**	**M&EE**	**CBM**	**Circular Design**	**Servitization**	**Cleaner Production**	**Industrial Symbiosis**	**Green SC**	**Sustainable SC**	**Circular SC**	**Reverse SC**	**Closed-loop SC**	**Open-loop SC**
x				x											x	
							x		x		x					
x	x	x		x					x					x	x	
x	x	x		x		x	x	x						x		
x	x	x												x		
x	x	x									x			x	x	
x	x	x	x											x	x	
x	x	x			x						x	x		x	x	
x	x	x												x	x	
															x	
x	x	x		x	x	x	x							x	x	
x	x	x			x				x		x	x			x	
x								x						x		
														x		
								x								
														x	x	
x	x	x		x										x		
x	x	x			x	x	x			x		x		x		
x		x		x	x	x	x						x	x	x	
x	x			x	x					x		x				
x	x	x		x				x				x		x	x	
						x						x			x	
x	x			x	x	x	x	x	x	x						
x	x						x		x		x	x		x		
x	x	x				x				x		x		x	x	
x				x	x	x	x								x	
									x	x		x				
x	x			x			x		x			x			x	
21	**17**	**14**	**1**	**11**	**8**	**8**	**9**	**5**	**7**	**5**	**5**	**10**	**1**	**17**	**17**	**0**

using companies selected both from the emerging reality of Brazil and the mature Scottish one.

Regarding the Chinese scenario, Park et al. (2010) investigated the challenges and opportunities of balancing economic growth and environmental stewardship in the context of the electronics industry. Xia and Ruan (2020) identified the critical barriers of Chinese circular agriculture. The results highlighted those institutional pressures have affected both supply relationship management and SSC design.

Lastly, 16 important barriers to CSC adoption in India were determined by Mangla et al. (2018). Among others, a lack of economic benefits in the short term and a lack of appropriate training, coordination, and collaboration among SC members were identified as the most relevant. A lack of private and public articulation of digital Business Model (BM) promotion was identified by Cezarino et al. (2019). Poor government policies and the lack of technology, techniques, farmers' knowledge, and awareness were defined as the most important barriers in Indian agri-food SCs (Y. K. Sharma et al., 2019). Regarding the latter sector, Farooque et al. (2019) stressed several obstacles, such as weak environmental regulations and a lack of collaboration among the SC actors.

In contrast, the manufacturing sector in Thailand focused on the need for large investment capacity, proper training, knowledge, and motivation (Piyathanavong et al., 2019).

A lack of tax relation policies and poor rules and regulations protecting the environment emerged as the most prominent barriers of the Indian plastics industry to implementing a CSCM (Khandelwal & Barua, 2020).

Bag et al. (2020) discussed key resources for I4.0 adoption in South Africa, such as green logistics and design, information technology, human resources, and project management. Luthra et al. (2020) identified significant I4.0 drivers in government supportive policies, collaboration, and transparency among SC members. The same scholars (Luthra & Mangla, 2018) stated that organizational challenges are prominent, followed by technological, strategic, legal, and ethical ones.

Several contributions regarding the logistics and procurement sector have been collected. Kaczmarek (2019) defined I4.0 as being

Table 5
CSC best practices category analysis.

AUTHORS	Life cycle phase				I4.0 technologies										Triple bottom line		
	BoL	**MoL**	**EoL**	**Whole LC**	**IoT**	**Big Data Analytics**	**Additive Manufacturing**	**Cloud**	**Autonomous Robots**	**Simulation**	**V&HSI**	**Augmented Reality**	**Cyber-Security**	**General**	**Economic**	**Environmental**	**Social**
(Kintscher et al., 2020)			x		x				x						x	x	
(Wang & Zhang, 2020)						x									x	x	x
(Garrido-Hidalgo et al., 2019)			x		x			x							x	x	
(Belaud et al., 2019)				x	x	x									x	x	x
(Daú et al., 2019)					x			x							x	x	x
(Jensen & Remmen, 2017)			x		x										x	x	x
(Mastos et al., 2020)			x		x	x				x					x	x	x
(Blömeke et al., 2020)			x		x	x			x						x	x	x
(Bagalagel & Elmaraghy, 2020)			x											x	x	x	x
(Manavalan & Jayakrishna, 2019b)				x	x										x	x	x
(Shao et al., 2021)				x	x	x	x	x	x	x			x				
(Kuo et al., 2021)					x	x		x							x	x	
(Frankó et al., 2020)					x			x		x					x		
(Khan et al., 2020)					x			x	x								
(Chandriah & raghavendra, 2020)					x			x									
(F. Müller et al., 2019)					x			x							x		x
(Hetterscheid & Schlüter, 2019)					x			x			x						
(Avventuroso et al., 2017)					x		x	x	x								
(Tedesco & Montacchini, 2020)				x											x	x	
(Maranesi & De Giovanni, 2020)				x			x					x			x	x	x
(Bressanelli et al., 2020)				x	x	x		x							x	x	x
(Cassol & Sellitto, 2020)															x	x	x
(Julianelli et al., 2020)			x		x										x	x	x
(Nandi et al., 2020)															x	x	x
(Van engeland et al., 2020)															x	x	x
(Santander et al., 2020)							x								x	x	
(Pinto & Diemer, 2020)			x														
(Kühl et al., 2019)					x												
(Castiglione & alfieri, 2019)															x	x	x
(Ripanti & Tjahjono, 2019)															x	x	x
(Xavier et al., 2019)															x	x	x
(Niu et al., 2019)					x	x		x	x		x	x					
(Islam & Huda, 2018)			x														
(De angelis et al., 2018)															x	x	x
(Hong et al., 2018)															x	x	x
(Hahladakis & Iacovidou, 2018)				x													
(Bernon et al., 2018)															x	x	
(Gaustad et al., 2018)			x												x	x	
(Herczeg et al., 2018)															x	x	x
(Mulrow et al., 2017)															x	x	x
TOTAL	**0**	**0**	**10**	**7**	**20**	**8**	**4**	**12**	**6**	**3**	**2**	**2**	**1**	**1**	**30**	**28**	**22**

characterized by CPS and logistics as a promising field of application. Müller and Voigt (2018) addressed the topic of SCM in the context of I4.0 by employing a case study of a German engineer-to-order industrial enterprise. Bienhaus and Haddud (2018) pointed out the digital impact on procurement and SCM. The barriers to digitizing procurement were found in existing procedures, processes, capacities, and capabilities. Lastly, how the buyer–supplier relationship is influenced by I4.0 technological changes was discussed by Veile et al. (2020). Future transactions were found to become mainly based on digitized, automated procedures transferring various value creation processes to platforms.

Regarding CE strategies, a considerable adoption of the 3Rs, waste management, M&EE and circular design was registered. Among others, Jia et al. (2020) highlighted the challenges of CE implementation and provided some suggestions for managers in the textile and apparel industry.

Moreover, the waste management strategy was further discussed in detail by two scholars. Paes et al. (2019) conducted a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of the organic waste industry, highlighting major issues in logistics costs, SCM, and the lack of technical standards and regulations. Zhang et al. (2019), instead, identified three main barriers, including a lack of regulatory pressures, market pressures and demands, environmental education, and culture.

Concerning the SC typologies, several contributions have defined SCs as closed-loop (19 articles) and reverse (16 articles). As an example, Zeng et al. (2017) presented a conceptual model underscoring institutional pressures and SCM impacts.

CLSC potentialities were highlighted by many scholars. Mishra et al. (2018), for instance, selected four CLSC companies and assessed how these cases create value and the key challenges regarding implementation. Factors influencing CLSC for Customer Relationship Management (CRM) development in the photovoltaic industry were examined by Lapko et al. (2019). Braz et al. (2018) compared the causes and factors of the bullwhip effect in CLSCs. Lastly, a paper by Masi et al. (2017) discussed the potentialities of the meso level, such as eco-industrial parks and CLSC but also the exposure to radical changes for BMs and SCs. Alternatively, Frei et al. (2020) identified barriers and challenges to implementing circular practices in reverse SCs.

Finally, the conducted research even offers insights into recent

CE strategy											SC typology					
Recycle	**Reuse**	**Remanufacturing**	**Disassembly**	**Waste Management**	**M&EE**	**CBM**	**Circular Design**	**Servitization**	**Cleaner Production**	**Industrial Symbiosis**	**Green SC**	**Sustainable SC**	**Circular SC**	**Reverse SC**	**Closed-loop SC**	**Open-loop SC**
x	x	x														
x	x	x			x	x										
x	x	x		x				x						x		
				x												
x	x			x	x							x				
x	x	x		x			x								x	
x	x			x	x						x	x				
x	x	x		x	x									x	x	
	x	x													x	
x	x	x		x	x					x		x			x	
					x											
				x												
x	x			x						x						
x	x			x	x		x	x		x			x	x	x	
x	x	x	x	x	x		x	x						x	x	
				x	x											
x	x	x		x	x					x				x	x	
x	x				x									x	x	
x	x	x			x	x	x	x						x	x	
x	x			x	x					x						
x	x	x		x	x	x	x							x	x	
x	x													x	x	
x		x		x											x	
x	x	x												x	x	
x		x			x	x	x						x		x	x
												x				
x	x	x		x											x	
x	x				x		x							x		
x	x	x		x	x		x	x							x	
				x	x				x	x						
	x			x		x			x	x					x	
26	**26**	**20**	**1**	**21**	**18**	**6**	**8**	**5**	**2**	**7**	**1**	**4**	**2**	**13**	**19**	**1**

circumstances. Ibn-Mohammed et al. (2021), indeed, outlined concrete recommendations on CE-related solutions for global economic growth and development in the post-COVID-19 world.

4.2.4. CSC business models and strategies category

Several scholars have introduced BMs to face the advent and implementation of CE strategies and I4.0 technologies. Among others, Garay-Rondero et al. (2019) presented a conceptual model for new digital SCs. Lüdeke-Freund et al. (2019) conducted an analysis of 26 CBMs, defining the major BM dimensions and characteristics. Lu et al. (2020) examined Carroll's pyramid model in SMEs for organizational performance enhancement. The obtained outcomes of the study confirmed that the inclusion of I4.0, cleaner production, and CE concepts provides business opportunities in the SME sector. Ghosh et al. (2020) reflected on different strategies and the greening effect in SCs. Zangiacomi et al. (2020) presented a multiple-business strategies analysis aimed at investigating managerial perspectives on investments, awareness, and knowledge sharing. Preindl et al.'s (2020) research focused on I4.0's impact on information sharing and SC decision making. The findings were threefold, as follows: technological interface standards to enable communication along the SC are missing, the impact of I4.0 and digital transformation is closely connected to information sharing, and companies' preparations for these impacts are different. Mihardjo et al. (2020) assessed the impact of co-creation strategies in the I4.0 SCM. Finally, managerial practices to design CBMs and to capture value were investigated by Ünal et al. (2019).

Regarding the proposition typology, the majority of documents are classified as models (11 articles), while five contributions have proposed guidelines, such as a pathway including the effective use of business analytics (Omar et al., 2019).

Concerning the TBL, the social perspective appears quite relevant in the domain since 52% of the selected articles included it in their analysis. Strategies and models, indeed, have to consider social factors as a relevant parameter to obtain successful outcomes, as stated by Dev et al. (2020).

Further analyzing the category, the LC has been analyzed comprehensively in five contributions.

Alternatively, the implementation of IoT technology represents a distinctive feature of articles related to the EoL phase. Tozanlı et al. (2020), for instance, presented the use of IoT-embedded products in a

blockchain system.

The adoption of I4.0 technologies is relevant in this category. Indeed, Lopes de Sousa Jabbour et al. (2018) proposed guidelines enhancing CE strategies and the application of I4.0 approaches.

Moreover, IoT has been identified as the most diffused technology since it is present in 70% (23) of the collected articles, as displayed in Table 4. Manavalan and Jayakrishna (2019) explored the potentialities of IoT-embedded SSCs. An IoT-enabled decision support system for CBMs allowing the tracking and monitoring of products in real time was proposed by Mboli et al. (2020).

Moreover, 13 contributions have implemented the IoT and big data analytics technologies jointly, and Hahn (2020) investigated the implications of I4.0 on SCM.

Additive manufacturing technology potentialities were discussed by Sun et al. (2020), focusing on the duality of virgin and recycled materials in 3D printing (3DP).

Sundarakani et al. (2019) defined cloud computing as a technology able to increase the competitiveness, elasticity, flexibility, and utilization of resources.

The reconfiguration of the core SCM process thanks to CE strategies underscoring current production and consumption patterns was studied by Hazen et al. (2020).

Regarding CE strategies, indeed, this category reports a majoritarian use of the 3Rs as 13 articles have adopted it. Among others, Dubey et al. (2019) proposed a theoretical framework to explain how top management's commitment mediates between external pressures and supplier relationship management. Pohlmann et al. (2020) studied the role of focal companies aimed at achieving the UN's Sustainable Development Goals (SDGs) in Brazilian food SCs.

Moreover, four contributions have implemented M&EE, waste management, circular design, and CBM jointly.

In this regard, Geissdoerfer et al. (2018) discussed CBM sustainability performance and proposed a framework integrating CBMs and CSCM toward sustainable development.

Garcia-Muiña et al. (2018) explored the transition from a linear economy to a CE through the CBM design, introducing the principles of sustainability (3 layers of the TBL) in the manufacturing context.

Concerning SC typologies, the analysis reveals a considerable diffusion of reverse and closed-loop terms. Indeed, 17 contributions from both parts and 11 joint applications are identified. For instance, Dev, Shankar, and Swami (2020) examined how product dynamics affect the economic and environmental performances of a production planning system. Tombido et al. (2018) reviewed the use of third parties in reverse logistics. Victor et al. (2020) proposed a CLSC model indicating processes to be applied to EoL-collected products. Winkler (2011) stated that negative environmental impacts, such as waste, energy consumption, and transport processes, can be avoided by establishing closed-loop production systems.

Despite the majority of reverse SCs and CLSCs, some scholars have focused on circular ones. Among others, Hussain and Malik (2020) presented a framework for CSCs combining sustainable performances, process, and organization facilitators to embrace the CE. González-Sánchez et al. (2020) studied CSCs in strategic management. Three dimensions have been identified to support the development of new SCs: relationships; the adaptation of logistics and organizational, disruptive, and smart technologies; and a functioning environment.

Moreover, a trend in articles focusing on the logistics sector can be identified. For instance, Facchini et al. (2020) presented a logistics 4.0 model able to identify the level of companies' maturity as to implementing I4.0 technologies in their logistics processes. Asdecker and Felch (2018) developed a model to describe the digitalization efforts in outbound logistics. Finally, Pekarcíková et al. (2019) studied demand-driven supply logistics in the context of I4.0 through a case study.

To conclude, two articles have focused on emerging economies. Cardoso de Oliveira et al. (2019) verified how governance instruments influence green practices in the Brazilian scenario, and Xiao and Zeng (2017) highlighted that supply relationship management and SSC design can benefit from institutional pressure.

4.2.5. CSC best practices category

This category appears almost equally divided with the different types of propositions reporting six approaches, four frameworks, four methodologies, and four models.

The work by Kuo et al. (2021) represents an example of the first type of proposition, developing an SC material resource management and allocation framework. Shao et al. (2021), instead, proposed a multi-stage implementation highlighting organizational enablers such as culture, continuous improvement, and cross-functional approaches. Hetterscheid and Schlüter (2019) presented, through two use cases of a German steel company, a methodology for the design of CPS during the planning and control phases of SC processes. An analytical model based on predictive optimization between supply and demands in SC 4.0 was proposed by Chandriah and Raghavendra (2020).

Concerning the LC phase, more EoL contributions (11 articles) than whole LC ones (7 articles) were collected, as shown in Table 5. Three articles are part of the WEEE industry, such as the example by Bagalagel and ElMaraghy (2020), which presented a manufacturing-remanufacturing system demonstrating the I4.0 potentials to improve the value recovery of used products.

Concerning the whole LC papers, most cases are part of the textile industry. For instance, Tedesco and Montacchini (2020) described that the LC approach is beneficial for textile products in relation to SC processes and to pre- and post-consumption wastes.

Concerning the TBL, 53% of the selected articles focused on all three fundamental aspects of sustainability. For instance, Manavalan and Jayakrishna (2019) analyzed the case of an SC organization willing to meet I4.0 requirements through CE and highlighted the circular opportunities available.

However, several contributions focus on only parts of the TBL, such as the example by Müller et al. (2019), where trends toward I4.0 applications in the wood SC were identified considering socio-economic challenges.

I4.0 technologies are considerably diffused in the collected best practices.

I4.0 is seen as a contribution to real-time information and distributed manufacturing systems and, therefore, to competitiveness and efficiency (Wang & Zhang, 2020). Frankó et al. (2020) presented a scalable solution for asset tracking and management in the context of I4.0.

IoT appears to be the most adopted technology since 50% of this category's articles referred to its opportunities. For instance, Mastos et al. (2020) discussed the impacts of an IoT solution on SSCM performance, demonstrating that I4.0 solutions have the potential to improve economic, environmental, and social sustainability. Khan et al. (2020) studied how IoT and blockchain applications enhance safety and transparency in food SCs. Jensen and Remmen (2017) stated that IoT and extended product service systems are fundamental requirements for becoming a sustainable manufacturer.

Contributions concentrating on the joint application of IoT and big data analytics have been reported. Among the seven identified articles, Belaud et al. (2019) developed an agricultural waste approach implementing big data to improve SC sustainability management. Moreover, the use of cloud technology is highly diffused in the category. Seven papers discuss it, and 12 refer to a joint adoption with IoT. For instance, a solution for reverse SCM, enabling cloud-based inventory monitoring thanks to IoT technology, was proposed by Garrido-Hidalgo et al. (2019). Avventuroso et al. (2017) studied SC data management within a products LC approach and I4.0 applications.

Regarding CE strategies, the 3Rs approach is present in 17 contributions. An example is the work by Nandi et al. (2020), presenting SC collaboration benefits. Blömeke et al. (2020) concentrated on electrical vehicles relying on Recycling 4.0 to digitalize EoL stages. In the same sector, Kintscher et al. (2020) presented an approach to study how I4.0 is

integrated into the recycling process, leading to Recycling 4.0.

Moreover, the combined implementation of waste management and M&EE or circular design and servitization is common in this domain of research. Kühl et al. (2019), for instance, identified how the implementation of different SC integration strategies, such as raw material self-sufficiency and resource ownership retention, could affect circularity. Herczeg et al. (2018) investigated industrial symbiosis from an SC collaboration perspective, deriving organizational and operational requirements. Mulrow et al. (2017) proposed a framework for the development of industrial symbiosis in the context of CLSCs. Moreover, Maranesi and De Giovanni (2020) discussed CE opportunities in the CSC inclusion of eco-innovations and information systems (IS). Castiglione and Alfieri (2019) focused on eco-industrial approaches considering practical SCM implications to reduce pollution and waste by sharing resources.

Waste management and remanufacturing strategies have proved to be linked with reverse SCs and CLSCs. Indeed, the review by Van Engeland et al. (2020) examined reverse logistics and waste management providing potentialities of waste reverse SCs thanks to combinatorial optimization models. Niu et al. (2019) explored the impact of design for remanufacturing by developing a modeling research framework of CLSC operations decision making. Xavier et al. (2019) reviewed the main WEEE management solutions in CLSCs focusing on recovering and classifying critical materials.

A total of 48% of the selected documents mentioned CLSCs, such as the example of Santander et al. (2020), exploring the distributed plastics recycling approach in the CLSC network.

Alternatively, 33% addressed reverse SCs. Among others, Bernon et al. (2018) presented a CE framework to implement reverse logistics operations. Julianelli et al. (2020) provided a framework integrating CSFs and reverse logistics in the context of CSC. Ripanti and Tjahjono's (2019) work was aimed at presenting CE values to design CLSCs and reverse logistics. Islam and Huda (2018) discussed a case of WEEE implementing reverse logistics in a CLSC.

Despite these two SC typologies, authors have even discussed sustainable and circular SCs. Respectively, Hong et al. (2018) investigated how SSCM practices impact on SC performance and the TBL, and De Angelis et al. (2018) presented the implications of CSC development.

A predominance of certain sectors can be identified; indeed, six contributions are part of the WEEE industry, such as the example by Bressanelli et al. (2020), investigating, through multiple-case study research, CE adoption in the household appliance industry. The steel, metal, and critical materials sectors are considerably diffused in the research domain. In this regard, Pinto and Diemer (2020) identified how SC integration strategies, such as raw material self-sufficiency and resource ownership retention, affect circularity.

Gaustad et al. (2018) assessed firms' vulnerability to SC critical material, providing business examples of circularity strategies.

Moreover, attention has been given to the electrical vehicle, agri-food, and plastics industries. Concerning the latter, Hahladakis and

Table 6
Articles' diffusion between the six dimensions and five categories.

		CSC I4.0 enabling tech	CSC performance tools & indicators	CSC challenges & barriers	CSC BM & strategies	CSC best practices	Total
proposition type	**Approach**	1	2	1	2	6	**12**
	Framework	2	6	6	5	4	**23**
	Methodology	5	1	6	0	4	**16**
	Guidelines	1	0	1	5	2	**9**
	Tool	0	4	0	0	0	**4**
	Model	4	3	4	11	4	**26**
LC phase	**BoL**	0	1	0	0	0	**1**
	MoL	0	0	0	0	0	**0**
	EoL	2	3	3	4	10	**22**
	Whole LC	6	3	11	5	7	**32**
I4.0 tech	**IoT**	32	11	29	23	20	**115**
	Big Data Analytics	30	8	25	14	8	**85**
	Additive Manufacturing	16	2	7	10	4	**39**
	Cloud	22	8	19	15	12	**76**
	Autonomous Robots	14	5	13	8	6	**46**
	Simulation	3	2	2	1	3	**11**
	V&HSI	5	1	4	0	2	**12**
	Augmented Reality	8	2	5	2	2	**19**
	Cyber-Security	6	2	5	3	1	**17**
	General	2	1	1	0	1	**5**
TBL	**Economic**	23	25	39	22	30	**139**
	Environmental	23	24	38	24	28	**137**
	Social	20	12	35	17	22	**106**
CE strategy	**Recycle**	14	17	31	21	26	**109**
	Reuse	12	19	25	17	26	**99**
	Remanufacturing	6	12	16	14	20	**68**
	Disassembly	1	0	0	1	1	**3**
	Waste Management	8	15	24	11	21	**79**
	M&EE	6	11	15	8	18	**58**
	CBM	1	4	9	8	6	**28**
	Circular Design	5	5	14	9	8	**41**
	Servitization	5	2	7	5	5	**24**
	Cleaner Production	0	3	6	7	2	**18**
	Industrial Symbiosis	0	3	10	5	7	**25**
SC Typology	**Green SC**	2	8	8	5	1	**24**
	Sustainable SC	4	5	6	10	4	**29**
	Circular SC	1	3	2	1	2	**9**
	Reverse SC	8	8	16	17	13	**62**
	Closed-loop SC	7	5	19	17	19	**67**
	Open-loop SC	1	1	0	0	1	**3**
TOTAL articles		**43**	**30**	**52**	**33**	**40**	**198**

Iacovidou (2018) discussed the need for an SC integration between systemic thinking, technological innovations, and regulations.

To conclude, a commitment to the analysis of emerging economies is present. Among others, Daú et al. (2019) focused on the healthcare sector by proposing a CE framework involving the TBL, I4.0, and corporate social responsibility. Alternatively, the importance of the relationships among the tiers to implement a sustainable BM was addressed by Cassol and Sellitto (2020) through studying a cosmetics company in Brazil.

5. Discussion

It is worth analyzing how the categories' peculiarities have emerged according to the dimensions of analysis, as reported in Table 6.

The Circular Supply Chain (*CSC) Industry 4.0 (I4.0) enabling technologies* category is characterized by methodologies and models predominantly addressing the possibilities and benefits of the Internet of Things (IoT), Big Data Analytics (BDA), cloud, autonomous robots, and additive manufacturing technologies. Indeed, important improvements in digitalization, data exchange, processes automation, and system productivity in the manufacturing context have been addressed by Raut et al. (2020).

The approach demonstrated an orientation to the entire Life Cycle (LC) and Triple Bottom Line (TBL).

The adopted Circular Economy (CE) strategies have been identified in the Reuse-Recycle-Remanufacturing (3Rs), waste management, Material & Energy Efficiency (M&EE), and circular design, usually related to reverse or closed-loop Supply Chain (SC)s. Through these strategies, the importance of sustainability awareness in the industrial sector has been remarked and enriched with innovative solutions like the new mechanism to minimize industrial negative effects provided by Safiullin et al. (2020). Frameworks and tools propositions define the *CSC performance tools and indicators* category, with poor social commitment regarding the Triple Bottom Line (TBL) as highlighted by Walker et al. (2021). Quantitative outputs have shown a focus on the End-of-Life (EoL) phases or the entire LC in order to gain a conscious and complete contribution, as the case of Hoffa-Dabrowska and Grzybowska (2020) and Shoaib-ul-Hasan et al. (2021). A predominance of IoT, BDA, cloud, and autonomous robots for I4.0 technologies and of the 3Rs, waste management, and M&EE for CE strategies has been highlighted. Green, sustainable, reverse, and closed-loop have proved to be the most diffused SC typologies.

Practical impediments have been addressed through frameworks and methodologies in the *CSC challenges and barriers* category, raising concerns in all TBL aspects. The references to I4.0 technologies and CE strategies are numerous and have displayed a scenario characterized by IoT, big data analytics, cloud, autonomous robots technologies and 3Rs, waste management, and M&EE circular design strategies. Obstacles have emerged during the entire LC by taking into account near reverse and closed-loop SCs (Jia et al., 2020; I. Kazancoglu et al., 2020; G. Yadav et al., 2020).

Moreover, this CSC category has particularly concentrated on the barriers encountered by SMEs, as the example of Dey et al. (2020) and Princes (2020b), and by emerging economies like the Indian example by Mangla et al. (2018).

Frameworks and guidelines guide the *CSC BM and strategies* category with managerial insights and approaches oriented to the entire LC and to economic and environmental aspects. The highlighted importance of

Table 7
Conceptual framework.

	CSC I4.0 enabling tech	CSC performance tools & indicators	CSC challenges & barriers	CSC BM & strategies	CSC best practices
Top industries	WEEE, Construction, Agri-food	Automotive, Agri-food, WEEE	Agri-food, Textile, Fashion, Automotive	WEEE, Electronics	WEEE, Electrical vehicles, Metal, Textile
Relevant literature	• Benefits, CSFs, potentials (flexibility and optimized decision), challenges and impacts in the different sectors adopting I4.0 (Rejikumar et al., 2019). Benefits of I4.0 enabling technologies in the manufacturing and SCM context (BDA: quality tracking, better demand forecasts and preventive maintenance) (Raut et al., 2020). Impacts of IoT on SCM, delivery process and applications of RFID for inventory accuracy (Ben-Daya et al., 2019).	• Emissions and costs reduction by implementing the autonomous vehicles strategy along with the consolidation warehouses (Gružauskas et al., 2018). Performance indicators for each stage of CSCs in terms of clean manufacturing, resource efficiency, eco-efficiency, reuse and remanufacturing, waste minimization (Jain et al., 2018). Performances comparison of traditional and circular production systems across indicators like direct, indirect LC emissions, waste recovered and virgin resources use (Genovese et al., 2017).	• Factors (integration, interoperability, predictive maintenance, recovery) and challenges (smart devices development, investment costs, compatibility) of CE and I4.0 in the SC context (Rajput & Singh, 2019). SMEs and internal challenges (organizational resistance at both employee and middle management levels) during the I4.0 technologies introduction (Horváth & Szabó, 2019). SSCM challenges (ineffective performance measurement system, resistance of culture change) and solutions (coordination and collaboration among SC members, educating customers for recycling practices)(S. Yadav et al., 2020).	• Co-creation strategy based on collaboration value as part of the digital transformation in I4.0 on SCM (Mihardjo et al., 2020). CBM driving SCCs in closing (reuse the materials through recycling), slowing loops (designing durable goods and product-life extension), narrowing and dematerializing loops (Geissdoerfer et al., 2018), (Hazen, Russo, Confente, et al., 2020).	• Mathematical model addressing manufacturing-remanufacturing planning from the perspective of a manufacturer pursuing joint implementation of I4.0 and CE principles (Bagalagel & Elmaraghy, 2020). IoT role in I4.0 as a facilitator of decentralized decisions and real-time responses (Manavalan & Jayakrishna, 2019b). End-to-end solution for Reverse SCM based on cooperation between different IoT communication standards, enabling cloud-based inventory monitoring of WEEE through embedded sensors (Garrido-Hidalgo et al., 2019).
proposition type	Model, Methodology	Framework, Tool	Framework, Methodology, Model	Model	Approach, Framework, Methodology, Model
LC phase	Whole LC	EoL, Whole LC	Whole LC	EoL, Whole LC	EoL, Whole LC
I4.0 tech	IoT, BDA, Cloud, AM, Autonomous Robots	IoT, BDA, Cloud, Autonomous Robots	IoT, BDA, Cloud	IoT, BDA, Cloud, AM	IoT, BDA, Cloud,
TBL	Economic, Environmental, Social	Economic, Environmental	Economic, Environmental, Social	Economic, Environmental, Social	Economic, Environmental, Social
CE strategy	Recycle, Reuse, WM	3Rs, WM, M&EE	Recycle, Reuse, WM	3Rs	3Rs, WM
SC Typology	Reversed, Closed-loop	Reversed, Green	Reversed, Closed-loop	Reversed, Closed-loop	Reversed, Closed-loop

I4.0 technologies, stated for instance in the paper of Manavalan and Jayakrishna (2019),and CE strategies is similar to that in the *CSC I4.0 enabling technologies* category but with the addition of CBM and cleaner production. SC typologies have referred mainly to sustainable, reverse, and closed-loop. In this regard, frameworks developing CBMs in CSC have been studied by Geissdoerfer et al. (2018) and Garcia-Muiña et al. (2018).

The *CSC best practices* category ends the analysis with successful approaches and "take-aways" displayed through frameworks, methodologies, and models. Examples have addressed the entire LC and, in some cases, such as Bagalagel and ElMaraghy (2020) studying the WEEE industry, the EoL phase only. A slight predominance of environmental and economic aspects according to the TBL have characterized the contributions, as the example by Müller et al. (2019). IoT, big data analytics, cloud technologies and the 3Rs, waste management, and M&EE have proved to be diffused, while SCs have been identified as reverse and closed-loop.

Best practices have emerged from various sectors like the electrical vehicle, agri-food, and plastic industries (Hahladakis & Iacovidou, 2018). Moreover, a commitment to the analysis of emerging economies has been detected in the frameworks proposed by Daú et al. (2019) and Cassol and Sellitto (2020).

Based on the numbers gathered in the previous table, a conceptual framework (Table 7) able to describe the main categories composed the CSC domain is proposed. The categories have been reordered to indicate to practitioners which dimension of CSC should first be addressed when they attempt to approach such a domain. Indeed, it is strategic for them to first realize the challenges and barriers that they have to cope with and that then they can address deploying and adequately employing a certain set of enabling technologies (Chiappetta Jabbour et al., 2020; Rosa et al., 2020) and best practices (Guldmann, 2016; Kirchherr & Piscicelli, 2019; Ünal et al., 2019). Through the combination of these assets, companies can choose suitable strategies (Acerbi & Taisch, 2020b) and build effective business models (Bocken et al., 2014, 2018; Rosa et al., 2019) to actually and effectively operate in a CSC. Finally, the last dimension that should be raised in companies should be the one related to performance tools and indicators. Indeed, it is key to be able to measure circularity performance for companies belonging to a CSC (Sassanelli et al., 2019; Vinante et al., 2021), managing data and information not only internally but also externally to the company ecosystem (Acerbi et al., 2021).

6. Conclusions

This research has offered a systemic analysis with the aim of integrating the threefold context of Industry 4.0 (I4.0), Circular Economy (CE), and Circular Supply Chain (CSC). To do so, a systematic literature review, leading to a descriptive and thematic analysis, has been performed to structure the knowledge regarding the embracement and implementation of the CSC concept, enabled by the joint adoption of CE strategies and I4.0 technologies.

Articles were investigated through six dimensions of analysis (LC phases, I4.0 technologies, Triple Bottom Line (TBL) layers, Circular Economy (CE) strategies, and Supply Chain (SC) typologies), leading to the detection of five thematic categories in the CSC domain (I4.0 enabling technologies, Performance tools and indicators, Challenges and barriers, Business models and strategies, Best practices). These five categories were also useful to build a framework able to describe the single dimensions of the CSC research domain and to gradually raise companies' managers awareness to successfully approach CSCs. The results of the analysis allowed to provide the peculiarities of each of the categories detected, also highlighting the attention devoted to the practical impediments to the CSC transition (since the *CSC challenges and barriers* category has resulted as the most pervasive in terms of number of articles (52)). The latter insight suggests a future concentration on studying the difficulties encountered by new firms and the eventual solutions able to overcome them. On the opposite side, papers addressing measurable outputs and CSC indicators are still lacking in the domain (30 out 198). This nascent circular paradigm has, indeed, not developed quantitative means to monitor and track the obtained outputs yet, especially at a meso and macro levels.

Furthermore, a CSC advancement of specific industries, such as manufacturing, Waste from Electrical and Electronic Equipment (WEEE), agri-food, and automotive, has been unveiled. The analysis raised a predominance of economic and environmental aspects, highlighting a shortage of interest in the social layer of the TBL. The selected contributions have mainly proposed models, frameworks, and methodologies to support the CSC domain evolution. Concerning the LC, the majority of the sample has focused on the entire cycle of circular solutions provided by CSCs. However, many cases have focused on the End-of-Life (EoL) phase mainly due to the industry nature, such as the case of the WEEE.

Regarding I4.0 technologies, results have shown a prevalence and a synergic implementation of Internet of Things (IoT), Big Data Analytics (BDA), and cloud technologies thanks to their beneficial impacts on resource and information management, production efficiency, stakeholder coordination, and collaboration. The most promising CE strategies have been identified in the Reuse-Recycle-Remanufacturing (3Rs), waste management, and Material & Energy Efficiency (M&EE) for their benefits in terms of costs and waste reduction. Lastly, in the CSC field, SC categories referred mostly to reverse and closed-loop.

The contribution of this paper is twofold: theoretical and practical. Firstly, the extant knowledge in the threefold domain of CE, I4.0 and SC has been systematized through a literature review. The selected papers have been analyzed through 6 dimensions, leading to the detection of 5 CSCs categories that can be used by researchers to lead future both theoretical and practical researches in more specific aspects. Indeed, through the results obtained, the authors were able to identify and present the major aspects, trends and most promising solutions to be adopted in the I4.0-driven CSC.

From a practical point of view, the research is contributing to the raising of circular sustainability awareness among practitioners belonging to different industries. Indeed, the results of the literature review represent useful guidelines and directions that can be used as managerial insights by firms. Through them, depending on their need to focus on different CSC aspects (enabling technologies, performance tools/indicators, challenges/barriers, business models/strategies, or best practices), managers could easily raise their knowledge about practices, methodologies, and technological solutions that may be helpful to support their CSC activities. Furthermore, the peculiarities of each sector according to the CE strategies and the I4.0 technologies adopted, further support specific industries to a shift toward CSCs.

Finally, the provided analysis could be enriched by future research to overcome the extant gaps in the domain. Indeed, beside the novelty of the contribution, being a literature review, the paper concentrates on a theoretical perspective, raising future possibilities and opening room for more practical investigations able to foster and gradually support firms in the practical switch from linear SCs to circular ones. Specific research in each of the 5 CSC categories could be carried out to better explore how to support the companies' transition towards a CSC, choosing the most promising strategies and technologies per each of them. In particular, it emerged that the challenges and barriers represent the key point to be coped with by researchers to trigger the wide employment of CSC in different industries. A model, able to guide practitioners in bridging the gradual shift from linear to CSCs, has also to be built and proposed in literature. Wrapping up, this literature review unveiled the major issues in the threefold research domain of SCS-CE-I4.0, calling for further attention from both a theoretical and practical perspective. Researchers willing to contribute to this domain should:

- propose solutions and techniques to practically enhance the implementation of CSCs, applying a systemic approach able to

comprehend all the three research topics (SCS-CE-I4.0) and to provide a general theoretical understanding of the CSC concept;
- define and list the main barriers, risks, and treats occurring while adopting a CSC as well as indicators and metrics able to support the evaluation of the effectiveness during the CSC transition;
- detect the main enablers of CSCs (such as the most suitable technologies and business models bolstering their evolution);
- develop researches able to support the definition of standards, laws and regulations, tax policies and incentives in the CSCs management;
- indicate how company should invest to support CSCs evolutions, enhancing technical equipment, and information and data management systems, streamlining and setting organizations, and developing training programs for managers, employees, and operators, to improve their (technical/organizational) knowledge and bolster communication and collaboration inside and outside their boundaries;
- clarify how to reach economic benefits and circular flows in the short run with CSCs adoption, winning reluctancy and fear of disruptive changes.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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