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Master of Science in Management Engineering

Sustainable Operations Management and Social Innovation

Circular Supply Chain in the era of Industry 4.0: a model to support approaching firms in the circular transition

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Acronyms

CE	Circular Economy
SC	Supply Chain
CSC	Circular Supply Chain
CSCM	Circular Supply Chain Management
CLSC	Closed-loop Supply Chain
SSC	Sustainable Supply Chain
SSCM	Sustainable Supply Chain Management
BM	Business Model
CBM	Circular Business Model
3Rs	Reuse-Recycle-Remanufacturing
LC	Life Cycle
BoL	Beginning of Life
MoL	Middle of Life
EoL	End of Life
TBL	Triple Bottom Line
I4.0	Industry 4.0
IoT	Internet of Things
IIoT	Industrial Internet of Things
BDA	Big Data Analytics
AM	Advanced Manufacturing
AR	Augmented Reality
CPS	Cyber Physical System
ICT	Information and Communications Technology
CSF	Critical Success Factor
CRM	Customer Relationship Management
3DP	3D Printing
ML	Machine Learning
SDGs	Sustainable Development Goals
LCA	Life Cycle Assessment
WM	Waste Management
M&EE	Material and Energy Efficiency
PSS	Product Service Systems

Abstract

The integrated benefits of Circular Economy (CE) and Industry 4.0 (I4.0) have fostered the transformation from a linear to a circular model able to capture additional value and integrate Supply Chain (SC) activities. CSCs allow the reduction of waste production and the achievement of self-sustaining production.
However, the research domain lacks a holistic and systematic approach able to present the characteristics of Circular Supply Chains (CSCs) and, at the same time, guide approaching firms interested in the circular transition.

The final aim of this work is to compensate the presented gap by proposing a CSC transitional model which addresses the evolution from a linear to a CSC providing support to practitioners.
To do so, a broad analysis and classification of the literature review have been conducted. Furthermore, the work has presented the main barriers that might undermine the circular process. Finally, thanks to the gathered and classified information, a CSC model containing practices and approaches has been built.

Findings have shown a predominance of economic and environmental aspects over the social ones; of Big Data Analytics (BDA), Internet of Things (IoT) and Cloud for the I4.0 technologies, of Reuse-Recycle-Remanufacturing (3Rs), Waste Management (WM) and Material and Energy Efficiency (M&EE) for the CE strategies and of environmental indicators as Life Cycle Assessment (LCA) and emissions level for the performance measurement. Moreover, significant Circular Business Models (CBMs) and design practices such as Product Service Systems (PSS), structural flexibility and closing resource loops have proved to be successful.
Three barriers (i.e. poor management support, lack of coordination and collaboration among SC members and lack of technical infrastructures) have resulted as the main practical impediments in the realization of the transition.

The value of the work is threefold since it enlarges the knowledge around CSC providing a complete and accurate literature review analysis, it contributes to the CSC practices building a practical guide to sustain the transition and it supports managers dealing with sustainability and CSC decision-making process.

Abstract in italiano

L'avvento della CE e delle tecnologie di I4.0 hanno favorito la transizione da un modello lineare ad uno circolare in grado di integrare le attività della SC. La CSC permette una riduzione dello spreco ed il raggiungimento di una produzione autosufficiente.
Tuttavia, il dominio di ricerca risente della mancanza di un approccio olistico e sistemico in grado di trattare le caratteristiche della CSC e, allo stesso tempo, di guidare le imprese interessate alla transizione circolare.

L'obiettivo finale di questo lavoro è quello di colmare il divario presentato proponendo un modello che affronta l'evoluzione da un modello lineare a uno di CSC fornendo pratiche ed approcci utili a gestire con successo la transizione.
Per fare ciò, è stata condotta un'ampia analisi di revisione della letteratura atta a riconoscere e comprendere le carenze dell'ambito di ricerca ed acquisire conoscenze fondamentali per strutturare le parti seguenti.
È stata successivamente realizzata una classificazione in 5 categorie definite sulla base dell'argomento dei diversi contributi. Inoltre, il lavoro presenta le principali barriere che potrebbero minare la riuscita del processo circolare. Infine, le informazioni raccolte e classificate, sono state usate per la strutturazione del modello.

Quanto ottenuto ha mostrato una predominanza degli aspetti economici e ambientali su quelli sociali; delle tecnologie di BDA, IoT e Cloud e di indicatori ambientali come LCA e il livello di emissioni per la misura delle prestazioni. Inoltre, CBMs e pratiche di progettazione come PSS, flessibilità strutturale e closing resource loops si sono dimostrati validi e diffusi.
Riguardo le barriere, lo scarso supporto gestionale, la mancanza di coordinamento e collaborazione tra i membri della SC e la mancanza di infrastrutture tecniche sono risultati i principali impedimenti pratici alla realizzazione della transizione.

Il valore del lavoro è triplice poiché amplia la conoscenza della CSC fornendo un'analisi completa della letteratura, contribuisce alle pratiche di CSC realizzando una guida pratica per la transizione e supporta i managers nella gestione della sostenibilità e del processo decisionale di una CSC.

Executive summary

In this section a brief summary of the thesis is reported. The aim is to enhance the reader's comprehension with a synthesis of the main insights and findings of the work. The structure of the summary follows the table of contents; therefore 4 paragraphs have been realized.
The first one is related to the research context and provides an overview of the main topics addressed in this paper.
Secondly, the methodology followed for the realization of the outputs is described.
Subsequently, the major findings and results are presented stressing the fundamental takeaways.
Lastly, discussions about the implications and contributions that this work is providing are highlighted in a conclusive paragraph.

Research context

The analysis has concentrated on an integrated context covering 3 main areas of interest: CE, I4.0 and CSC. In this sense, the investigation purpose was to acquire insights about existing CSCs that are implementing a circular approach thanks to CE practices and I4.0 technologies.

CE is defined by the Ellen MacArthur Foundation (EMF, 2015) as "The 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".
Therefore, CE aims at overcoming the dominant linear (take, make, dispose) economy model by minimising the consumption of finite resources.
The CE strategies taken as a reference in this thesis are referred to the paper by Acerbi & Taisch (2020) including cleaner production, circular business model, waste management, disassembly, remanufacturing, reuse, recycle, servitization, industrial symbiosis and eco-industrial parks, material and energy efficiency and circular design practices.

I4.0 technologies are connected systems, referred to Cyber Physical System (CPS), that can interact using standard Internet-based protocols. In particular, the Boston Consulting Group identifies 9 technologies as building blocks of I4.0: Big data 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 technologies enable to gather and analyse data across machines through a fast, flexible and efficient process and nowadays they have numerous industrial applications.

The integrated benefits of CE and I4.0 have fostered the transformation from a linear to a circular model by involving return processes that capture additional value and further integrate the SC activities.

Therefore, CSCs allow the reduction of waste production and the achievement of self-sustaining production systems in which materials are returned to the production cycle. To do so, the organizations network establishes upward and downward linkages in the different processes and activities.

Methodology

The research methodology of this work is composed by a process involving 4 main phases as presented in the figure afterwards.

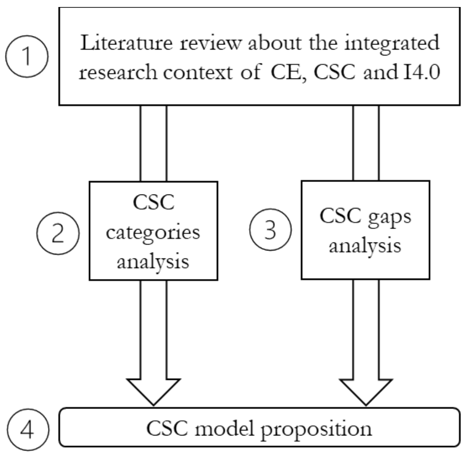

Figure 1: Research methodology process

Firstly, a systematic literature review about the research context comprehending approximately 200 articles from the Scopus® academic search engine has been accomplished. This latter identifies the relationship between the topics described above.

After having performed the analysis of the literature to gain a knowledge recognition of the domain, the contributions have been structured and classified based on their proposal (framework, approach, guidelines, model, methodology, tool), the life cycle phase (Beginning of Life (BoL), Middle of Life (MoL), End of Life (EoL), whole), the I4.0 technologies assessed (according to the 9 pillars described above), the triple bottom line layers (economic, environmental, social), the CE strategies (presented in the previous paragraph) and the SC typologies (green, sustainable, circular, reverse, open-loop and closed-loop).
According to the papers main subject of interest, a further classification has been realized gathering the selected articles in 5 main categories: *CSC I4.0 enabling technologies, CSC performance tools and indicators, CSC challenges and barriers, CSC business models and strategies and CSC best practices.*

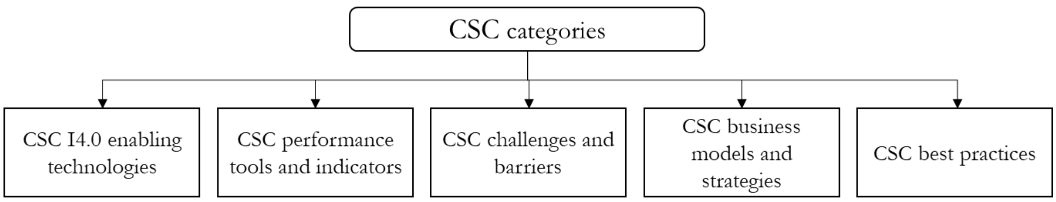

Figure 2: CSC categories

The *CSC I4.0 enabling technologies* category presents I4.0 enabling technologies that are fostering the CSC adoption.
The second macro topic, *CSC performance tools and indicators*, emphasizes the importance of the performance measurement offering guidelines and practical tools to achieve relevant assessments.
In the category of *CSC challenges and barriers* are gathered all the articles addressing problematic and challenging issues that may occur in the development of a CSC.

CSC business models and strategies presents managerial and organization models proved to be efficient in this field.
Finally, successful case studies and practices in implementing CSC are clustered in the *CSC best practices* category.

As a third step, since the *CSC challenges and barriers* category has proved to be the largest in terms of number of contributions, it has been decided to concentrate the attention on the gaps encountered in the domain.
The followed methodology has, therefore, proceeded distinguishing in theoretical and practical gaps.
The first ones represent open points identified by the scholars in their papers which need further investigations. According to the topics addressed, a classification has been realized gathering them in 10 categories (practical, systemic, general, barriers, benefits, perspectives, strategical, measurable, enablers and formal).
Secondly, the analysis has concentrated on the practical gaps, namely the actual barriers regarding the implementation and the adoption of the CSC approach.
In particular, 17 barriers have been collected and grouped into 5 main categories (political, economic, social, organizational, technical).

The literature outcome, together with the analysis of the gaps encountered in the research domain, have been then used as the groundwork for the definition and development of the CSC model.
The methodology for the realization of the model follows the necessity to address each phase of the CSC transition in order to support approaching firms in every single step.
To do so, the model has been distinguished in 3 main phases: conceptualization, development and measurement, which represent foundamental stages of the CSC process according to the obtained results.
Each step of the model provides approaches, guidelines and practices to follow and warnings to be aware of during the CSC transition.

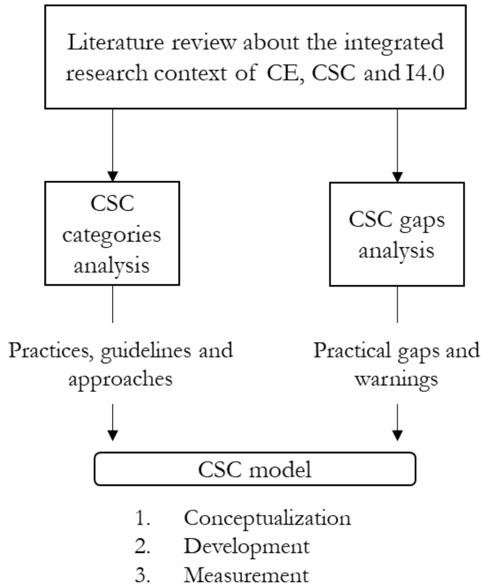

Figure 3: CSC model proposition methodology

Results

The literature analysis and the subsequent CSC categories definition suggest a predominance of contributions studying the impediments of the CSC development, highlighting the difficulty encountered by approaching firms and the willingness to find solutions able to overcome them. On the opposite side, papers addressing measurable outputs and CSC indicators are still lacking in the domain.

Regarding the I4.0 technologies, the findings have shown a prevalence of IoT, BDA and Cloud technologies among the 9 defined, thanks to their beneficial impacts on production efficiency, resource management, stakeholders' coordination and collaboration and information management.

The most promising CE strategies have been identified in 3Rs, WM and M&EE since their beneficial power in terms of costs and waste reduction.

In addition, the analysis confirmed a predominance of economic and environmental aspects and impacts, leaving aside the social sphere, according to the Triple Bottom Line (TBL).

The theoretical gaps analysis has suggested that, besides the theoretical studies that usually focus on a singular aspect of the research context (CE, I4.0 or CSC), articles discussing practical implications of the CSC adoption with a systemic and holistic point of view are needed.

The research domain lacks, indeed, an approach able to practically present the characteristics of CSCs and, at the same time, guide approaching firms interested in the transition to a circular pattern.

The practical gaps analysis, instead, has demonstrated the synergic importance of political, financial, technical, social and organizational commitment in order to achieve a smooth circular transition. While political and financial aspects matter in the decision and in the undertake of a process oriented to a circular paradigm of SC; organizational, technical and social barriers have proved to be impactful during the implementation and the transition to a CSC.

Indeed, management support, strategic planning, mitigation of the fear of change, compatibility of technological infrastructures, information systems and skilled workforce are some of the main requirements for an optimal CSC, whose lack may hinder the entire process.

By leveraging on the theoretical identified gaps, the final aim of this work is to compensate the presented lack by proposing a CSC transitional model which addresses the evolution from a linear to a CSC providing a practical support to practitioners.

In this sense, the proposition has been structured in 3 main subsequent and circular phases: conceptualization, development and measurement.

In the conceptualization phase practitioners are provided with several models, frameworks and guidelines offering guidance and supporting directives.

In the second phase, more operational and practical aspects have been discussed. The development, indeed, regards the implementation and employment of practices, technologies and approaches to realize the CSC transition.

Finally, in the measurement phase, practitioners can benefit from innovative tools, indicators and frameworks. The performances tracking is useful not only for an external point of view, but also for an internal one, to monitor the initial plan and eventually suggest adjustments through circular and continuous improvements.

The 3 phases are related to the main steps of the transitional process and are structured on the 5 introduced *CSC business models and strategies, challenges and barriers, I4.0 enabling technologies, performance tools and indicators, best practices*. They have been assessed to understand how each of them impacts the timeline concerning the CSC transition, from its initial adoption up to its full achievement.

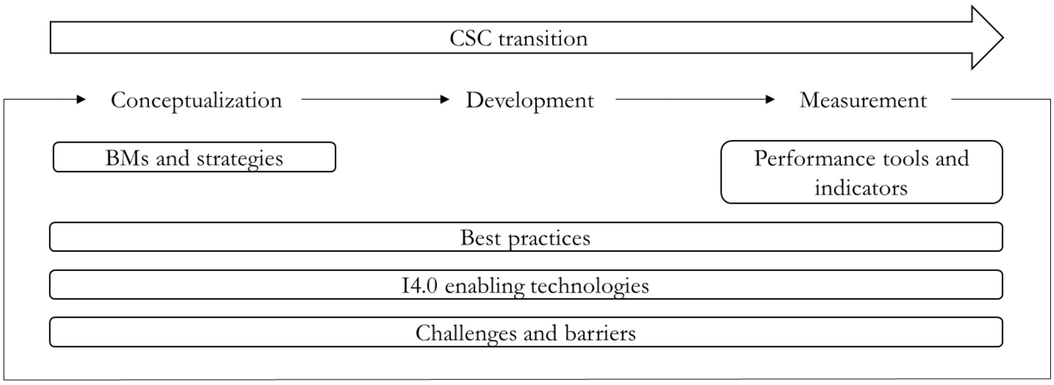

Figure 4: CSC model

Through the dimensions of the *CSC best practices* category, successful CSC examples and practices, proving to be appropriate in each stage of the transition have been provided.

The *I4.0 enabling technology* insights guide the approaching companies mostly in the central phase thanks to the improvements during the development activities. However, their use is crucial even in the initial phase and during the measurement one, for instance to manage massive quantities of data needed.

Since the practical gaps analysis has shown several difficulties and *barriers* in the CSC transition, the model provides accurate warnings to support companies in overcoming challenges that might undermine the process.

The remaining *CSC business models and strategies* and *performance tools and circular indicators* categories have been respectively considered in the conceptualisation and measurement phases due to their content. The first category provides outcomes which are the foundations of a managerial decision oriented to the circular transition and responsible for the management of the latter.

Finally, CSCs need to be measured to monitor the transition in quantitative and qualitative terms and to, eventually, improve the process through a continuous and circular improvement.

The model presents some guidelines, practices and approaches able to support approaching firms in the different phases of the circular transition.

The major results are synthetised hereunder.

Conceptualization phase

Why? Encountered practical gaps	How? Proposed practices and approaches[1]	What? Adopted I4.0 technologies and CE strategies	
B7: Resistance and fear against disruptive changes B10: Lack of coordination and collaboration among the SC members B11: Lack of appropriate training and educational programmes B13: Poor management support and commitment B14: Lack of effective strategic planning	Guidance for reorganizing structure and processes, identifying synergistic approaches to form channel partners and sources of conflicts during the CSC transition (Nandi et al., 2020).	Cloud BDA IoT	CBMs 3Rs WM M&EE
	A model to enhance SC capabilities and co-creation strategy with partners and customers, optimised through the use of Cloud and BDA technologies (Mihardjo et al., 2020).		
	Best practices for the CSCM as configuration organisational functions, coordination of organisational functions, closing resource loops, slowing resource loops and narrowing resource loops (Geissdoerfer et al., 2018).		
	Model proposition of a IoT enabled decision support system (DSS) for CBMs that effectively allows tracking, monitoring and analysing products in real time with the focus on residual value (Mboli et al., 2020).		
	A conceptual model illustrating how PSS BMs impact SC collaboration through increased product longevity, closure of resource loops and resource efficiency (Kühl et al., 2019).		
	Practices as structural flexibility, open and closed material loops in technical and biological cycles and closer collaboration (De Angelis et al., 2018).		

Table 1: Conceptualization phase summarising table

Development phase

Why? Encountered practical gaps	How? Proposed practices and approaches[2]	What? Adopted I4.0 technologies and CE strategies	
B8: Lack of skilled workforce B15: Lack of technological resources and infrastructures B16: Lack of compatibility and integration of technical platforms B17: Lack of information systems and data management	UAV (Unmanned aerial vehicles) system that, together with BDA, supports industries in automating inventory tasks and traceability (Fernández-Caramés et al., 2019).	IoT BDA Cloud AM A Rob	3Rs WM M&EE CD
	Circular model to reuse scrap electronic devices integrating reverse logistics and AM (Nascimento et al., 2019).		
	Methodology for asset tracking, based on UWB radio technology and RFID, supporting global asset management for I4.0 (Frankó et al., 2020).		
	A hybrid model based on recurrent neural networks (RNN) to enhance safety and transparency in food SCs (Khan et al., 2020).		
	End-to-end solution for reverse SCM based on cooperation between different IoT communication (Garrido-Hidalgo et al., 2019).		

Table 2: Development phase summarising table

[1] Environmental and economic aspects slight predominance.

[2] Environmental and economic aspects slight predominance.

Measurement phase

<table>
<tr><th>Why?</th><th>How?</th><th colspan="2">What?</th></tr>
<tr><th>Encountered practical gaps</th><th>Proposed practices and approaches[3]</th><th colspan="2">Adopted I4.0 technologies and CE strategies</th></tr>
<tr><td rowspan="7">B3: Lack of global standards and performance measurements</td><td>CO_2 emission level and logistics costs reduction thanks to the I4.0 adoption strategy (Gružauskas et al., 2018).</td><td rowspan="7">IoT
BDA
Cloud</td><td rowspan="7">3Rs
WM
M&EE</td></tr>
<tr><td>Conceptual framework, including the LCA, to examine food loss and waste (Luo et al., 2021).</td></tr>
<tr><td>KPI capable of measuring the impact of energy consumption on the Nakajima's 6 big losses (Morella et al., 2020).</td></tr>
<tr><td>LC emissions, waste recovered, carbon maps indicators to compare traditional and circular production systems (Genovese et al., 2017).</td></tr>
<tr><td>Carbon emissions reduction achieved through CE practices (Nasir et al., 2017).</td></tr>
<tr><td>Coordination index among the SC actors (Singh et al., 2019).</td></tr>
<tr><td>CEPA methodology, LCA and LCC to exploit quantitative assessments of CBMs (Rocca et al., 2021).</td></tr>
</table>

Table 3: Measurement phase summarising table

Implications and contributions

The value that this thesis is leaving to the domain is threefold.

Firstly, it enlarges the knowledge around CSC providing a complete and accurate literature review analysis and compensates the presented theoretical gaps by proposing a practical and systemic model to guide interested practitioners.

Secondly, it contributes to the CSC practices building a practical guide to sustain the transition by overcoming the newness and difficulty of implementing the circular paradigm from an initial linear model.

A systematisation and categorisation of methods, approaches, guidelines and warnings is provided in order to guide practitioners in adopting the optimal digital technologies and circular strategies during the entire CSC transition.

Finally, findings have also managerial implications since the model helps managers in the decision-making process throughout the CSC transition.

The model, indeed, contributes to the generation of awareness among the industrial sector creating the recognition of the importance that sustainability aspects have nowadays. Being now informed and theoretically aware, managers have the

[3] Environmental and economic aspects significant predominance.

instruments and knowledge of the practices and approaches to face the circular change and lead the internal transition of the company.

This work could be seen as an initial step to pave the way to future contributions oriented to a systemic and practical approach and willing to compensate the highlighted CSC gaps.

The CSC model proposition suggests a further development with an industrial validation of the latter. This step is needed in order to have a proof and a confirmation of the model effectiveness and accuracy. Therefore, future research could interview interested companies to get feedbacks about the insights and findings of the model.

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1 Introduction

Price volatility, SC risks, technological growth rates, severe environmental issues, restrictive directives and growing pressures on resources have been starting to alert business leaders and policy makers to the necessity of rethinking materials and energy use arguing the potential benefits of CE (Rosa et al., 2019b).
CE is defined as "an industrial economy that is restorative and regenerative by intention and design" and it relies on 3 principles: preserve and enhance natural capital, optimize resource yields and foster systems effectiveness (EMF, 2015). CE aims to reduce resources consumption by slowing, closing and narrowing resource loops (Geissdoerfer et al., 2018). This sustainable promising approach addresses resource-related challenges for business and economies, generates growth, creates jobs and reduces environmental impacts.

At the same time, advanced digital technologies have spread across the industrial sector. In particular, I4.0 technologies are based on connected systems which can interact using standard Internet-based protocols, analyze data, configure themselves and adapt to changes. This enables faster (30%), more flexible and more efficient (25%) processes to produce higher quality goods and elevate mass customization at reduced costs. Therefore, I4.0 is significantly transforming the design, manufacturing and services of products and production systems (Russmann et al., 2015).

CE and I4.0 represent the two most important industrial paradigms driving academia and industry in recent years. The integration of these technologies within an industrial context can enable a set of important improvements in competitiveness, especially for what concerns the SCM (Rosa et al., 2020).

In this context, CSC plays a fundamental role since it promotes the transformation from a linear to a circular model by involving return processes that capture additional value and further integrate the SC activities. The organizations network establishes upward and downward linkages in the different processes and activities among multiple actors (González-Sánchez et al., 2020). Therefore, CSCs benefits are twofold: the reduction of waste production and the achievement of self-sustaining production systems in which materials return to the production cycle (Genovese et al., 2017).

Nevertheless, very limited contributions about which kind of technologies can support the implementation of CSC are available. Regarding the I4.0 perspective, many contributions assessed the potential support offered by key enabling technologies to companies. However, only very few cases have presented the circularity level reachable through the adoption. Moreover, innovative BMs and industrial strategies adequate to this new context are still under either development or implementation (Rosa et al., 2019a).
To date there are no useful models and tools to support the establishment of CSCs. Efforts have concentrated only at the company individual level lacking a formal support to the approaching ones. Therefore, a shift is needed.

To this aim, the final objective of the thesis is to compensate the literature gap by proposing a CSC transitional model which addresses the evolution from a linear to a CSC. The transitional process is accompanied by practical support, useful insights and warnings to guide practitioners in the management.

The paper is structured as follows. Section 2 displays the integrated research context characterized by the 3 main topics of CE, CSC and I4.0. Section 3 explains the adopted research methodology. Section 4 provides the major findings and analyses the results. Section 5 discusses knowledge, practices and managerial implications of the work. Finally, section 6 argues some conclusions and considerations while debating limitations and future research trends.

2 Research context

To structure the knowledge recognition, an integrated context of research has been taken as a reference. The analysis has, indeed, focused on the contents of CE, CSC and I4.0 to gain an overall perspective of the domain and collect a significant number of contributions.

2.1 Circular Economy

A commonly agreed definition of the CE was proposed by the Ellen MacArthur Foundation (EMF, 2015). Among those, the increasingly adopted states "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".

First, the CE is defined as a global economic model to minimise the consumption of finite resources, by focusing on intelligent design of materials, products, and systems. Second, the CE aims at overcoming the dominant linear (take, make, dispose) economy model.
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 CE category classification is referred to the definition of CE strategies exhibited in the paper by Acerbi & Taisch (2020). This latter includes cleaner production, circular business model, waste management, disassembly, remanufacturing, reuse, recycle, servitization, industrial symbiosis and eco-industrial parks, material and energy efficiency 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.
To achieve this, the organizations network establishes upward and downward linkages in the different processes and activities (González-Sánchez et al., 2020).
Therefore, CSCs benefits are twofold: the reduction of waste production and the achievement of self-sustaining production systems in which materials are returned to the production cycle (Genovese et al., 2017).

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. However, slight differences appear between those terms.

The reverse SC includes activities, dealing with product design, operations and 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.
On the other hand, 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). As opposed to traditional SC, "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).

According to this latter description, CSC is a step beyond closed-loop and green SCs. Firstly, it expands the number of actors in the chain by considering even sectors other than that of origin. Secondly, the relationships between actors are empowered.
The classification according to the terminology used in the field of CSC has been further explored in the categorization of the literature.

2.3 Industry 4.0

I4.0 is a paradigm referring to a wide range of concepts, whose clear classification, as well as their precise distinction, is not possible. Most definitions of I4.0 consider, however, advanced digital technologies as the main driver (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). The paper states that these connected systems (also referred to CPS) can interact using standard Internet-based protocols. I4.0, therefore, enables to gather and analyse data across machines through a fast, flexible and efficient process.
The presented 9 pillars of technological advancement have been employed in the literature categorization of I4.0 technologies described afterwards.

Considering the aim of defining a model to guide companies towards the creation of a CSC, the integrated research framework of CE, I4.0, CSC requires to be deeply investigated, as shown in the next section.

3 Research methodology

The research methodology of this work is composed by a process involving 4 different phases.

Firstly, a systematic literature review about the research context has been accomplished, which identifies the relationship between the topics described above. The analysis of the literature and its classification in 5 main categories, as described in detail in Section 3.2 and 4.2, has been the foundation of the theory building and the knowledge recognition. Its outcome, together with the analysis of the gaps encountered in the research domain, are the groundwork for the definition and development of the CSC model. This latter is the output of the work and a guide for practitioners interested in the field of research.

Figure 5 summarizes the followed methodology.

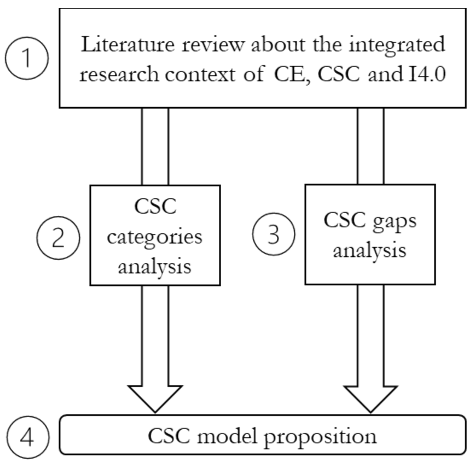

Figure 5: Research methodology process

3.1 Literature review

In order to systematize the 3 main presented topics: CE, CSC and I4.0, a comprehensive literature review has been conducted. Scientific articles published from 2010 up to the first quarter of 2021 have been gathered from the Scopus® academic search engine. Without considering any field content limitation, a total amount of 4 searches have been performed. The set of queries selected for conducting the searching process on title, abstract and keywords has been reported in Figure 6.

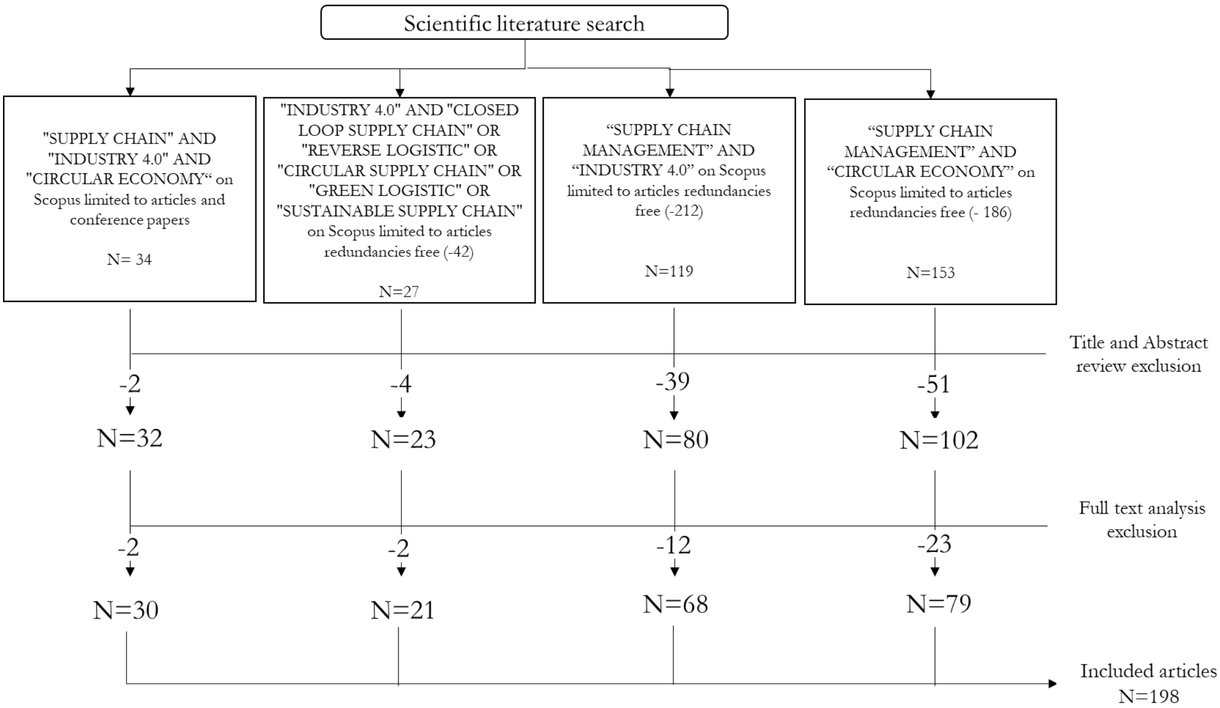

Figure 6: Literature search approach

The first research related to the query "SUPPLY CHAIN" AND "INDUSTRY 4.0" AND "CIRCULAR ECONOMY" has been limited to Articles and Conference papers (23%) since it was the main and broader field of the analysis, instead the other 3 searches were limited only to Articles. This choice was even driven by the willingness to restrict the search to a reasonable number of final documents.
The combination, after discarding the redundancies, has led to a total amount of 333 articles.

A first selection has been conducted by reviewing titles and abstracts, then a second screening was performed by reading the entire manuscript. The selection was 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 I4.0 technologies.
By applying this refining criteria, the set of documents found was reduced at the end to 198 selected articles, considered as reference literature and analysed into detail.
As shown in Section 4.1, all these papers have been categorized by year, journal, document type, research type and industry.

3.2 CSC categories

To structure the literature contributions, a classification based on their proposal (framework, approach, guidelines, model, methodology, tool), the life cycle phase (BoL, MoL, EoL, whole), the I4.0 technologies assessed (according to the 9 pillars described in Section 2.3), the triple bottom line layers (economic, environmental, social), the CE strategies (presented in Section 2.1) and the SC typologies (green, sustainable, circular, reverse, open-loop and closed-loop) has been realized.

Thanks to the described categorization, a way to structure the analysis has emerged. Indeed, since the final aim of the work is to define a model to guide companies towards the creation of a CSC, articles have been gathered according to their contribution to the CSC model design. In this sense, 5 main categories have been defined: *CSC I4.0 enabling technologies, CSC performance tools and indicators, CSC challenges and barriers, CSC business models and strategies and CSC best practices*. The literature diffusion according to each category is shown in Figure 7.

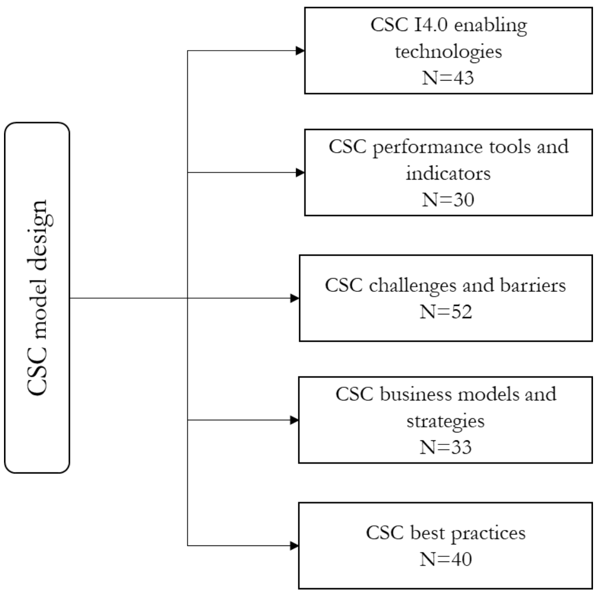

Figure 7: CSC categories distribution

The presented categories, and their analysis, are broadly discussed in Section 4.2.

3.3 CSC gaps

To obtain and analyse the main gaps encountered through the contributions, the followed methodology has proceeded distinguishing in theoretical and practical gaps. The first ones represent the open points identified by the scholars in their papers which need further investigations.

After a careful selection, relevant theoretical gaps have been identified in 107 articles out of the 198 selected ones, as shown in Figure 8.

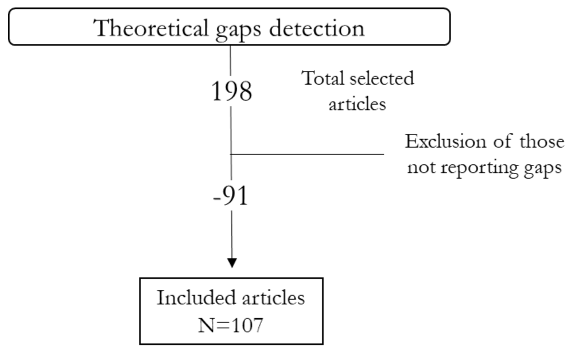

Figure 8: Theoretical gaps search strategy

According to the topics addressed by each gap, a classification has been realized gathering them in 10 categories (practical, systemic, general, barriers, benefits, perspectives, strategical, measurable, enablers and formal), as explained in detail in Section 4.3.1.

Secondly, the analysis has concentrated on the practical gaps namely the actual barriers regarding the implementation and the adoption of the CSC approach.

These limitations derive from the analysis of the papers belonging to *CSC challenges and barriers* category (52 articles). In particular, 17 barriers have been collected and grouped into 5 main categories (political, economic, social, organizational, technical) as further described in Section 4.3.2.

To obtain these impediments, the analysis has been shrunken to the 52 articles composing the *CSC challenges and barriers* category.

Firstly, a selection of articles that present a critical and systematized discussion about relevant barriers in the context of CSC has been performed, leading to 18 selected papers.
Then, 5 contributions have been discarded since the proposed practical gaps were very sector-specific preventing the creation of a universal point of view relevant for all the industries.
Therefore, 13 resulting documents have been taken as a reference for the final barriers' selection according to their diffusion and importance reported by the authors.
A graphical representation of the selection process is presented in Figure 9.

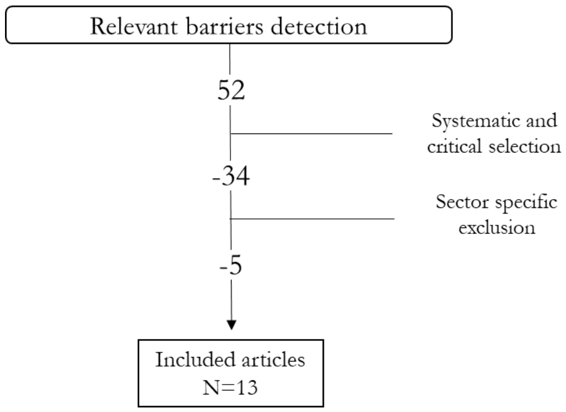

Figure 9: Practical gaps search strategy

3.4 CSC model proposition

The model proposition, desctibed in detail in Section 4.4, is grounded on the analysis of the contributions. Indeed, the literature review, the subsequent catergories classification and encountered gaps investigation represent the foundations of the model structure.
The acquired knowledge has been used to provide a practical guide to interested practitioners by leveraging on the main insights emerged from the previous analysis.
The methodology for the realization of the model follows the necessity to address each phase of the CSC transition in order to support approaching firms in every single step.
To do so, the model has been distinguished in 3 main phases: conceptualization,

development and measurement, which represent foundamental stages of the CSC process according to the obtained results.
These 3 phases are based and caractherized on the 5 CSC categories described in Section 4.2.
Each step of the model provides, according to the approaching firms' point of view, approaches, guidelines and practices to follow and warnings to be aware of during the CSC transition.
The synthesized methodology, followed for the realization of the model, is described in Figure 10.

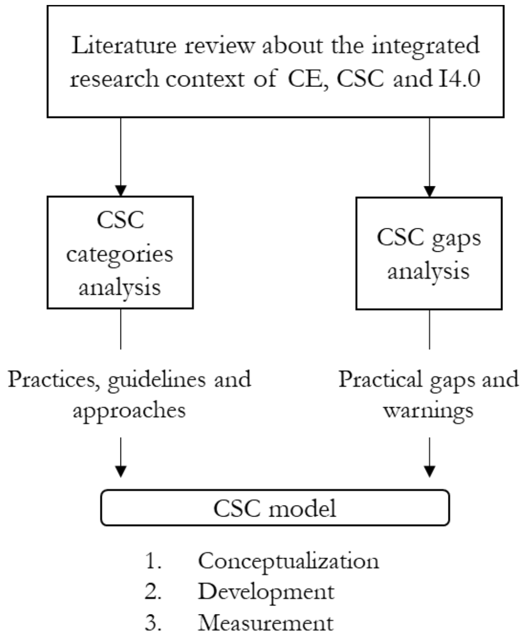

Figure 10: CSC model proposition methodology

4 Results

Firstly, the analysis of the literature review has been conducted in order to build the theory and gain recognition for the CSC model definition.
As shown in Section 4.1, all these papers have been categorized by year, journal, document type, research type (divided in theoretical assessment; analytical assessment; case studies and application cases and surveys) and industry.

Subsequently, a categorisation of the contributions has been realized to meet the main purpose of the research. Therefore, documents have been clustered into 5 main CSC categories detected through the manuscript analysis and further explained in Section 4.2.

Finally, the encountered gaps have been reported and analysed (Section 4.3). They have been divided in theoretical gaps, relative to the research gaps of the selected documents, and practical gaps. These latter collect the barriers experienced in the adoption and implementation of a CSC.

To conclude, as a result of the previous analysis, the draft of a CSC model has been proposed in Section 4.4. The aim is to guide and support approaching firms in the transition from a linear to a CSC.

4.1 Descriptive analysis

The total amount of 198 articles have revealed a relevant attention devoted to the topic domain especially in the last 3 years, as presented in the chronological distribution of the publications (Figure 11). This latter shows a growing trend in papers starting from 2016, with a peak reached in 2020 (94 articles). The degradation trend in 2021 can be explained by the fact that only the data related to the first quarter were used. Therefore, it represents just a portion of the annual documents that will be published in the following months.

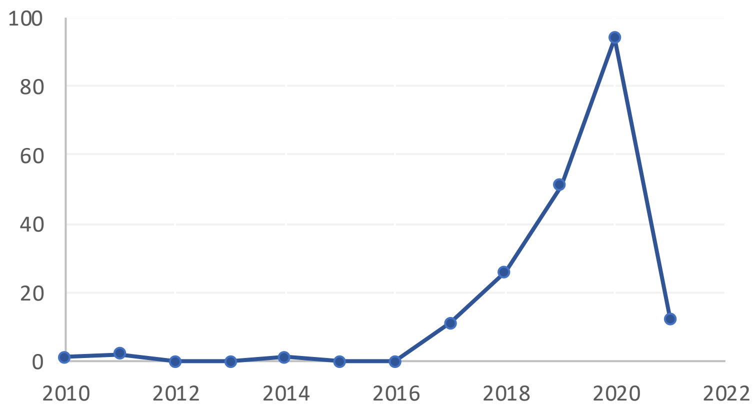

Figure 11: Historical publication trend by year

The principal publishing location of the analysed articles is the Journal of Cleaner Production (20 publications), followed by Resources Conservation and Recycling (15), Sustainability (Switzerland) (11), Sustainability (7), Production Planning and control (7), IFAC-PapersOnLine (7), Benchmarking (6), International Journal of Production research (6), Journal of Manufacturing Technology Management (6) and International Journal of Supply Chain Management (5). Figure 12 presents the distribution of selected documents according to the top 10 relevant.

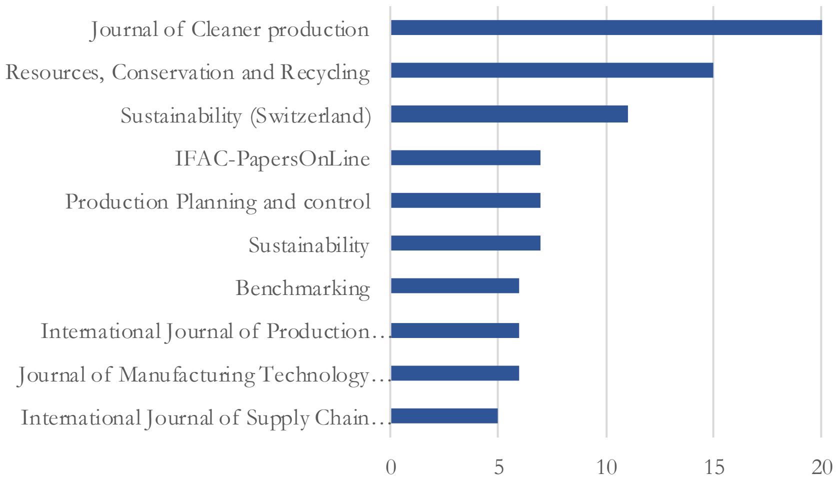

Figure 12: Top 10 journals

Despite the fact that the majority of the studies appeared in journals related to business, management and engineering, Figure 13 shows that there are many different industry fields contributing to developing the literature on the application of CSC through I4.0 technologies.

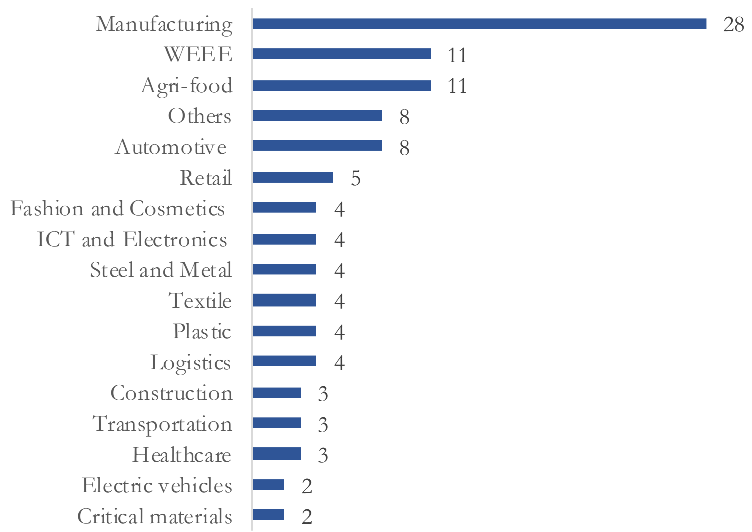

Figure 13: Top addressed Industries

Expectably, the most addressed industry is the general manufacturing one, thanks to the applications and opportunities offered by the I4.0 technologies. However, numerous contributions come even from the agri-food, WEEE and automotive industries where the search of circularity in the SC has been deeply stressed in the last years.

Finally, regarding the research type, the majority of the articles has been classified as theoretical assessments (56%) or case studies and application cases (25%), while the remaining ones as analytical assessments and surveys. A visual representation of the research types is provided in Figure 14.

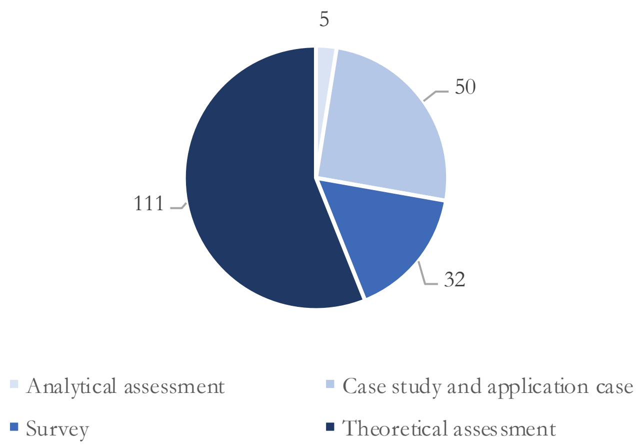

Figure 14: Research types

4.2 CSC thematic classification analysis

After having identified and selected the limited group of documents, the present section regards the thematic analysis of detailed macro topics addressed by the literature.
Indeed, articles have been gathered according to the contribution to the CSC model design in 5 main categories: *CSC I4.0 enabling technologies, CSC performance tools and indicators, CSC challenges and barriers, CSC business models and strategies and CSC best practices*, as shown in Figure 15.

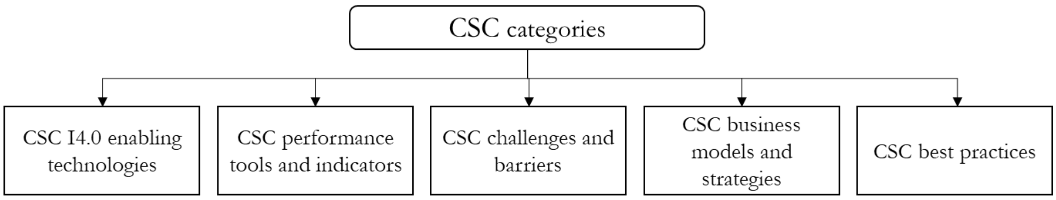

Figure 15: CSC categories

The cluster distribution is almost homogeneous highlighting the relevance and reliability of the literature analysis to the ultimate purpose of this paper.
The decided macro topics division enables and facilitates the CSC model development by providing a systematized and effective approach.
A brief description of each category is reported hereunder.

Firstly, I4.0 enabling technologies that are fostering the CSC adoption are presented in the *CSC I4.0 enabling technologies* category.
The second macro topic, *CSC performance tools and indicators*, emphasizes the importance of the performance measurement. The collected documents offer, indeed, guidelines and practical tools to achieve relevant assessments.
In the category of *CSC challenges and barriers* are gathered all the articles addressing problematic and challenging issues that may occur in the development of a CSC, particularly when this requires a considerable change from the previous organization.
CSC business models and strategies presents managerial and organization models proved to be efficient in this field.
Finally, successful case studies and practices in implementing CSC are clustered in the *CSC best practices* category.

The introducing order of the categories, which has been further adopted in the detailed analysis discussed afterwards, is not casual. Indeed, the sequence has been studied in order to enhance the understanding of the reader and the flow of the discourse.

In particular, the *CSC I4.0 enabling technologies* category has been discussed first. The reason behind lies in willingness to firstly present and explore the I4.0 technologies and their role in the research domain. In fact, all the remaining categories leverage on these technologies to foster the development of CSCs and, thus, the previous discussion will strengthen the comprehension.

The *CSC performance tools and indicators, CSC challenges and barriers* and *CSC business models and strategies* categories represent, instead, the core of the analysis and the pillars on which the development of the CSC model is based.

Lastly, as a conclusive takeaway, the *CSC best practices* category leaves to the reader examples about successful cases comprehending several insights described in the previous categories.

Firstly, the contributions, divided into the 5 CSC categories, have been analysed according to their proposed output (framework, approach, guidelines, model, methodology, tool). The numerical diffusion is provided in Figure 16. A detailed discussion for each category is, then, provided in the specific analysis presented afterwards.

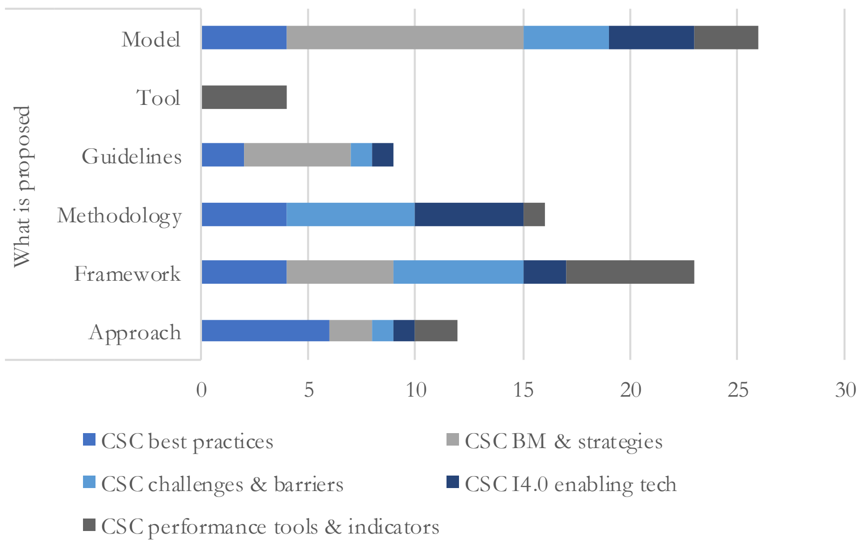

Figure 16: Proposition types

Subsequently, the documents have been clustered in the 5 categories and analysed. Five tables (Table 2, 3, 4, 5 and 6) have been built for each category with the aim of characterizing the contributions according to the life cycle phase (BoL, MoL, EoL, whole), the I4.0 technologies used (the 9 pillars described in Section 2.3), the triple bottom line layers (economic, environmental, social), the CE strategies adopted (presented in Section 2.1) and the SC typologies (green, sustainable, circular, reverse, open-loop and closed-loop).

A legend of the definitions used in the following tables is provided in Table 4 to enhance the comprehension of the reader.

BoL	Beginning of Life
MoL	Middle of Life
EoL	End of Life
IoT	Internet of Things
BDA	Big Data Analytics
AM	Advanced Manufacturing
Cl	Cloud
A rob	Autonomous Robots
Sim	Simulation
V&HSI	Vertical and Horizontal System Integration
AR	Augmented Reality
C-s	Cyber-security
In gen	In general
Eco	Economic
Env	Environmental
Soc	Social
Rec	Recycle
Reu	Reuse
Rem	Remanufacturing
Dis	Disassembly
WM	Waste Management
M&EE	Material and Energy Efficiency
CBM	Circular Business Model
CD	Circular Design
Ser	Servitization
CP	Cleaner Production
IS	Industrial Symbiosis
Cl-loop	Closed-loop
Op-loop	Open-loop

Table 4: Acronyms

	LIFE CYCLE PHASE				I4.0 TECHNOLOGIES										TRIPLE BOTTOM LINE			CE STRATEGY											SC TIPOLOGY					
AUTHORS	**BoI**	**MoL**	**EoL**	**Whole**	**IoT**	**BDA**	**AM**	**Cl**	**A Rob**	**Sim**	**V&HSI**	**AR**	**C-s**	**In gen**	**Eco**	**Env**	**Soc**	**Rec**	**Reu**	**Rem**	**Dis**	**WM**	**M&EE**	**CBM**	**CD**	**Ser**	**CP**	**IS**	**Green**	**Sustainable**	**Circular**	**Reverse**	**Cl-loop**	**Op-loop**
(CHIAPPETTA JABBOUR ET AL., 2020)					x	x									x	x	x													x				
(CWIKLICKI & WOJNAROWSKA, 2020)				x	x	x	x	x	x									x	x	x			x										x	
(RIZVI ET AL., 2020)				x	x	x	x								x	x	x	x	x	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	x	x	x		x	x	x	x					x		x	x	
(BORREGAN-ALVARADO ET AL., 2020)					x	x	x	x							x	x	x												x	x				
(SUNG ET AL., 2020)			x		x											x		x				x										x		
(GONZALEZ RODRÍGUEZ ET AL., 2020)														x					x														x	
(R. SHARMA ET AL., 2020)				x	x	x	x	x							x	x	x	x	x	x		x			x	x			x			x	x	
(ZHENG ET AL., 2020)				x	x	x	x	x	x	x	x	x			x	x	x						x		x	x								
(VAN LOPIK ET AL., 2020)												x																						
(TAKHAR & LIYANAGE, 2020)						x												x	x															x
(FRANCO ET AL., 2020)							x								x	x		x																
(NUNEZ-MERINO ET AL., 2020)					x	x	x	x	x			x			x	x																		
(RAMIREZ-PENA ET AL., 2020)					x	x	x	x	x	x	x	x	x		x	x	x						x							x				
(J. SHARMA ET AL., 2020)					x	x				x					x	x	x															x		
(DANJOU, ET AL., 2020)																																		
(RAUT ET AL., 2020)					x	x		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																	x								
(ZEKHNINI ET AL., 2020)					x	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	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									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	x	x			x												
(SAFIULLIN ET AL., 2020)					x										x	x	x					x									x		x	
(GARRIDO-HIDALGO ET AL., 2020)			x		x										x	x	x	x	x			x										x		
(DEL GIUDICE ET AL., 2020)					x	x		x							x	x	x	x	x			x	x											
(HAZEN, RUSSO, & CONFENTE, 2020)				x	x	x	x	x	x			x			x	x	x	x	x	x					x								x	
(S. GUPTA ET AL., 2019)						x		x							x	x	x	x	x	x													x	
TOTAL	**0**	**0**	**2**	**6**	**32**	**30**	**16**	**22**	**14**	**3**	**5**	**8**	**6**	**2**	**23**	**23**	**20**	**14**	**12**	**6**	**1**	**8**	**6**	**1**	**5**	**5**	**0**	**0**	**2**	**4**	**1**	**8**	**7**	**1**

Table 5: CSC I4.0 enabling technologies category analysis

4.2.1 Analysis of the *CSC I4.0 enabling technologies* category

The first CSC category, named *CSC I4.0 enabling technologies*, discusses the I4.0 enabling technologies that are fostering the CSC adoption.

Indeed, the collected documents assess the opportunities and applications of the 9 main presented technologies (Russmann et al., 2015), enhancing the technological foundations for the further categories' analysis.

The *CSC I4.0 enabling technologies* category represents the second most numerous in terms of contributions, since it gathers 43 articles. Technical considerations, indeed, are essential for the development of CSCs and, thus, in the research domain.

Concerning the proposition types, 5 papers have presented an innovative methodology, as the work by Fernández-Caramés et al. (2019) in which the design and evaluation of a UAV (Unmanned aerial vehicles) based system is presented. Findings have shown that UAVs, together with BDA, help industries in automating inventory tasks and traceability ensuring SC efficiency and effectiveness.

On the other hand, 4 contributions have proposed a model. For instance, supporting the rise of the procurement 4.0 concept, Tripathi & Gupta (2020) re-designed a procurement framework leveraging on I4.0 technologies.

Several documents have focused on helping managers to understand the importance of I4.0 in SCM (Dhamija, 2020) aggregating success and failure factors, potential and difficulties (Rejikumar et al., 2019). Moreover, R. Sharma et al. (2020) proposed a robust roadmap in the field of I4.0 highlighting the benefits in favour of the sustainability dimension.

I4.0 has been defined as a concept that focuses on automation of systems and processes, digitalization and data exchange, aimed at reducing the lead time and improving the productivity of the system (Abdirad & Krishnan, 2020).

Commonly to the entire category, Raut et al. (2020) evaluated the current adoption of I4.0 enabling technologies in the manufacturing context. The discussion framed strategies to prioritize efforts for I4.0 enabling technologies incorporation.

Among the 9 technologies defined by Russmann et al. (2015), some result more diffused and adopted than others. In particular, IoT has been addressed in the 74% of the selected articles.
IoT is a global platform of Internet-connected smart devices that strengthens the SC Information and Communication technology (ICT) infrastructure for greater internal and external integration (de Vass et al., 2020). The latter study revealed the provision of additional capabilities, visibility, intelligence and information sharing thanks to the multiple IoT forms.
Ben-Daya et al. (2019) explored the role of IoT and its impact on SCM and found limited analytical models and empirical studies.

In addition, the opportunities enhanced by the BDA technologies are discussed. For instance, Chiappetta Jabbour et al. (2020) stated that developing BDA capability has become a business priority to effectively build competitive SSC.
Oncioiu et al. (2019) studied how BDA can help Romanian SC companies assessing their experience, strategies and professional capabilities.

Despite these 2 presented technologies, IoT and BDA, that appear as the most known and adopted even in the contributions from the following categories, other technologies have been considered. Among others, Augmented Reality (AR) potentials in SCM and logistics were examined by Rejeb et al. (2020) and van Lopik et al. (2020). AR has, thus, been identified as a potential solution for enhancing business processes, improving operational efficiencies and increasing overall competitiveness.

On the other hand, several scholars have focused on AM. For instance, Jermsittiparsert & Boonratanakittiphumi (2019) examined the role of Advanced Manufacturing (AM) in improving SC performance. In particular, the results of the study showed the relationship between SC flexibility, management and performance.
Franco et al. (2020) explored the effects of AM adoption on how companies conduct business. The paper identified managerial and technological aspects to be considered when adopting AM. Nascimento et al. (2019), instead, recommended a circular model to reuse scrap electronic devices integrating reverse logistics and AM to support CE practices.

Predictably, some scholars have assessed all the proposed 9 technologies. It is the case of the systematic review about I4.0 technologies applications in the business processes of manufacturing companies (Zheng et al., 2020). In addition, Ramirez-Peña et al. (2020) conducted a study of the key enabling technologies of I4.0 aimed at obtaining a general overview.

Moreover, the jointly development of IoT, BDA, AM, Cloud and Autonomous robots has received attention. For instance, Cwiklicki & Wojnarowska (2020) identified the relationships between the CE and I4.0 demonstrating the importance of micro and meso levels application areas. While Taboada & Shee (2020) explored the role of 5G.

Several contributions are committed to present a comprehensive picture of the innovative efforts in sustaining the SCM (Ardito et al., 2019). The SCM concept was, thus, considerably discussed.

In this regards, Hazen et al. (2020) presented the CE concept in the plastic industry from a SCM perspective.

Zekhnini et al. (2020) evaluated the relationship between digital technologies and SCM identifying the major impacts.

Chauhan & Singh (2019) assessed how the emergent theme of I4.0 is considered in the context of SCM. The review provided insights into under-researched areas and highlighted the need of practical models to guide the implementation.

Gupta et al. (2020) identified and prioritized a list of key digitalization enablers that can improve the SCM. The results revealed that "big data science skills", "tracking and localization of products" and "adoption of BDA technologies and techniques" are the top 3 IT enablers to improve SC performances.

Finally, 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 industrial managers and policy makers.

Concerning the LC, 2 articles about the 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 regards, Garrido-Hidalgo et al. (2020) proposed a CSC framework for EoL management aimed at satisfying the information infrastructure requirements for the recovery of Electrical vehicle batteries.
On the other hand, 6 documents concentrate on the entire LC. However, the in dept analysis of this and the 4 other categories, demonstrates that often the inclusion of all phases can be identified as a trend rather than a serious commitment.
Indeed, concentrating on the whole LC enhances the CE practices and minimizes the impacts, leading, thus, to a positive reputation and image effect. This choice requires several efforts along the company strategy, that frequently are underestimated or not addressed.
It is important, indeed, to distinguish between a serious commitment and a more tactical inclination.
The latter tendency, when analysed in the selected literature, leads to a loss in the information about the I4.0 technologies and CE strategies demonstrating, thus, the strategic aim.
This trend is, nevertheless, not so common in this CSC category since the attention paid to the enabling technologies. Indeed, only some lacks in the CE strategies may be identified.

For what regards the TBL, 19 articles have reported the entire inclusion of the 3 layers. Among others S. Gupta et al. (2019) argued that mutual support and coordination, coupled with holistic information processing and sharing along the entire SC, can effectively create a basis for achieving the TBL. Ciccullo et al. (2021), instead, have stated that food systems are plagued by the grand sustainability challenge of food waste, which represents an urging issue from economic, environmental and social point of view.

Further analysing the selected papers, several scholars have addressed the CE strategies of WM, Material and M&EE, Circular Design (CD) and servitization.
However, the majority (6 articles) have implemented the Reuse-Recycle-Remanufacturing (3Rs) one. For instance, J. Sharma et al. (2020) explained the general aspects of food SC and its linkage in the context of 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 contribution have 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 Rodríguez et al.(2020), on the contrary, presented a new methodology to solve a CLSC management problem through a decision-making system built on Machine Learning (ML).

However, several scholars have focused on the circular SC, as the paper by Del Giudice et al. (2020) exploring the moderating role of BDA in SC relationships.

Takhar & Liyanage (2020), instead, proposed the adoption of an open loop manufacturing system through CE. The conclusions provided an assessment of how I4.0 may aid reporting needs.

Finally, Borregan-Alvarado et al. (2020) discussed I4.0 and AM tendencies in the context of Sustainable Supply Chains (SSCs).

Besides the common industries discussed in the literature review analysis, several contributions have focused on the construction sector. For instance, Danjou et al. (2020) explored the technological applications associated with I4.0 in the construction industry. In the same sector, Patrucco et al. (2020) discussed how I4.0 technologies can support process re-engineering. Finally, the logistic sector has been addressed in different occasions. Moldabekova et al. (2020), indeed, provided a systematic review of the role of ICT in logistics services. Ivanov et al. (2018), instead, stated that an extended cooperation between control engineers and SC experts may improve the performance in production and logistics systems.

	LIFE CYCLE PHASE				I4.0 TECHNOLOGIES										TRIPLE BOTTOM LINE			CE STRATEGY											SC TYPOLOGY					
AUTHORS	**Bol**	**MoL**	**EoL**	**Whole**	**IoT**	**BDA**	**AM**	**Cl**	**A Rob**	**Sim**	**V&HSI**	**AR**	**C-s**	**In gen**	**Eco**	**Env**	**Soc**	**Rec**	**Reu**	**Rem**	**Dis**	**WM**	**M&EE**	**CBM**	**CD**	**Ser**	**CP**	**IS**	**Green**	**Sustainable**	**Circular**	**Reverse**	**Cl-loop**	**Op-loop**
(MORELLA ET AL., 2020)	x				x			x							x	x		x	x				x						x					
(HOFFA-DABROWSKA & GRZYBOWSKA, 2020)				x											x	x	x													x			x	
(IVASCU, 2020)				x	x	x		x	x	x		x	x		x	x	x	x	x	x		x			x							x		
(BHAGAWATI ET AL., 2019)					x										x	x														x				
(GRUZAUSKAS ET AL., 2018)					x	x		x	x						x	x														x				
(FATORACHIAN & KAZEMI, 2020)					x	x		x	x						x	x																		
(XIE ET AL., 2020)					x	x		x							x	x		x	x															
(DE GIOVANNI & CARIOLA, 2020)					x				x						x	x			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	x	x			x									x	x		
(LUO ET AL., 2021)						x									x	x	x					x												
(ALKHUZAIM ET AL., 2021)															x	x	x	x	x			x			x			x	x					
(SHOAIB-UL-HASAN ET AL., 2021)				x														x	x	x					x									
(VEGTER ET AL., 2020)			x												x	x	x	x	x	x		x	x								x	x		
(TAHU ET AL., 2020)															x	x	x	x	x			x	x	x										
(INOUE ET AL., 2020)			x		x										x	x			x	x		x												

(ISERNIA ET AL., 2019)			x												x	x	x	x	x	x		x										x		
(DONI ET AL., 2019)															x	x		x	x	x			x			x			x					
(JAIN ET AL., 2018)															x	x	x	x	x	x		x		x	x	x		x	x		x	x	x	
(Y. KAZANCOGLU ET AL., 2018)															x	x	x	x	x	x		x	x				x		x				x	
(BRAUN ET AL., 2018)															x	x		x		x		x	x	x								x		
(LARSEN ET AL., 2018)															x	x			x				x									x		
(GENOVESE ET AL., 2017)															x	x	x		x	x				x			x			x		x	x	x
(ZHU ET AL., 2011)															x	x		x	x						x		x							
(NASIR ET AL., 2017)															x	x		x	x	x		x	x						x	x			x	
(WEI ET AL., 2014)															x	x		x				x	x						x					
(HALSTENBERG ET AL., 2017)																		x	x	x		x	x					x						
TOTAL	**1**	**0**	**3**	**3**	**11**	**8**	**2**	**8**	**5**	**2**	**1**	**2**	**2**	**1**	**25**	**24**	**12**	**17**	**19**	**12**	**0**	**15**	**11**	**4**	**5**	**2**	**3**	**3**	**8**	**5**	**3**	**8**	**5**	**1**

Table 6: CSC performance tools and indicators category analysis

4.2.2 Analysis of the *CSC performance tools and indicators* category

The category of *CSC performance tools and indicators* represents a minor contribution to the entire scientific research since it accounts for the 15% (30 articles) of the total selected. According to the results, the literature review appears deficient of documents which are covering and presenting quantitative performance metrics. Moreover, the latter issue has been discussed by many scholars in their contributions raising this gap in the domain of research. The main reason for the presented lack might be presumably found in the complex and the unprecedented purpose of defining a complete and accurate indicator able to systematically evaluate the CSC performances.

Despite their belonging to this category, only 4 out of the 30 articles have explicitly proposed a tool. Among them, just the half has defined a new KPI (Ante et al., 2018; Morella et al., 2020). In particular, Morella et al. (2020) developed a new KPI capable of measuring the impact of energy consumption on the Nakajima's 6 big losses (breakdowns, setups, minor stoppages, speed loss, quality defects and start-ups).
Ante et al. (2018) proposed a 3-like structure of KPIs to describe the performance measurement system of a lean production system. In detail, the KPIs and their supporting measurement elements were identified and characterized in a multi-level hierarchy designed to give answers at strategic, tactical and operational level.
For what regards the remaining tools, Singh et al. (2019) determined an index able to quantify the coordination of a SC for an effective benchmarking of the SC performance in the I4.0 era. The graph theoretic approach was used for evaluating the coordination index of an Indian organization SC.
Wei et al. (2014), instead, presented a performance evaluation system for green SCM focusing on Guangxi's manufacturing industry.
Eventually a common characteristic among the collected documents can be identified. The tool proposition is, in fact, a merely characteristic of specific fields such as automotive and manufacturing.

Further analysing the papers contributing to this CSC category, the TBL dimension raises a second deficiency since the 60% of the selected documents have not focused on social aspects. The social dimension of sustainability appears as a subject of minor relevance comparing with the economic and environmental ones, especially when obtaining quantitative measures is the purpose of the work.

The partial analysis of the TBL line is stressed by several scholars, Walker et al.(2021) for instance, have highlighted that the social dimension is the least assessed and integrated in the sustainability assessment and when it is included, the analysis is frequently superficial.

Moreover, among those contributions that, on the contrary, integrate social aspects, a trend is observable. The inclusion of social themes, in fact, acts as a generalizer and leads to a loss of information concerning the I4.0 technologies and/or the CE strategies.

Additionally, the SC typologies have resulted in more generic definitions (sustainable, green). It is the case of 3 examples, (Alkhuzaim et al., 2021; Genovese et al., 2017; Luo et al., 2021), acting in the agri-food industry.

Specifically, Luo et al. (2021) have proposed a conceptual framework to systematically examine food loss and waste issues within food SCs in the field of operations management.

Alkhuzaim et al. (2021) have discussed how Sustainable Supply Chain Management (SSCM) and CE performance measurement methods can be expanded. The findings suggest that the measures and approaches can help decision makers in organizations and across SCs in managing material sourcing, supplier selection, and network and CE flow designs.

Lastly, Genovese et al. (2017) compared the performances of traditional and circular production systems across a range of indicators. The paper asserted than an integration of CE principles within SSCM can provide clear advantages from an environmental point of view.

A tendency of the agri-food sector to the previously discussed characteristics is, thus, identified.

Similar considerations have been derived from the analysis of the manufacturing industry contributions. The 5 collected works appear, indeed, general in the provided information and applications, especially the articles by Zhu et al. (2011) and Larsen et al. (2018).

These latter examined, respectively, the role of environmental SC cooperation practices and how reverse SC contribute to the financial performance.

Concerning the LC phase, 3 documents have stated their commitment to the entire LC; however, the inclination to the optimal inclusion of all the phases is frequently linked to a popular trend rather than a serious application. According to this interpretation, the SSC model proposition of Hoffa-Dabrowska & Grzybowska (2020) appears strategic in the intention of presenting the benefits of SSCs. Actually, no references to the instrumental I4.0 technologies or the CE strategies were presented and the SC category was defined just as sustainable. The same trend emerges from Shoaib-ul-Hasan et al. (2021), here hints in favour of the LCA have been addressed, but no applications are provided besides the use of the 3Rs and CD strategy.

On the other hand, Ivascu (2020) proposed a hierarchical framework which integrates the goals for a sustainable development and those of I4.0 by considering the whole LC through reverse SC, taking in account several CE strategies and the technologies of IoT, BDA, Cloud and Autonomous robots. The latter four I4.0 technologies frequently recurs in the analysed CSC category. Ehie & Ferreira (2019), Fatorachian & Kazemi (2020), Gružauskas et al. (2018), Singh et al. (2019), Tjahjono et al. (2017) and Xie et al. (2020) demonstrated that, through those technologies, SCs enhance the digitalization, coordination and operation excellence.
In particular, Ehie & Ferreira (2019) developed a conceptual framework to describe the relationship among SC digitalization and performances.
Tjahjono et al. (2017) and Fatorachian & Kazemi (2020) analysed and explored the impact of I4.0 on the SC providing a thought towards SC 4.0. In detail, the later paper attempted to explore the impact of Industry 4.0 on SC performance and to conceptualise and develop findings into an operational framework underpinned by Systems Theory.
Xie et al. (2020) analysed key characteristics of intelligent SCs and proposed an indicator that monitors the SC performances.
Lastly, Gružauskas et al. (2018) highlighted how the adoption of these technologies (IoT, BDA, 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). The study provided an integrative framework for

designing and evaluating a Circular Supply Chain Management (CSCM) performance matrix. In this contribution the attention is on the CE strategies (3Rs, M&EE, CBM, CD, servitization and IS) rather than the I4.0 technologies.

Further documents have focused on the CE strategies. For instance, the servitization theme and its opportunities were profoundly discussed by Doni et al. (2019). The article, indeed, assessed the potential impact on sustainability through a sample of 208 European listed manufacturing companies by investigating corporate sustainability disclosure, environmental performance and policies.

Regarding the same industry, Halstenberg et al. (2017) presented the industrial symbiosis as a promising approach to foster the transformation towards CE. To involve businesses in IS, online platforms and input-output matching tools for facilitating the exchange of by-products have been provided by industry organizations and facilitators.

The numerical recurrence of the IoT technology in the selected documents represents more than 1/3 of the total, a result which demonstrates the potentialities of its application. Even if implemented without other I4.0 technologies, the IoT fosters the SC digitalization and optimization as highlighted by Bhagawati et al. (2019) and De Giovanni & Cariola (2020). Inoue et al. (2020) stated that when companies monitor product usage through IoT, they can make proposals to users of appropriate lifecycle options, such as reuse and remanufacturing, leading to customer retention.

Concerning the LC phase, besides the cases of the whole LC, 3 documents express their attention exclusively to the EoL (Inoue et al., 2020; Isernia et al., 2019; Vegter et al., 2020). Two of them, (Isernia et al., 2019) and (Vegter et al., 2020), focused on the WEEE sector. The link between EoL and this specific industry is not casual, being identified even previously in the *CSC I4.0 enabling technologies* category.

According to a similar interpretation, 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.

Lastly, a tendency in the adoption of CE strategies results from the analysis. Several contributions have implemented the synergic use of WM and M&EE since the material efficiency potential is assessed through the waste recovery by CE activities along the

SC (Braun et al., 2018). The latter paper, indeed, assessed the opportunities to realise material efficiency improvements within the company borders on the SC and by using CE measures.

The potential of these joint strategies is further demonstrated by other contributions which combine them with the 3Rs ones (Y. Kazancoglu et al., 2018; Nasir et al., 2017; Tahu et al., 2020; Wei et al., 2014). In detail, Y. Kazancoglu et al. (2018) proposed a new holistic conceptual green SCM performance assessment framework.

Tahu et al. (2020) analysed the effects of CE, SCM innovation and sustainability on organization performances.

Lastly, Nasir et al. (2017) demonstrated the environmental gains, in terms of carbon emissions, that can be achieved through some CE principles in the context of sustainable, green and CLSC.

	LIFE CYCLE PHASE				I4.0 TECHNOLOGIES										TRIPLE BOTTOM LINE			CE STRATEGY											SC TYPOLOGY					
AUTHORS	**BoL**	**MoL**	**EoL**	**Whole**	**IoT**	**BDA**	**AM**	**Cl**	**A rob**	**Sim**	**V&HSI**	**AR**	**C-s**	**In gen**	**Eco**	**Env**	**Soc**	**Rec**	**Reu**	**Rem**	**Dis**	**WM**	**M&EE**	**CBM**	**CD**	**Ser**	**Cp**	**IS**	**Green**	**Sustainable**	**Circular**	**Reverse**	**Cl-loop**	**Op-loop**
(KUMAR ET AL., 2021)				x	x		x	x							x	x	x	x	x			x	x		x	x		x	x			x	x	
(OZKAN-OZEN ET AL., 2020)				x	x								x		x	x	x	x	x	x				x	x								x	
(G. YADAV ET AL., 2020)				x														x	x	x												x		
(BAG & PRETORIUS, 2020)				x	x	x		x	x						x	x	x	x	x	x		x	x			x	x		x			x	x	
(PHILIP ET AL., 2020)				x	x	x				x					x	x		x	x										x					
(RAJPUT & SINGH, 2019)				x	x	x		x							x	x	x	x	x			x			x	x							x	
(CEZARINO ET AL., 2019)				x	x	x		x	x		x	x			x	x	x	x	x	x			x		x								x	
(CAÑAS ET AL., 2020)				x	x	x					x	x			x	x	x					x	x						x				x	
(PANETTO ET AL., 2019).				x	x	x	x		x			x			x	x	x																x	
(LUTHRA & MANGLA, 2018)					x	x		x	x						x	x	x													x				
(ACHARYA ET AL., 2019)					x	x		x	x																	x								
(M. SHARMA ET AL., 2020)					x	x	x	x	x			x			x	x	x	x		x		x	x							x				
(BAG ET AL., 2020)					x	x	x	x	x		x							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					x	x							x				
(PANDEY ET AL., 2020)					x			x					x																					
(PESSOT ET AL., 2020)					x	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																	

(HORVATH & SZABO, 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													x																
(MAJEED & RUPASINGHE, 2017)					x	x		x																										
(I. KAZANCOGLU ET AL., 2021)															x	x	x	x	x	x		x	x	x	x							x		
(ETHIRAJAN ET AL., 2021)															x	x	x	x	x			x											x	
(IBN-MOHAMMED ET AL., 2021)					x	x		x	x						x	x	x		x			x	x	x	x							x	x	
(I. KAZANCOGLU ET AL., 2020)				x											x	x	x	x	x	x		x		x	x					x		x	x	
(DEY ET AL., 2020)														x	x	x	x	x	x			x	x		x			x			x	x		
(FREI ET AL., 2020)															x	x	x	x		x		x	x	x								x		
(XIA & RUAN, 2020)															x	x	x	x				x		x										
(JIA ET AL., 2020)				x											x	x	x	x	x	x		x	x					x				x	x	
(KHANDELWAL & BARUA, 2020)			x												x	x	x	x	x			x			x									
(ZHANG ET AL., 2019)					x	x		x							x	x	x	x	x	x		x				x								
(PAES ET AL., 2019)															x	x	x	x				x			x			x					x	
(SEHNEM ET AL., 2019)															x	x	x	x	x			x			x			x		x			x	
(FAROOQUE ET AL., 2019)					x	x									x	x	x	x	x	x		x					x	x	x				x	
(PIYATHANAVONG ET AL., 2019)															x	x		x	x			x	x				x					x		
(Y. K. SHARMA ET AL., 2019)															x	x	x	x	x			x		x	x									
(LAPKO ET AL., 2019)			x															x					x									x	x	
(BRAZ ET AL., 2018)															x	x		x	x	x												x	x	

(MANGLA ET AL., 2018)															x	x		x	x	x		x		x		x	x	x			x			
(MISHRA ET AL., 2018)															x	x	x	x	x	x				x		x						x	x	
(ZENG ET AL., 2017)															x	x	x	x	x									x		x		x	x	
(MASI ET AL., 2017)															x	x	x	x	x	x		x					x	x	x				x	
(PARK ET AL., 2010)			x												x	x	x	x				x	x		x		x	x	x			x		
TOTAL	**0**	**0**	**3**	**11**	**29**	**25**	**7**	**19**	**13**	**2**	**4**	**5**	**5**	**1**	**39**	**38**	**35**	**31**	**25**	**16**	**0**	**24**	**15**	**9**	**14**	**7**	**6**	**10**	**8**	**6**	**2**	**16**	**19**	**0**

Table 7: CSC challenges and barriers category analysis

4.2.3 Analysis of the *CSC challenges and barriers* category

As said, the *CSC challenges and barriers* category gathers the contributions that address problematic and challenging issues occurring in the development of a CSC.
Regarding the total of 198 articles, 52 of them have been identified and grouped in this category which represents, indeed, the most numerous one in terms of articles. The latter result highlights the considerable attention paid by scholars about this topic in the research domain. As stated by Ozkan-Ozen et al. (2020), in fact, the Industry is facing a transition from the Industry 3.0 to the 4.0 one. Therefore, in the 3.5 stage, synchronized barriers of CSC and I4.0 need to be taken into consideration.

The analysed category is mainly composed by framework and methodology propositions thanks to the use of these instruments in the search, analysis and prioritization of barriers. Among all, an example of this approach is provided by Rajput & 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. The trend identified in the previous analysis of the CSC performance tools and indicators reoccurs leading to a certain generalization of the information about the technologies and/or the CE strategies. Three articles, (Jia et al., 2020; I. Kazancoglu et al., 2020; G. Yadav et al., 2020), out of the 11 identified appear to have a more strategic rather than operational intent in the inclusion of the entire LC.
The same amount of documents concentrated, instead, on the the EoL phase. No particular linkages are identified among those, unless the type of industries, all acting in the waste treating sphere, and the recycling approach (Khandelwal & Barua, 2020; Lapko et al., 2019; Park et al., 2010).

For what regards the adoption of I4.0 technologies, several contributions have analysed a jointly application. The 40% of the collected documents, indeed, referred the use of IoT and BDA with Cloud or Autonomous robots. Further investigations identify most of these cases acting in the manufacturing, automotive and agri-food sector.

The central role of BDA was stressed by many scholars. Bag & Pretorius (2020) stated that sustainable manufacturing, strongly influenced by the adoption of BDA powered with AI, is the only choice left to manufactures in the transition to a CE. BDA technology adoption can, thus, positively influence sustainable manufacturing and CE capabilities.

Moreover, Ogbuke et al. (2020) conducted a comprehensive review on BDA SCs exploring the benefits of BDA for organisations and society. BDA is seen as an enabler to reinvent the SC, having the potential to support more responsive next generations of global companies who are operating in an increasingly challenging and uncertain environment.

On the other hand, S. Yadav et al. (2020) identified the critical challenges of IoT adoption in agriculture SCs. Software issues, security issues, technical issues, IoT based infrastructure, BDA issues, proper connection of agriculture SC entities and IoT technology, developing IoT-based cloud system, automation of agriculture process based on IoT, scalability of service issues and congestion and overload issues of IoT network were identified as the 10 main challenges.

Majeed & Rupasinghe (2017) focused on the use of RFID technology to improve the operations in the fashion industry. Smarter companies and improved outbound and inbound operations enhance the reduction of costs, the improvement of customer services and the increase the return of investments.

The spread of the I4.0 enabling technologies can considerably affect all the sectors, in particular, the manufacturing one.

For instance, Sharma et al. (2020) assessed the importance of I4.0 advancements to foster SSC initiatives aimed at maximizing the economic gains, reducing the environmental impacts and contributing to the social development.

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

Lastly, Ethirajan et al. (2021) have identified the risks of promoting effective circular SC initiatives aimed at minimizing the environmental impact in the manufacturing industry. The results have showed that 'transparent process' is the most prominent risk and 'branding' is the least significant one, while financial risk is identified as most vulnerable to CSC.

Moreover, several scholars have addressed the Cyber-security (C-s) technology. In particular, Pandey et al. (2020) examined C-s risks in globalized SCs for improving the performance. Sixteen C-s risks have been categorized into three categories, namely, supply risk, operational risk and demand risk. The paper proposed a framework consisting of different cyber-attacks across the information that flows in global SCs along-with suitable mitigation strategies.
Ivanov et al. (2018) analysed how the control theory can enhance the risk analytics in cyber SCs. In the frameworks of SC, risk management, dynamics and resilience and control theoretic approaches can be considered useful tools to tackle the issues of performance achievement under operational and disruption risks.

Further analysing the papers contributing to this CSC category, several references about the future characteristics of factories can be found. This theme, in fact, raises multiple challenges that firm may face during their innovative transition.
Pessot et al. (2020) studied the extent of the transformation of European manufacturing companies towards the factory of the future by encompassing the technological, strategic, managerial and organisational perspective. Similar concepts were addressed by Panetto et al. (2019) through a summarized vision of the challenges facing the so called "industry of the future".
Their conclusion highlighted the need of models and systems to be modular and support modification and self-adaptation and of organisational structure to shape from highly centralised into more collaborative entities.

Concerning the TBL, the *CSC challenges and barriers* category, collects several approaches that understand the importance of considering a holistic meaning of sustainability. Indeed, the 65% of the selected contributions have reported the entire TBL and the 67% has addressed social issues.
Although in the I4.0 and CE literature the environmental aspects are predominant over the social ones, as stated by Cañas et al. (2020) and Sassanelli et al. (2019), the presented category seems to oppose this trend. The importance that social factors held in the challenges and barriers scenario might be a proper and coherent reasoning for that.

Therefore, documents have additionally analysed the behavioural response and impacts that the green and digital evolution can have on various stakeholders, as employees and consumers.

For instance, Acharya et al. (2019) identified challenging factor as the increasingly consumers' autonomy of choices and the retirement and turn-over of skilled workers. Liboni et al. (2019) concentrated on addressing the potential impacts of I4.0 on human resource management with a particular focus on employment, job profile and qualification, and skill requirements in the workforce.

Horváth & Szabó (2019) stated that organizational resistance of both employees and middle management levels can significantly hinder the introduction of I4.0 technologies.

A considerable attention to the presented barriers that employees and consumers might foster is, thus, suggested to be paid.

Moreover consumers related aspects were crucial in the analysis. Philip et al.' (2020) research paper was aimed at comprehending how media manoeuvre customers to indulge fast fashion, the second largest polluter industry in the world.

Princes (2020), instead, highlighted that the customer experience will be the first brand differentiator in the future. The article discussed the disruptive challenges faced by modern manufacturing industry.

Being the purpose of the contributions gathered in this category, several of them have identified and prioritized barriers. Hereunder are presented the most relevant ones according to the research domain.

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

In relation to the textile sector, Kazancoglu et al. (2021) have identified several barriers, the majority of which is related to institutions. For instance, lack of legislation for efficient CE and government support for environmental-friendly policies. The same authors classified 25 barriers under 9 categories including lack of knowledge and awareness, lack of integration and collaboration and costs (I. Kazancoglu et al., 2020).

Barriers and challenges may vary according to the sector, but also to the dimension of the company and its location.

Several scholars, indeed, have focused on the SMEs. It is the case of Dey et al. (2020) who derived the issues, challenges and strategies in the implementation of CE in SMEs. The study revealed that all CE fields of action (take, make, distribute, use and recover) of SMEs are correlated to economic performances, but only make and use are related to environmental and social ones.

Princes (2020b) developed 9 steps (preparation, organization contextual approach, leadership and management, leadership styles, time span and dynamic capabilities, marketing capabilities, process, challenges, solutions) 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 the emerging countries discovering specific barriers that, in some cases, present significant differences from the developed nations ones. Among others, Sehnem et al. (2019) stressed this duality by analysing the Critical Success Factors (CSFs) for the adoption of the CE using companies selected both from the emerging reality of Brazil and the mature Scottish one. The study suggested that companies that are more proactive towards the CE demonstrate better management of CSFs and have a top management supportive of sustainability.

Regarding the Chinese scenario, Park et al. (2010) investigated the challenges and opportunities of balancing the economic growth and environmental stewardship in the context of the electronics industry. The blended economic and environmental value can be created by adopting a SSCM approach.

Xia & Ruan (2020) identified critical barriers for the government, farmers and enterprises to develop a circular agriculture in China. The results highlighted that institutional pressure have a positively and significantly affect both on supply relationship management and SSC design. This study not only enriched the research boundary of SSCM, but also provided theoretical guidance for green production practices of eco-industrial park enterprises.

Lastly, 16 important barriers to the CSC adoption in India were determined by Mangla et al. (2018). Among others, lack of economic benefits in short-run, lack of appropriate training, coordination and collaboration among SC members were identified as the most relevant.

Further analysing the emergent scenario, many barriers have been reported. A lack of articulation of public and private spheres in the promotion of new digital BM, was identified by Cezarino et al. (2019). Poor government policies, 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 lack of collaboration among the SC actors.
Instead, the manufacturing sector in Thailand focused on the need of large investment capacity, proper training, knowledge and motivation (Piyathanavong et al., 2019).
Lack of tax relation policies and poor enforcement of rules and regulations to protect the environment emerged as the most prominent barriers of the Indian plastic industry that implements a CSCM (Khandelwal & Barua, 2020).
Moreover, Bag et al. (2020) discussed about key resources for the I4.0 adoption in South Africa such as green logistics and design, information technology, human resources and project management.
Regarding the Indian manufacturing sector, significant drivers of I4.0 have been reported. Luthra et al. (2020) identified them in government supportive policies, collaboration and transparency among SC members. The same scholars, (Luthra & Mangla, 2018), stated that organizational challenges holds the highest importance followed by the technological, strategic, legal and ethical ones.

By comparing the challenges and barriers that have emerged both from developed and developing countries, two main reflections can be presented. Firstly, similarities may be observed since both parts have identified major issues in the coordination, investments, awareness and knowledge. However, further analysing the emergent economies contributions, a specific characteristic appears. Several scholars, indeed, have stressed the centrality of government policies, incentives and regulations. This latter result appears in line with the power of governments in nascent economies and the consequent subordination of industries.

Unlike the other categories, several contributions about the logistic and procurement sector have been collected. Kaczmarek (2019) defined the I4.0 as characterized to a large extent by the use of CPS and logistics as an extremely predestined field of application.

Müller & 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. The article aimed at stressing the interconnection across the entire SC to successfully obtain the potentials predicted for I4.0.

Bienhaus & Haddud (2018) identified the impact of digitalization on procurement and its role within the area of SCM. The barriers to digitising procurement were found in the existing procedures, processes, capacities and capabilities.

Lastly, how technological changes influence buyer-supplier relationships in the context of I4.0 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. Moreover, companies consolidate their supplier base by focusing on important strategic suppliers.

For what regards the CE strategies, a considerable adoption of 3Rs, WM, M&EE and CD was registered. Many of these cases concern the textile industry and, thus, a link can be identified. Among others, Jia et al. (2020) highlighted the challenges in CE implementation and provided some suggestions for managers in the textile and apparel industry.

Moreover, the WM strategy was further discussed in detail by 2 scholars. Paes et al. (2019) conducted a SWOT analysis of the organic waste industry, highlighting major issues in logistic costs, SCM and lack of technical standards and regulations. Zhang et al. (2019), instead, identified 3 causal barriers: lack of regulatory pressures, market pressures and demands and environmental education and culture.

Concerning the SC typologies, from the analysis can be observed that several contributions have defined the SCs as closed-loop (19 articles) and reverse (16 articles). Moreover the 17% of the total selected documents have used both terms. As an example, Zeng et al. (2017) presented a conceptual model according to the paradigm of "institution-conduct-performance" underlining institutional pressures and SCM impacts.

CLSC potentialities were highlighted by many scholars. Mishra et al. (2018), for instance, selected 4 CLSC companies and assessed how these cases create value and the key challenges for their implementation. The findings stressed that each case was different. Closing loops and creating successful value propositions is, indeed, complex and requires simultaneous reconfiguration of key building blocks to ensure customer acceptance and business viability. Lapko et al. (2019) examined factors influencing CLSC for the Customer Relationship Management (CRM) development in the photovoltaic industry.

Braz et al. (2018), instead, compared the causes and mitigating factors of the bullwhip effect in CLSCs. Closing a SC was discussed as a suggestion to reduce the bullwhip effect, which could lead to positive impacts in the environmental performance of SCs. Lastly, opportunities and challenges related to these latter were discussed by Masi et al. (2017). The paper provided a discussion about the potentialities of the meso level such as eco-industrial parks and CLSC, but also the exposition to radical changes for BMs and SCs.

On the other hand, Frei et al. (2020) identified vulnerabilities, barriers and challenges to implement circular practices in reverse SCs.

Finally, the conducted research offers even insights about recent circumstances. Ibn-Mohammed et al. (2021), indeed, have outlined concrete recommendations on CE-related solutions for the global economic growth and development of the post Covid-19 world.

	LIFE CYCLE PHASE				I4.0 TECHNOLOGIES										TRIPLE BOTTOM LINE			CE STRATEGY											SC TYPOLOGY					
AUTHORS	**Bol**	**MoL**	**EoL**	**Whole**	**IoT**	**BDA**	**AM**	**CI**	**A Rob**	**Sim**	**V&HSI**	**AR**	**C-s**	**In gen**	**Eco**	**Env**	**Soc**	**Rec**	**Reu**	**Rem**	**Dis**	**WM**	**M&EE**	**CBM**	**CD**	**Ser**	**CP**	**IS**	**Green**	**Sustainable**	**Circular**	**Reverse**	**Cl-loop**	**Op-loop**
(SUN ET AL., 2020)				x			x									x		x				x											x	
(LU ET AL., 2020)					x	x		x	x						x	x	x								x		x		x					
(DEV, SHANKAR, & QAISER, 2020)				x	x		x	x							x	x	x	x	x	x		x					x					x	x	
(GARCIA-MUIÑA ET AL., 2018)				x	x	x	x	x	x						x	x	x	x	x	x		x		x	x	x						x		
(LOPES DE SOUSA JABBOUR ET AL., 2018)				x	x		x	x							x	x		x	x	x												x		
(DEV, SHANKAR, & SWAMI, 2020)			x		x			x							x	x		x	x	x									x			x	x	
(TOZANLI ET AL., 2020)			x		x				x						x	x	x	x	x	x	x											x	x	
(MANAVALAN & JAYAKRISHNA, 2019A)					x	x		x					x		x	x	x	x	x	x			x						x	x		x	x	
(TOMBIDO ET AL., 2018)			x		x			x										x	x	x												x	x	
(VICTOR ET AL., 2020)			x		x																												x	
(MBOLI ET AL., 2020)				x	x		x	x								x		x	x	x		x	x	x	x							x	x	
(GHOSH ET AL., 2020A)					x	x	x	x	x				x		x	x		x	x	x			x				x		x	x			x	
(HAHN, 2020)					x	x	x		x									x								x						x		
(ZANGIACOMI ET AL., 2020)					x	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																				x								
(GARAY-RONDERO ET AL., 2019)					x	x		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	x	x	x		x										x		
(ASDECKER & FELCH, 2018)					x																													
(HUSSAIN & MALIK, 2020)					x	x									x	x	x	x	x	x			x	x	x			x		x		x	x	
(GONZÁLEZ-SÁNCHEZ ET AL., 2020)					x	x	x	x	x			x	x		x	x	x	x		x		x	x	x	x						x	x	x	
(POHLMANN ET AL., 2020)					x										x	x	x	x	x			x	x					x		x				
(HAZEN, RUSSO, CONFENTE, ET AL., 2020)					x		x								x	x	x	x	x	x		x				x				x		x	x	
(DUBEY ET AL., 2019)															x	x	x							x						x			x	
(ÜNAL ET AL., 2019)															x	x	x	x	x			x	x	x	x	x	x	x						
(CARDOSO DE OLIVEIRA ET AL., 2019)															x	x		x	x						x		x		x	x		x		
(LÜDEKE-FREUND ET AL., 2019)							x								x	x	x	x	x	x				x				x		x		x	x	
(GEISSDOERFER ET AL., 2018)															x	x	x	x				x	x	x	x								x	
(XIAO & ZENG, 2017)															x	x	x										x	x		x				
(WINKLER, 2011)															x	x		x	x			x			x		x			x			x	
TOTAL	**0**	**0**	**4**	**5**	**23**	**14**	**10**	**15**	**8**	**1**	**0**	**2**	**3**	**0**	**22**	**24**	**17**	**21**	**17**	**14**	**1**	**11**	**8**	**8**	**9**	**5**	**7**	**5**	**5**	**10**	**1**	**17**	**17**	**0**

Table 8: CSC business models and strategies category analysis

4.2.4 Analysis of the *CSC business models and strategies* category

As previously discussed, this category proposes innovative BMs and business strategies to foster the adoption of CSCs. Like the *CSC performance tools and indicators* category, it accounts only for the 17% of the total selected articles, since it gathers 33 contributions.

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 that defines the essential components of shaping the new digital SC.

Lüdeke-Freund et al. (2019) conducted an analysis of 26 current CBMs defining the major Business Model (BM) dimensions and identifying the specific characteristics.

Instead, a large majority of contributions have presented managerial and organizational strategies. For instance, Lu et al. (2020) examined the Carroll's pyramid model in SMEs as an effective business strategy for organizational performance enhancement in industries of developing countries. The obtained outcomes of this study have confirmed that the inclusion of I4.0, Cleaner Production (CP) and CE concepts in SME sector provides a synergic business opportunity.

Ghosh et al. (2020) reflected about which strategy should firms adopt and when does each greening effect will benefit SCs. Among other results, was found that in the presence of a dominant retailer and competing manufacturers, the retailer shares more greening cost with the manufacturer than the corresponding decentralized channel.

Zangiacomi et al. (2020) presented a multiple business strategies analysis aimed at investigating managerial perspectives about investments, awareness and knowledge sharing. The results proposed, in terms of key challenges, common mistakes and best practices according to the level of digital implementation.

Preindl et al. (2020) research focused on the impact of I4.0 and digital transformation on information sharing and decision making across the SC. The findings were threefold: technological interface standards to enable the communication along the SC are missing, the impact of I4.0 and digital transformation is highly connected to the information sharing and companies' preparations for these impacts are different.

Mihardjo et al. (2020) assessed the impact of co-creation strategies as part of digital transformation in I4.0 on SCM. The paper indicated that these strategies have emerged as a key to focus on developing customer experience and providing distinctive capabilities.
Finally, Ünal et al. (2019) investigated the managerial practices that companies can implement in order to design CBMs and to capture value from them.

Regarding the proposition typology, the majority of documents are classified as models (11 articles), while 5 contributions have proposed guidelines. This result is in line with the definition of the category and its final aim to discover and collect BMs and strategies.
Guidelines, instead, are usually strategic advices to follow; for instance, a pathway to attain market leadership through the effective use of business analytics (Omar et al., 2019).

For what concerns the TBL, the social perspective appears quite relevant in the domain since the 52% of selected articles have included it in the 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). The research, in fact, stressed that it is necessary to focus on the cost of the socially influenced operations to reach the operations excellence of sustainable reverse logistics.

Further analysing the category, the LC has been entirely analysed in 5 contributions, of which one appears more in line with the previously presented trend than committed to its adoption. However, a detected common characteristic of these articles concentrating in the whole LC lies in the jointly implementation of the 3Rs strategy, further discussed afterwards.
On the other hand, the implementation of the IoT technology represents the 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-enabled disassembly to order system to determine the optimal trade in to upgrade policy.

The considerable adoption of I4.0 technologies is relevant in this category. Indeed, Lopes de Sousa Jabbour et al. (2018) proposed a pioneering roadmap to enhance the application of CE principles in organisations by means of I4.0 approaches.

Moreover, the IoT has been identified as the most diffused technology since it is present in the 70 % (23) of the collected articles. Manavalan & Jayakrishna (2019) stressed this trend by exploring the potential opportunities available in IoT embedded SSCs for I4.0 transformation. A framework for assessing the readiness of SC organization was introduced to meet the requirements of the 4th industrial revolution. Mboli et al. (2020) proposed an IoT enabled decision support system for CBMs that effectively allows tracking, monitoring and analysing products in real time with the focus on residual value.

Moreover, 13 contributions have jointly implemented the IoT and BDA technologies while 10 articles: IoT, BDA, AM and/or Cloud ones. For instance, Hahn (2020) used the theoretical lens of SC innovation to investigate the implications of I4.0 on SCM. The AM technology potentialities were discussed by Sun et al. (2020) focusing on the duality of virgin and recycled materials in 3D Printing (3DP).

On the other hand, Sundarakani et al.(2019) defined Cloud computing as a technology that increases the competitiveness, elasticity, flexibility and maximises the utilization of resources.

CE initiatives are taking hold across both developed and developing nations. Central to these initiatives is the reconfiguration of the core SCM process that underlines current production and consumption patterns (Hazen, Russo, Confente, et al., 2020). Regarding the CE strategies, indeed, this category reports a majoritarian use of 3Rs, since 13 articles have adopted it. Among others, Dubey et al. (2019) proposed a theoretical framework to explain how the top management commitment mediates between external pressures and supplier relationship management practices for CE. Pohlmann et al. (2020) studied the role of focal companies for achieving Sustainable Development Goals (SDGs) in a Brazilian food SC.

Moreover, 4 contributions have jointly implemented M&EE, WM, CD and CBM. While the first 3 strategies result as considerable diffused in all the analysed categories, the CBM one is usually less frequent. However, the *CSC business models and strategies* category is by definition oriented to the search and identification of CBM; the outcome was, thus, foreseeable.

In this regard, Geissdoerfer et al. (2018) discussed the sustainability performance of CBMs and CSCs necessary to implement the CE concept on an organisational level

and proposed a framework to integrate CBMs and CSCM towards a sustainable development.
Garcia-Muiña et al. (2018) explored the phases of the transition from a linear to a CE through the design of a new CBM and provided a procedure for introducing the principles of sustainability (3 layers of the TBL) in a manufacturing environment through the design of a new CBM.

Concerning the 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, & Swami (2020) attempted to model the reverse logistics and examined how product diffusion dynamics in the market affect the economic and environmental performances of an inventory and production planning system.
Tombido et al. (2018) reviewed the entry and use of third parties in reverse logistics.
Victor et al. (2020) proposed a CLSC model that meets the sales and collection centre demands and maximizes the total profit by indicating processing to be applied to EoL collected products.
Winkler (2011) stated that many negative environmental impacts, such as waste, energy consumption, transport processes and packaging can be avoided by establishing closed-loop production systems.
Despite the majority of reverse and CLSCs, some scholars have focused on circular ones. Among others, Hussain & Malik (2020) presented a framework for CSCs and sustainable performances as a combination of process facilitators and persuasive organizational narrative that enables organization to embrace the CE practices.
González-Sánchez et al. (2020) studied CSCs by using the main theoretical perspectives of strategic management. Four dimensions have been identified to support the development of these new SCs: greater relationships, adaption of logistics and organizational, disruptive and smart technologies and functioning environment.

Moreover, a trend of articles focusing on the logistics sector can be identified. For instance, Facchini et al. (2020) presented the application of a maturity model for logistics 4.0 able to identify the level of maturity of companies implementing I4.0 technologies in their logistics processes.

Asdecker & Felch (2018) developed a model to describe the *status quo* of digitalization efforts in outbound logistics, creating a corporate vision for delivery logistics excellence and providing guidance on the development path.
Finally, Pekarcíková et al. (2019) extended the knowledge base in the area of demand-driven supply logistics in the context of I4.0 and verified the processed theoretical knowledge through a case study. The article dealt with the issue of SCM reflecting demand behaviour using the methodology Demand driven MRP system.

To conclude, 2 articles have focused on emerging economies highlighting, as previously discussed in the *CSC challenges and barriers* category, the importance of governmental instruments. In this sense, Cardoso de Oliveira et al. (2019) verified how formal and informal instruments of governance influence the induction of green practices in a green network located in Brazil.
Xiao & Zeng (2017) highlighted that institutional pressure have a positively and significant effect both on supply relationship management and SSC design.

	LIFE CYCLE PHASE				I4.0 TECHNOLOGIES										TRIPLE BOTTOM LINE			CE STRATEGY											SC TIPOLOGY					
AUTHORS	**BoL**	**MoL**	**EoL**	**Whole**	**IoT**	**BDA**	**AM**	**Cl**	**A Rob**	**Sim**	**V&HSI**	**AR**	**C-s**	**In gen**	**Eco**	**Env**	**Soc**	**Rec**	**Reu**	**Rem**	**Dis**	**WM**	**M&EE**	**CBM**	**CD**	**Ser**	**CP**	**IS**	**Green**	**Sustainable**	**Circular**	**Reverse**	**Cl-loop**	**Op-loop**
(KINTSCHER ET AL., 2020)			x		x				x						x	x		x	x	x														
(WANG & ZHANG, 2020)						x									x	x	x	x	x	x			x	x										
(GARRIDO-HIDALGO ET AL., 2019)			x		x			x							x	x		x	x	x		x				x						x		
(BELAUD ET AL., 2019)				x	x	x									x	x	x					x												
(DAÚ ET AL., 2019)					x			x							x	x	x	x	x			x	x							x				
(JENSEN & REMMEN, 2017)			x		x										x	x	x	x	x	x		x			x								x	
(MASTOS ET AL., 2020)			x		x	x				x					x	x	x	x	x			x	x						x	x				
(BLÖMEKE ET AL., N.D.)			x		x	x			x						x	x	x	x	x	x												x	x	
(BAGALAGEL & ELMARAGHY, 2020)			x											x	x	x	x		x	x													x	
(MANAVALAN & JAYAKRISHNA, 2019B)				x	x										x	x	x	x	x	x		x	x					x		x			x	
(SHAO ET AL., 2021)				x	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														x												
(F. MULLER 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		x	x			x						x						
(MARANESI & DE GIOVANNI, 2020)				x			x					x			x	x	x	x	x			x	x		x	x		x			x	x	x	
(BRESSANELLI ET AL., 2020)				x	x	x		x							x	x	x	x	x	x	x	x	x		x	x						x	x	
(CASSOL & SELLITTO, 2020)															x	x	x					x	x											
(JULIANELLI ET AL., 2020)			x		x										x	x	x	x	x	x		x	x					x				x	x	
(NANDI ET AL., 2020).															x	x	x	x	x	x			x	x									x	
(VAN ENGELAND ET AL., 2020)															x	x	x	x	x	x		x										x		
(SANTANDER ET AL., 2020)							x								x	x		x	x	x		x										x	x	
(PINTO & DIEMER, 2020)			x															x	x				x									x	x	
(KÜHL ET AL., 2019).					x													x	x	x			x	x	x	x						x	x	
(CASTIGLIONE & ALFIERI, 2019)															x	x	x	x	x			x	x					x						
(RIPANTI & TJAHJONO, 2019)															x	x	x	x	x	x		x	x	x	x							x	x	
(XAVIER ET AL., 2019)															x	x	x	x	x													x	x	
(NIU ET AL., 2019)					x	x		x	x		x	x						x		x		x											x	
(ISLAM & HUDA, 2018)			x															x	x	x												x	x	
(DE ANGELIS ET AL., 2018)															x	x	x	x		x			x	x	x						x		x	x
(HONG ET AL., 2018)															x	x	x													x				
(HAHLADAKIS & IACOVIDOU, 2018)				x														x	x	x		x											x	
(BERNON ET AL., 2018)															x	x		x	x	x			x		x							x		
(GAUSTAD ET AL., 2018)			x												x	x		x	x	x		x	x		x	x							x	
(HERCZEG ET AL., 2018)															x	x	x					x	x				x	x						
(MULROW ET AL., 2017)															x	x	x		x			x		x			x	x					x	
TOTAL	**0**	**0**	**10**	**7**	**20**	**8**	**4**	**12**	**6**	**3**	**2**	**2**	**1**	**1**	**30**	**28**	**22**	**26**	**26**	**20**	**1**	**21**	**18**	**6**	**8**	**5**	**2**	**7**	**1**	**4**	**2**	**13**	**19**	**1**

Table 9: CSC best practices category analysis

4.2.5 Analysis of the *CSC best practices* category

Successful case studies and practices in implementing CSC are clustered in this *CSC best practices* category, gathering 40 articles out of the 198 selected.

It appears almost equally divided in the different types of propositions reporting 6 approaches, 4 frameworks, 4 methodologies and 4 models.

The work by Kuo et al. (2021) represents an example of the first type of proposition developing a material resource management and allocation approach among the SC members, based on the information sharing.

Shao et al. (2021), instead, have proposed a multistage implementation framework that highlights the organizational enablers such as culture, cross-functional approach and continuous improvement activities.

On the other hand, Hetterscheid & Schlüter (2019) presented, through 2 use cases of a German steel company, a methodology for the design of CPS regarding the planning and control of SC processes.

Lastly, Chandriah & Raghavendra (2020) proposed an analytical model where predictive optimization is carried out towards bridging the gap between supply and demands in SC 4.0.

A peculiarity in opposition to all the other categories can be identified. Indeed, concerning the LC phase, have been collected more EoL contributions (11 articles) than the whole LC ones (7 articles). The reason behind this opposite trend might be found in the presence of sectors particularly suited to manage EoL phases. Three articles, in fact, are part of the WEEE industry, as the example by Bagalagel & ElMaraghy (2020) that presented an advanced manufacturing-remanufacturing system to demonstrate the potentials of I4.0 principles for improving the value recovery of used products.

The remaining contributions can be classified in electrical vehicles, metal and raw material sectors.

Concerning the whole LC papers, the majority appears strongly committed to the purpose. Indeed, the generalizer principle in this category is, thus, not so frequent. Therefore, best practices are related to a committed adoption to the entire LC rather than a mere strategic approach.

Moreover, most cases are part of the textile industry. For instance, Tedesco & Montacchini (2020) described the LC approach potentials for the development of new building products in the textile industry both in relation to the SC processes and to pre and post consumption waste. In particular, the paper highlighted the methodological "grave to cradle" logic in which the waste from one process becomes a new resource for another.

For what regards the TBL, the 53% of the selected articles have focused on all the 3 fundamental aspects of sustainability. For instance, Manavalan & Jayakrishna (2019) analysed a case of a SC organization willing to meet the I4.0 requirements and enable CE highlighting the opportunities available in the transformation from linear to CE.
However, several contributions only focus on parts of the TBL, as the example by Müller et al. (2019), where trends towards the smart wood SC and concrete I4.0 applications were identified considering socio-economic challenges.

The I4.0 technologies are considerably diffused in the collected best practices. Several scholars, indeed, have stressed their importance.
I4.0 is seen as a contribution to distributed manufacturing systems, real time information and, therefore, competitiveness and efficiency (Wang & Zhang, 2020).
Frankó et al. (2020) presented a novel, reliable and scalable solution for asset tracking, supporting global asset management for I4.0.
IoT appears to be the most adopted technology since the 50% of the category articles have referred to its opportunities.
For instance, Mastos et al. (2020) provided evidence of an IoT solution impact on the SSCM performance demonstrating that I4.0 solutions have the potentials to improve the economic, environmental and social sustainability.
Khan et al. (2020) studied how IoT and blockchain applications enhance safety and transparency in food SCs.
Finally, Jensen & Remmen (2017) stated that IoT and extended product service systems are fundamental requirements for becoming a sustainable manufacturer. The paper analysed how different product stewardship and EoL strategies can support the CE in the context of CLSCs.
Contributions concentrating on the jointly application of IoT and BDA have been reported. Among the 7 identified articles, Belaud et al. (2019) developed an approach

that integrates big data to improve sustainability management in SC design with the aim of valorising agricultural waste.
Moreover, the use of Cloud technology is very diffused in the category. Seven papers have discussed about it and 12 have referred to a jointly adoption with IoT. For instance, Garrido-Hidalgo et al. (2019) proposed an end-to-end solution for reverse SCM based on cooperation between different IoT communication standards, enabling cloud-based inventory monitoring.
Avventuroso et al. (2017) considered SC and related data management within an integrated vision of the product LC management implemented through a proper I4.0 unified approach.

Regarding the CE strategies, the 3Rs one is present in 17 contributions. This diffusion is in common with the previously discussed categories. An example of those articles is the work by Nandi et al. (2020) presenting the benefits of SC collaboration and infrastructure components.
Further analysing the recycling strategy, several documents have referred to the concept of Recycling 4.0. For instance, (Blömeke et al., 2020) concentrated on electrical vehicles relying on Recycling 4.0 to digitalize process with a focus on EoL stages. In the same sector, Kintscher et al. (2020) presented an approach to study how I4.0 can be integrated into the recycling process, leading to Recycling 4.0.
Moreover, the jointly implementation of WM and M&EE or CD and servitization is common in this domain of research. Kühl et al. (2019), for instance, identified how the implementation of different SC integration strategies oriented towards raw material self-sufficiency and resource ownership retention could affect circularity.
Finally, several contributions have focused on the Industrial Symbiosis (IS) strategy. Among others, Herczeg et al. (2018) investigated IS from a SC collaboration perspective, deriving propositions on the organizational and operational requirements related to SC integration and coordination practices.
Mulrow et al. (2017) proposed a framework for the development of facility-scale IS with symbiotic interfirm relationships in the context of CLSCs.
Moreover, Maranesi & De Giovanni (2020) discussed the CE opportunities in the CSC inclusion of eco-innovations and IS.

Castiglione & Alfieri (2019) focused on eco-industrial parks, industrial areas where firms collaborate to reduce pollution and waste by sharing resources, considering practical SCM implications.

WM and remanufacturing are strategies that have proved to be linked with reverse and CLSCs.
Indeed, the review by Van Engeland et al. (2020) examined an integrated point of view on reverse logistics and waste management aimed at a better integration. More specifically, the paper provided a concise, but complete overview of the efforts performed in in waste reverse SCs by means of combinatorial optimization models.
Niu et al. (2019) explored the impact of design for remanufacture in CLSCs by developing a modelling research framework of CLSC operations decision-making.
Finally, Xavier et al. (2019) reviewed the main CE solutions for e-waste management in CLSCs highlighting the importance of recovering and classifying critical materials.

The latter SC typologies, reverse and closed-loop, are considerably spread. Indeed, the 48% of the selected documents have mentioned CLSCs, as the example of Santander et al. (2020) exploring the economic and environmental feasibility of a distributed plastic recycling approach in the CLSC network.
The 33%, instead, have addressed reverse SCs. Among others, Bernon et al. (2018) presented a conceptual framework that supports the adoption of CE values with reverse logistics operations.
Julianelli et al. (2020) provided a framework that represents the relationship between the CSFs and revere logistics in the context of CSC.
In addition, 9 contributions have jointly applied the 2 presented SC typologies. Ripanti & Tjahjono' (2019) work was aimed at unveiling the CE values to provide tenets potentially used for designing CLSCs and reverse logistics. The paper contributed to the redefinition, identification and implementation of the CE values as a basis for the transformation from a traditional to a more circular SC.
Instead, Islam & Huda (2018) stated that reverse logistics and CLSC are integral parts of the holistic waste management process, providing the case of WEEE.
Despite these 2 SC typologies, authors have even discussed about sustainable and circular SCs.

Respectively, Hong et al. (2018) investigated the impact of SSCM practices on SC dynamic capabilities and enterprise performance. The results revealed that SSCM practices have a significant positive effect on SC dynamics capabilities and on the 3 dimensions of sustainability (economic, environmental and social).
De Angelis et al. (2018) presented preliminary propositions concerning the implications of the CSCs development.

Further analysing the selected documents, a predominance about certain sectors can be identified. Indeed, 6 contributions are part of the WEEE industry, as the example by Bressanelli et al. (2020) investigating, through a multiple case study research, how CE has been adopted in the household appliance industry. Two main patterns of CE emerged from the cases: incremental and radical adoption. Incremental adoption patterns are based on design strategies focused on reduce and recycle, mainly led by manufacturers. Radical adoption patterns are, instead, focused on disruptive practices based on reuse, remanufacture, servitization and sharing, where digital 4.0 technologies serve as enablers.

Steel, metal and critical materials sectors are considerably diffused in the research domain. In this regards, Pinto & Diemer (2020) identified how the implementation of different SC integration strategies oriented towards raw material self-sufficiency and resource ownership retention could affect circularity. The results brought to light that different approaches can be environmentally and strategically promising, as well as able to drive improvements in raw material self-sufficiency and in resource ownership retention.
Gaustad et al. (2018) examined how certain firms assess and monitor their vulnerability to critical material SC issues and provided specific business examples for integrating circularity strategies. Results indicated that risk reduction potentials could be gained from the implementation of these strategies, specifically recycling.
Moreover, attention has been given to electrical vehicles, agri-food and plastics industries. Concerning the latter, Hahladakis & Iacovidou (2018) underpinned the need for research that integrates systemic thinking with technological innovations and regulations at all stages of the SC.

To conclude, as highlighted in the previously discussed CSC categories, a commitment to the analysis of emerging economies is present. Among others, Daú et al. (2019) focused on the healthcare SSC 4.0 of Rio de Janeiro by proposing a CE transition conceptual framework. The research concluded that the union among the triple bottom line, Industry 4.0, and the corporate social responsibility allows the transition from the linear model to the circular model and can improve the sustainable healthcare SC 4.0.

The importance of relationships among the tiers to implement a sustainable BM was, instead, addressed by Cassol & Sellitto (2020) studying a cosmetics company in Brazil.

4.3 CSC gaps analysis

As previously presented, this section describes and analyses the encountered gaps. The decision of analysing both the theoretical and the practical gaps lies in the willingness to ensure a solid investigation base to further enhance the development of the CSC model.

Firstly, the theoretical gaps identified by the scholars in their papers are introduced to report open points needing further investigations in the CSC domain. They represent the collected lacks of content in the literature and thus, highlight the needed focus for future contributions about CSC.
According to the topics addressed by each gap, a classification has been realized gathering them in 10 categories, as explained in detail in the next paragraph.

Secondly, the analysis concentrates on the practical gaps namely the actual barriers addressed by the authors regarding the implementation and the adoption of the CSC approach.
These limitations, deriving from the analysis of the papers and belonging to *CSC challenges and barriers* category (52 articles), have been further detailed and gauged with a critical perspective, regardless the industry affiliation.
In particular, 17 barriers have been collected and grouped into 5 main categories.

4.3.1 Theoretical gaps

Relevant theoretical gaps have been identified in 107 articles out of the 198 selected ones. By referring them to the CSC categories of the previous analysis, the category contributing more is the *CSC challenges and barriers* (63%) one.

To systematise the discussion, the reported gaps have been gathered in 10 categories, ordered according to the decreasing diffusion rate.

- Practical gaps (G1): deficiency of solutions, implementations, techniques, initiatives and solutions to practically enhance the implementation;

- Systemic/integration gaps (G2): lack of a systemic approach able to comprehend and integrate all the 3 topics of the research context (I4.0, CE, CSC);
- Theoretical/general gaps (G3): lack of researches, studies, evolution of science, knowledge and theoretical understanding about general concept related to CSCs;
- Gaps about barriers/risks/treats (G4): lack of barriers, risks and treats in CSC research domain;
- Gaps about potentialities/benefits (G5): deficiency of the benefits presentation which adopting a CSC can lead to;
- Gaps about perspectives (G6): various perspectives not analysed in detail, for instance the social related one;
- Strategical/business-based gaps (G7): lack of strategical approaches, managerial discussion, systemic management and strategic plan;
- Measurable gaps (G8): metrics, indicators, evaluations and measurable effects missing in the context of CSC;
- Gaps about enablers (G9): articles concentrating on the main enablers such as technologies are deficient in the literature;
- Formal gaps (G10): formal identifications, definitions, classifications and standardization absent in the literature research domain.

Besides this categorization, many contributions have stressed more than one gap simultaneously.

A table presenting the diffusion and characterization of the CSC categories in respect to the identified gap types is displayed in Table 10.

	AUTHORS	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10
CSC I4.0 ENABLING TECHNOLOGIES	(CHIAPPETTA JABBOUR ET AL., 2020)			x						x	
	(CWIKLICKI & WOJNAROWSKA, 2020)	x	x							x	
	(BORREGAN-ALVARADO ET AL., 2020)		x	x							
	(GONZALEZ RODRIGUEZ ET AL., 2020)	x	x								
	(ZENG ET AL., 2017)	x	x								
	(FRANCO ET AL., 2020)	x			x	x					
	(NUÑEZ-MERINO ET AL., 2020)		x	x							
	(RAMIREZ-PEÑA ET AL., 2020)		x				x				
	(J. SHARMA ET AL., 2020)			x							
	(DANJOU ET AL., 2020)	x									
	(RAUT ET AL., 2020)	x								x	
	(PATRUCCO ET AL., 2020)							x			
	(ABDIRAD & KRISHNAN, 2020)			x							
	(ZEKHNINI ET AL., 2020)		x		x						
	(TIWARI, 2020)	x	x								
	(MOLDABEKOVA ET AL., 2020)	x									x
	(DE VASS ET AL., 2020)	x				x					
	(CHAUHAN & SINGH, 2019)			x							x
	(ONCIOIU ET AL., 2019)			x							
	(ARDITO ET AL., 2019)		x							x	
	(BEN-DAYA ET AL., 2019)		x			x					
	(JERMSITTIPARSERT & BOONRATANAKITTIPHUMI, 2019B)			x						x	
	(BARATA ET AL., 2018)				x		x				
	(CICCULLO ET AL., 2021)	x									
	(DEL GIUDICE ET AL., 2020)		x				x			x	
CSC PERFORMANCE TOOLS AND INDICATORS	(MORELLA ET AL., 2020)			x					x	x	x
	(IVASCU, 2020)	x								x	
	(GRUŽAUSKAS ET AL., 2018)	x					x				
	(XIE ET AL., 2020)								x		
	(DE GIOVANNI & CARIOLA, 2020)		x						x	x	
	(EHIE & FERREIRA, 2019)									x	
	(SINGH ET AL., 2019)								x		
	(WALKER ET AL., 2021)	x	x				x		x		
	(LUO ET AL., 2021)	x				x			x		
	(ALKHUZAIM ET AL., 2021)								x		
	(DONI ET AL., 2019)				x	x			x		
	(JAIN ET AL., 2018)			x					x		
	(Y. KAZANCOGLU ET AL., 2018)		x				x		x		
	(GENOVESE ET AL., 2017)			x							
	(HALSTENBERG ET AL., 2017)	x									x

CSC CHALLENGES AND BARRIERS	(KUMAR ET AL., 2021)		x		x						
	(OZKAN-OZEN ET AL., 2020)		x		x						
	(G. YADAV ET AL., 2020)	x			x	x					
	(M. SHARMA ET AL., 2020)						x				
	(BAG ET AL., 2020)	x									
	(PRINCES, 2020B)	x	x								
	(LUTHRA ET AL., 2020)		x	x							
	(PANDEY ET AL., 2020)				x		x				
	(VEILE ET AL., 2020)	x	x					x			
	(S. YADAV ET AL., 2020)	x	x		x						
	(OGBUKE ET AL., 2020)	x									
	(HORVÁTH & SZABÓ, 2019)				x	x					
	(KRYKAVSKYY ET AL., 2019)				x	x					
	(KACZMAREK, 2019)				x	x			x		
	(LIBONI ET AL., 2019)		x				x				
	(JERMSITTIPARSERT & BOONRATANAKITTIPHUMI, 2019A)		x	x							
	(BIENHAUS & HADDUD, 2018)				x	x				x	
	(J. M. MÜLLER & VOIGT, 2018)			x							
	(ETHIRAJAN ET AL., 2021)	x			x						
	(DEY ET AL., 2020)	x									
	(JIA ET AL., 2020)		x				x				
	(KHANDELWAL & BARUA, 2020)	x	x								
	(ZHANG ET AL., 2019)							x			
	(PAES ET AL., 2019)		x								
	(SEHNEM ET AL., 2019)	x				x			x		
	(FAROOQUE ET AL., 2019)	x					x				
	(PIYATHANAVONG ET AL., 2019)	x									
	(Y. K. SHARMA ET AL., 2019)	x									
	(LAPKO ET AL., 2019)		x	x							
	(BRAZ ET AL., 2018)			x							
	(MANGLA ET AL., 2018)				x						
	(MISHRA ET AL., 2018)	x	x								
	(ZENG ET AL., 2017)				x	x	x				
CSC BUSINESS MODELS AND STRATEGIES	(TOZANLI ET AL., 2020)	x									
	(MANAVALAN & JAYAKRISHNA, 2019A)		x	x							
	(TOMBIDO ET AL., 2018)	x				x		x	x		
	(MBOLI ET AL., 2020)			x						x	
	(GHOSH ET AL., 2020B)	x				x			x		
	(HAHN, 2020)	x								x	
	(ZANGIACOMI ET AL., 2020)	x	x		x	x					
	(FACCHINI ET AL., 2020)							x			
	(GARAY-RONDERO ET AL., 2019)	x									
	(SUNDARAKANI ET AL., 2019)					x		x			

	(OMAR ET AL., 2019)	x						x			
	(ASDECKER & FELCH, 2018)			x							
	(HUSSAIN & MALIK, 2020)	x	x	x			x	x			
	(GONZÁLEZ-SÁNCHEZ ET AL., 2020)	x					x	x			
	(POHLMANN ET AL., 2020)			x				x			
	(DUBEY ET AL., 2019)	x						x			
CSC BEST PRACTICES	(GARRIDO-HIDALGO ET AL., 2019)	x	x		x						
	(JENSEN & REMMEN, 2017)	x						x			
	(MASTOS ET AL., 2020)	x							x		
	(BAGALAGEL & ELMARAGHY, 2020)					x				x	
	(SHAO ET AL., 2021)	x									
	(FRANKÓ ET AL., 2020)	x									
	(HETTERSCHEID & SCHLÜTER, 2019)	x									x
	(BRESSANELLI ET AL., 2020)	x									
	(JULIANELLI ET AL., 2020)					x				x	
	(VAN ENGELAND ET AL., 2020)	x						x			
	(SANTANDER ET AL., 2020)			x				x			
	(KÜHL ET AL., 2019)	x		x							
	(NIU ET AL., 2019)			x							
	(ISLAM & HUDA, 2018)	x									
	(DE ANGELIS ET AL., 2018)		x					x			
	(BERNON ET AL., 2018)		x				x	x			
	(HERCZEG ET AL., 2018)			x							
	(MULROW ET AL., 2017)						x				
	TOTAL	**49**	**33**	**25**	**18**	**18**	**16**	**16**	**15**	**15**	**5**

Table 10: CSC theoretical gaps literature analysis

4.3.1.1 Theoretical gaps analysis

By analysing the diffusion of the different gaps among the CSC categories, some considerations can be traced.

The identified lack are perfectly in line with the content developed in each category. Indeed, the *CSC I4.0 enabling technologies* category has collected the highest number of enabling (G9) deficiencies (6), highlighting the importance of I4.0 technologies to foster the adoption of the circular approach.

G1 and G2 are also spread. The relevance of studying the practical implications of technological advancements with a systemic aim, is, thus, remarked.

As could be expected, the *CSC performance tools and indicators* category has gathered 10 measurable gaps (G8). The research domain, indeed, is deficient of measurable indicators to track the performances, as already discussed.
A combination of G1 (14), G2 (13) and G4 (12) characterizes the *CSC challenges and barriers* category. This consideration stresses the need of a critical, practical and holistic analysis of the major impediments when adopting CSCs.
Regarding *CSC business models and strategies* category, several G7 (8) have been highlighted together with G1 (10) deficiencies. The research domain looks, indeed, scarce of managerial considerations to support and enhance the practical implementation of SC changes.
Lastly, the *CSC best practices* category has stressed the necessity of more practical cases (G1) that can be taken as a reference by interested companies.

In detail, relevant G1 were recognised as integral solutions to solve the problem of managing the production in a CLSC context in the presence of uncertainties (González Rodríguez et al., 2020), standard guidelines or roadmap to implement I4.0 enabling technologies specific to the manufacturing and SC (Raut et al., 2020) and applications of BDA in the context of SCM (Ogbuke et al., 2020).
Investigations about the implications of I.4.0 for SC operating models, have received only limited attention in the literature (Hahn, 2020).
Moreover, Garay-Rondero et al. (2019) discussed the deficiency of solid frameworks to provide guidance for IoT and CPS adoption in a SC context with clear guidelines and models addressing SC problems in an new technological environment.
Lastly, a lack of general CSC practices was raised (Kühl et al., 2019).

Systemic and holistic analysis (G2) integrating various aspects are scarce in the research domain. For instance, Ramirez-Peña et al. (2020) denounced a lack of integration of the 3 TBL layers into the SCM, while an holistic view of implementing CSCM in the Indian plastic industry was raised by (Khandelwal & Barua, 2020).
Lapko et al. (2019) suggested a limited holistic understanding of CLSC considering multiple actors.

Regarding the theoretical area, the main reported G3 are: the evolution of science in the fields of I4.0 and AM (Borregan-Alvarado et al., 2020); studies related to BDA

(Oncioiu et al., 2019) and to the relationship between SCM and Knowledge Management (Jermsittiparsert & Boonratanakittiphumi, 2019a).

Examples of G4 can be observed in a deficiency of synchronized integrated barriers of CSC and I4.0 (Ozkan-Ozen et al., 2020), challenges adopting decision making approaches in SSC (S. Yadav et al., 2020) and CSC risks (Ethirajan et al., 2021).

On the other hand, the potentialities and benefits (G5) of the CSCs adoption have not been discussed in dept. Lack of CSFs for improving SSC performance through operational excellence approaches was stressed by Sehnem et al. (2019).
Moreover, potential benefits of the emerging technologies in the I4.0 field of remanufacturing and product recovery systems have received less attention (Bagalagel & ElMaraghy, 2020).

Certain perspectives (G6) have not collected relevant considerations. The existing studies on the I4.0, indeed, have mostly focused on analysing the technological and organizational impacts with a lack of focus on the societal and environmental perspectives (M. Sharma et al., 2020).
Similarly, significant gaps regarding research into social sustainability (Barata et al., 2018; Gružauskas et al., 2018) and HRM-related topics and implications (Liboni et al., 2019) in SCM were denounced.
On the other hand, effects on SSCM considering the IP perspective are lacking (Zeng et al., 2017).

The G7 type is characterized by a discussion deficiency about governmental policies, business models and management decisions that can drive or impede the deployment of appropriate technologies (Zhang et al., 2019).
The strategic intent required to integrate the concept of the CLSC into mainstream business activity (De Angelis et al., 2018) and discourse evaluating the managerial implications from the adoption of a more CE-based view (Bernon et al., 2018) are lacking.

A lack of measurable indicators is stressed by the G8 category. Indeed, studies on performance measurement indicators of intelligent SC (Xie et al., 2020) and adequate quantitative and qualitative indicators to measure performance of CSCs (Jain et al., 2018) are still lacking.

Singh et al. (2019) highlighted limited research available for developing an index evaluating the effectiveness of SC coordination in the era of I4.0.

An integrative view of the enabling technologies required to digitise firm processes, such as SCM market integration (Ardito et al., 2019) and empirical investigation about the role of SCM as an enabler of supply flexibility (Jermsittiparsert & Boonratanakittiphumi, 2019b) have been loosely defined.

Several papers have suggested little consideration in investigating how and why digital technologies can create performance gains by improving and transforming SC capabilities (Ehie & Ferreira, 2019).

Other examples regarding G9 are: limited research investigating I4.0 technologies for CSC to build a DSS (decision support system) (Mboli et al., 2020) and BDA implications for sustainable SCM (Chiappetta Jabbour et al., 2020).

Lastly, a unified accepted definition of I4.0 in the context of SCM (Chauhan & Singh, 2019), the standardization of green SC indicators (Morella et al., 2020) and a systematic foundation of models supporting the design of CPS with regard to applicable technical functions in the planning and control of SC processes (Hetterscheid & Schlüter, 2019) were unveiled as the major G10.

Taking all into account, G1 (49) and G2 (33) gaps are the most diffused in the analysed research domain. This suggests that, besides the theoretical studies that usually focus on a singular aspect of the research context (I4.0, CE, CSC), articles discussing practical implications of the CSC adoption with a systemic and holistic point of view are needed. In this sense, the presented discussion is aimed at overcoming the reported research gaps.

4.3.2 Practical gaps

The theoretical gaps findings have suggested to investigate in depth the practical barriers encountered by practitioners when adopting a circular approach in SCs.
These considerations, indeed, draw the attention to the main impediments trying to inform companies and suggesting ways to overcome them and foster the adoption of CSCs.
Thanks to those selected articles and evaluating the most recurrent and important barriers, 17 impeding factors have been identified and gathered in 5 main categories.
The presentation order follows the reported priority ranking. Scholars, indeed, commonly agree on the major impediments that political and financial barriers can lead to, followed by organizational and social ones, while technical barriers are perceived as less important.

Legislative/political barriers:

- Lack of tax policies and incentives (B1): Kumar et al. (2021) have stated that governments fail to encourage the process since there are no tax rebate policies to promote CSCM (Khandelwal & Barua, 2020) or incentives for greener activities and tax policies for promoting circular models (Mangla et al., 2018);
- Weak environmental laws and regulations (B2): a deficiency in enforcement rules and systematic regulations for environmental was denounced by Jia et al. (2020), Khandelwal & Barua (2020) and Ozkan-Ozen et al. (2020);
- Lack of global standards and performance measurements (B3): effective mapping of performances and SC activities tracking (Kumar et al., 2021; G. Yadav et al., 2020) are lacking due to a weak performance measurement system and inexistent global standards and sharing data protocols (Luthra & Mangla, 2018).

Financial/economic barriers:

- Limited financial resources and support (B4): shortage of financial resources (Horváth & Szabó, 2019) and support (Dey et al., 2020) were identified and addressed;

- High investments and implementation costs (B5): in order to transform SCs into circular ones, current SCs need to be redesigned in parallel with the adoption I4.0 enabling technologies (Ozkan-Ozen et al., 2020) that requires technical equipment, training and consultancy (M. Sharma et al., 2020). These transactions, however, demand high investments and implementation costs;
- Uncertainties about economic benefits and circular flows in the short run (B6): the return of investment is mostly unknown and the uncertain nature of circular flows increases the risk (Ozkan-Ozen et al., 2020) affecting companies expectations and reluctancies in making investments (I. Kazancoglu et al., 2020).

Social barriers:

- Resistance and fear against disruptive changes (B7): the internal resistance to change makes the adoption very difficult (G. Yadav et al., 2020). Indeed, employees may fear a loss of jobs caused by the automation and the new capabilities required (Kumar et al., 2021);
- Lack of skilled workforce (B8): deficiencies in capabilities are able to impact the result of the adoption since enhanced skills are required for managing the new I4.0 technologies (M. Sharma et al., 2020) and the workers have no experience of the circular approaches (I. Kazancoglu et al., 2020);
- Inadequacy of knowledge and awareness (B9): a conscious lack of CSCM initiatives (B9) was denounced both at an organizational point of view leading to a lack in the motivation (Kumar et al., 2021) and from customers (Khandelwal & Barua, 2020).

Organizational barriers:

- Lack of coordination and collaboration among the SC members (B10): SC actors are reluctant to collaborate and support CSC initiatives (Farooque et al., 2019). This is due to a lack of common vision, fear of losing control or a lack of trust between them (I. Kazancoglu et al., 2020);
- Lack of appropriate training and educational programmes (B11): appropriate training and development programmes for SC members and HR are fundamental (Mangla et al., 2018). For instance, human-machine interaction is

a promising approach for circular operations, however it requires a detailed and efficient training to be managed successfully (Ozkan-Ozen et al., 2020);

- Lack of organization willingness and trust (B12): the transition from linear to circular flow requires redesigning the SC network while embracing a sustainable point of view and conducting, simultaneously, an I4.0 transition. Organizations, however, do not fully trust this new concept (Ozkan-Ozen et al., 2020) lacking a futuristic outlook (M. Sharma et al., 2020);
- Poor management support and commitment (B13): due to a lack of a full comprehension of business opportunities (Cezarino et al., 2019), vision and finance resources, the management is usually reluctant in supporting activities for sustainable operations (Kumar et al., 2021);
- Lack of effective strategic planning (B14): a deficiency of the planning and management of CSCM concepts was reported by Mangla et al. (2018) and strongly confirmed by Khandelwal & Barua (2020).

Technical barriers:

- Lack of technological resources and infrastructures (B15): poor Internet connectivity and lack of related infrastructures are imperative impediments to I4.0 and sustainable practices (M. Sharma et al., 2020);
- Lack of compatibility and integration of technical platforms (B16): besides the technological resources gaps, the systemic integration of new and old systems requires compatibility (M. Sharma et al., 2020). Different components and software need to interface and integrate with each other in a flexible way;
- Lack of information systems and data management (B17): while in the linear economy, the number of stakeholders is not so high and relationships among them are usually one sided, in a CSC the complexity increases tremendously resulting in a greater need for data management skills (Ozkan-Ozen et al., 2020). Indeed, a lack of information systems and data management is considered a relevant barrier. The security and the capacity of data storage systems are also denounced as important issues.

Table 11, summarising the barriers diffusion in respect to the selected articles, is displayed.

Moreover, a further characterization of the papers regarding the dimension of the industry (SMEs) and the economy (emerging) addressed, is added to better understand the link with the practical gaps.

AUTHORS	SMEs	Emerging eco	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17
(KUMAR ET AL., 2021)			x	x	x	x	x	x	x	x	x				x	x	x		
(OZKAN-OZEN ET AL., 2020)				x			x	x			x	x	x	x	x		x	x	x
(G. YADAV ET AL., 2020)					x	x	x		x			x	x		x				
(CEZARINO ET AL., 2019)		x	x	x		x				x	x				x		x	x	
(LUTHRA & MANGLA, 2018)		x			x	x		x	x	x	x	x	x		x		x	x	x
(M. SHARMA ET AL., 2020)		x		x	x		x	x	x	x	x			x	x		x	x	
(HORVÁTH & SZABÓ, 2019)	x				x	x		x	x	x		x		x	x	x		x	x
(I. KAZANCOGLU ET AL., 2020)		x		x	x		x	x		x	x	x	x	x			x		
(DEY ET AL., 2020)	x		x			x									x		x		x
(JIA ET AL., 2020)			x	x	x	x				x		x	x				x		x
(KHANDELWAL & BARUA, 2020)		x	x	x	x	x	x	x			x	x	x		x	x	x		x
(FAROOQUE ET AL., 2019)		x	x	x		x	x	x	x		x	x			x	x	x		
(MANGLA ET AL., 2018)		x	x	x				x			x	x	x		x				x
TOTAL	**2**	**7**	**7**	**9**	**8**	**9**	**7**	**9**	**6**	**7**	**9**	**9**	**7**	**4**	**11**	**4**	**10**	**5**	**7**

Table 11: CSC practical gaps literature analysis

4.3.2.1 Practical gaps analysis

Since the limited articles and the single category analysed, fewer reflections have been raised compared to the theoretical gaps part.

A first consideration that can be traced from the analysis concerns the characterization of the papers. Indeed, out of the 13 selected, 7 have considered possible barriers in the implementation of CSCs in emerging economies and 2 in SMEs.

This suggests that the difficulties and impediments related to the adoption are more frequent and, thus, need a higher attention in these 2 scenarios.

It is not casual, indeed, that legislative/political barriers are ranked as one of the major impediments. As previously discussed in the *CSC challenges and barriers* category, in fact, the power of government in nascent economies is considerable. Therefore, when government policies, incentives and regulations are lacking, the industries might face several troubles.

Moreover, financial barriers are obviously significant in the context of SMEs and emerging economy.

However, according to this analysis, the 5 most diffused barriers are B2, B4, B5, B10, B13 and B15, which belong to all the 5 different categories. The latter consideration highlights the systematic and holistic impact on political, economic, technical, social and organizational layers of the CSC adoption.

4.4 CSC model

The analysis of the theoretical gaps has raised a deficiency of articles studying the integrated context of I4.0, CE, CSC to suggest practical and systemic implications for the CSC adoption.
Therefore, this work is aimed at compensating the presented lack by proposing a CSC transitional model which addresses the evolution from a linear to a CSC. Thanks to the following model, practitioners are provided with useful insights to adopt and successfully manage the circular transition.

To better structure this section, a further and detailed analysis of the collected frameworks and models among the selected articles have been performed. In particular, 2 main contributions have been detected (González-Sánchez et al., 2020; Jain et al., 2018) respectively belonging to the *CSC business models and strategies* and *CSC performance tools and indicators* categories. Indeed, since the 2 papers are particularly in line with the model proposition, they have been used as a guide for its draft.
The first (González-Sánchez et al., 2020), proposed a conceptual model to support the CSC design and implementation based on the 4 main dimensions presented in Figure 17.

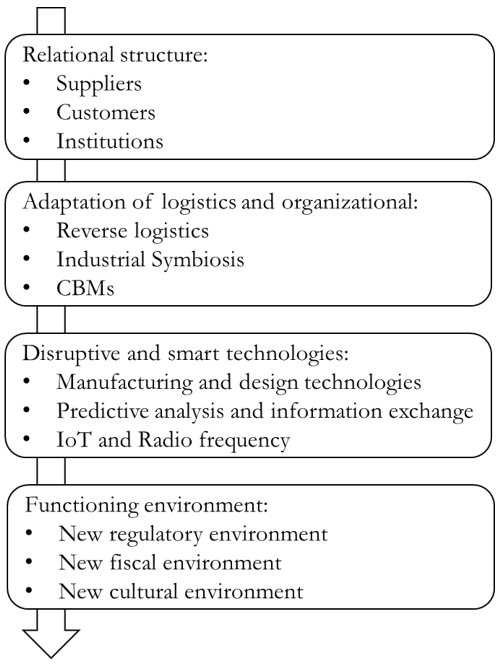

Figure 17: Conceptual model adopted by González-Sánchez et al. (2020)

Successful circularization requires integrated synergic actions by all actors and sectors involved, supported by improved flows of knowledge.

In addition, the company needs to adapt both logistically and organizationally. Reverse logistics encourage the return of material, IS favours the exchange of waste between industrial partners, while CBMs model the dynamic management of the resource loops. The main role of information and communication technologies is the application of innovative and efficient methods to optimize the economic processes of production, consumption and circulation.

As a final point, the company can capture value through long-term agreements, the establishment of reward systems and the achievement of financial and legal commitments.

Jain et al. (2018), on the other hand, proposed a 3-dimensional strategy for CSCs incorporating innovative BMs (strategic level), product design or eco-design (tactical level) and effective SCM (operational level) decision making.

A successful transition to a CSC, indeed, requires multi-dimensional changes such as: product redesigning, reducing SC complexity, adopting innovative BMs and continual measurement of progress towards circularity.

In this sense, the paper provided some general multi-dimensional indicators for CSCs, in opposition to the traditional ones, listed in Table 12.

Traditional SC indicators	Indicators for CSC
Plan	Product design/eco-design
	New BMs
Source	Sustainable procurement
	Supplier selection
Make	Manufacturing
	Material reduction
	Energy reduction
Deliver	Logistics
	Sales and marketing
	Product use/share
	Waste reduction
Return	Reverse logistics
	Reuse
	Remanufacturing
	Recycle
	EoL disposal

Table 12: Multi-dimensional indicators adopted by Jain et al. (2018)

The presented contributions have shown the importance of holistic frameworks in helping companies to ensure an environmental consciousness and in providing a roadmap in terms of environmental, economic, logistical, operational and organizational activities to adopt CSC models effectively.

However, besides the systematicity, the 2 propositions share a generic and superficial approach describing more the boundary conditions of CSCs rather than proper specific characteristics, expectations and practical insights.

This work, instead, is aimed at addressing the CSC transition through the perspective of an approaching firm. Therefore, based on the literature analysis, the model (Figure 18) offers a description of CSC peculiarities, practices and warnings supporting transitional companies.

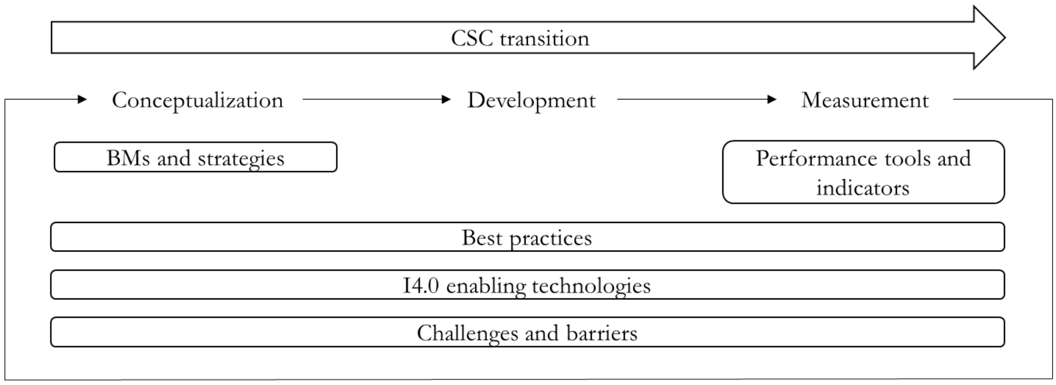

Figure 18: CSC model

The model is structured on the 5 categories introduced in Section 4.1 (CSC thematic classification analysis): *CSC business models and strategies, challenges and barriers, I4.0 enabling technologies, performance tools and indicators, best practices*. They have been assessed to understand how each of them impacts the timeline concerning the CSC transition, from its initial adoption up to its full achievement.

Indeed, the transition has been distinguished in 3 main subsequent phases: conceptualisation, development and measurement. In addition, the pattern is circular since the performance evaluation corresponds to a further input to the initial phase, enhancing a continuous development and improvement perfectly in line with the circular principle.

The 3 main phases are, hence, characterized by the 5 categories, distributed among them according to the content and in relation to the sequence of the CSC transition.

In this sense, the categories of *CSC best practices, challenges and barriers and I4.0 enabling technologies* have been considered transversal, impacting the entire transition, while *CSC business models and strategies* and *CSC performance tools and indicators* have been referred only to single phases.

Through the dimensions of the *CSC best practices* category, successful CSC examples and practices, proving to be appropriate in each stage of the transition have been provided. Indeed, upgrades and further improvements might be suggested looking at different implementation methods and managerial approaches.

The *I4.0 enabling technology* insights guide the approaching companies mostly in the central phase thanks to the improvements during the development activities. However,

their use is crucial even in the initial phase and during the measurement one, for instance to manage massive quantities of data needed.
Since the practical gaps analysis has shown several difficulties and *barriers* in the CSC transition, the model provides accurate warnings to support companies in overcoming challenges that might undermine the process. This is particularly relevant in the initial phase to efficiently avoid drawbacks or impediments in the further adoption. However, concerns are spread even in the implementation and the performance monitoring phases as highlighted afterwards.
The remaining *CSC business models and strategies* and *performance tools and circular indicators* categories have been respectively considered in the conceptualisation and measurement phases due to their content. The first category provides outcomes which are the foundations of a managerial decision oriented to the circular transition and responsible for the management of the latter.
Finally, CSCs need to be measured to monitor the transition in quantitative and qualitative terms and to, eventually, improve the process through a continuous and circular improvement.

Each phase has been described according to the main dimensions of the included categories and analysed according to the following features: proposition type, TBL, CE strategies and I4.0 technologies.
Moreover, for each phase, specific characterizations, successful recurrent practices and approaches have been then listed and, finally, the encountered practical barriers have been analysed to provide warnings and support the realization of the transition.

4.4.1 Conceptualization

The model begins with the conceptualization phase. It is, indeed, an introductive and preliminary step in which firms build and experience the starting point of the CSC pathway. The discussion addresses the 3 transversal categories (*CSC best practices, challenges and barriers and I4.0 enabling technologies)* and the characterizing one: *CSC business models and strategies.*
In this initial phase, practitioners are provided and can benefit from several models, frameworks and guidelines offering guidance and supporting directives.

During the strategy definition, planning and management, the review has suggested a slight concentration on the economic and environmental dimensions, while leaving social considerations for the following phases.
This predominance, is however, something to be carefully managed. As highlighted in the Section 4.2.2 (Practical gaps), indeed, the transition could scare the employees of a possible job loss caused by the automation and the new capabilities required (B7). According to this warning, it is strongly important to be prepared to face a potential internal resistance, promptly handle it and, when possible, prevent it to enhance a further smooth development. The mentioned prevention might be partly realized through training and educational programmes (B11) which are still lacking in the field of adoption.

Compared to the following 2 steps, the conceptualization phase has reported a poor debate around the I4.0 technologies. At the beginning, indeed, technologies have been mainly considered as instruments to foster the predictive analysis and the exchange and monitoring of information, as demonstrated by the significant predominance of Cloud, BDA and IoT.

The information flow and, consequently, the coordination and collaboration among the SC members (B10) is something that practitioners should particularly consider and preserve. Its failure might, indeed, hinder the entire transitional process. Therefore, specific SC actors' selections, development programmes and multidisciplinary systems are needed.

The importance to adopt and structure circular strategies and more complex and narrow type of BMs involving dynamic management of the resource loops, has been highlighted. CBMs implementation, in fact, encourages the design of CSCs, allowing products at the end of their LC to re-enter the SC, while CD practices foster the circular transition in the subsequent and more operative steps.
Moreover, 3Rs, WM and M&EE should be further considered as useful tools for the CSC transition and implementation.

To enhance the approaching firms' knowledge and readiness, successful promising approaches and practices have been listed hereunder.

Firstly, a path, suggested by Nandi et al. (2020), can be followed when realizing a CSC transition. It, indeed, provides guidance for reorganizing structure and processes, identifying synergistic approaches to form channel partners and identifying sources of conflicts.
Achieving a fully circular model of adoption implies its application both internally and externally, involving suppliers and customers in the activities and leading to an essential development of relational capacity. According to this transition, even customers become key participants of the CSC strategic network, raising the need of their loyalty and satisfaction to establish longer-term relationships.
A best practice to enhance SC capabilities with partners and customers, optimised through the use of Cloud and BDA technologies, was proposed by Mihardjo et al. (2020), arguing the importance of co-creation strategy based on collaboration value. The strategic input is derived from external factors associated with customer experience and internal factors related to core SCM competences.
Some main means and best practices for the CSCM as configuration organisational functions, coordination of organisational functions, closing resource loops, slowing resource loops and narrowing resource loops, were proposed by Geissdoerfer et al. (2018). Moreover, the approach highlighted essential factors in the pro-active multiple stakeholder management and long-term perspective within short term actions.
Managerial practices that companies can implement to design CBMs and to capture value from them were investigated by Ünal et al. (2019). The managerial commitment, as moderating factor between the value network and the customer value proposition, indeed, is identified as essential for reaching the intended goals of CBMs. In addition, an interdisciplinary approach is essential to investigate the circular economy, considering its multifaceted and complex nature.
An IoT enabled decision support system (DSS) for CBMs that effectively allows tracking, monitoring and analysing products in real time with the focus on residual value was proposed by Mboli et al. (2020). The approach applied DSS and the ontological model in a real-world use case and demonstrate viability and applicability. In particular, it addressed the requirement of real-time monitoring of products LC using I4.0 technologies, namely, IoT and 5G.
A conceptual model illustrating how PSS BMs impact SC collaboration through increased product longevity, closure of resource loops and resource efficiency was

identified by Kühl et al. (2019). It also determined 6 contextual factors including economic attractiveness, firm sustainability strategy, policy and societal environment, product category, SC relationships and technology.
A shift from product ownership to leasing and access in SC relationships, the relevance of structural flexibility and start-ups in regional or local loops, open and closed material loops in technical and biological cycles, closer collaboration within and beyond immediate industry boundaries and public and private procurement were presented (De Angelis et al., 2018) as preliminary implications for CSCs and as levers for CBMs.

Finally, the analysis has demonstrated that an approaching firm should always consider fundamental aspects to reach a successful handling such as a strong and substantial management support (B13) and an effective strategic planning (B14). These issues have proved to be undervalued organizational barriers so far and, therefore, practitioners should be warned.
A summary to advise and support approaching firms is presented in Table 13.

<table>
<tr><th>Why?
Encountered practical gaps</th><th>How?
Proposed practices and approaches[4]</th><th colspan="2">What?
Adopted I4.0 technologies and CE strategies</th></tr>
<tr><td rowspan="6">B7: Resistance and fear against disruptive changes
B10: Lack of coordination and collaboration among the SC members
B11: Lack of appropriate training and educational programmes
B13: Poor management support and commitment
B14: Lack of effective strategic planning</td><td>Guidance for reorganizing structure and processes, identifying synergistic approaches to form channel partners and sources of conflicts during the CSC transition (Nandi et al., 2020).</td><td rowspan="6">Cloud
BDA
IoT</td><td rowspan="6">CBMs
3Rs
WM
M&EE</td></tr>
<tr><td>A model to enhance SC capabilities and co-creation strategy with partners and customers, optimised through the use of Cloud and BDA technologies (Mihardjo et al., 2020).</td></tr>
<tr><td>Best practices for the CSCM as configuration organisational functions, coordination of organisational functions, closing resource loops, slowing resource loops and narrowing resource loops (Geissdoerfer et al., 2018).</td></tr>
<tr><td>Model proposition of a IoT enabled decision support system (DSS) for CBMs that effectively allows tracking, monitoring and analysing products in real time with the focus on residual value (Mboli et al., 2020).</td></tr>
<tr><td>A conceptual model illustrating how PSS BMs impact SC collaboration through increased product longevity, closure of resource loops and resource efficiency (Kühl et al., 2019).</td></tr>
<tr><td>Practices as structural flexibility, open and closed material loops in technical and biological cycles and closer collaboration (De Angelis et al., 2018).</td></tr>
</table>

Table 13: Conceptualization phase summarising table

[4] Environmental and economic aspects slight predominance.

4.4.2 Development

The development step has been built considering the 3 transversal categories (*CSC best practices, challenges and barriers and I4.0 enabling technologies*).
In this second phase, more operational and practical aspects have been discussed in methodology and model propositions. The development, indeed, regards the implementation and employment of practices, technologies and approaches to realize the CSC transition.
Similar to the previous paragraph, the analysis tends to suggest a combination of economic and environmental perspectives. However, warnings regarding the social sphere have been stressed: among others the requirement of technical skilled workforce to assist and manage the process (B8). Therefore, even social aspects should be taken into consideration since they can undermine the transitional implementation and realisation.

I4.0 technologies represent useful enabling tools to support the development and are essential to foster a CSC. Their comprehensive application is able to bring significant performance improvements in SCM by enabling a holistic approach from the extensive SC integration as well as information sharing, connectivity and transparency. Moreover, these technologies allow huge performance improvements within individual SC processes such as procurement, production, inventory management and retailing through enabling integration, digitization, automation and novel analytical capabilities.
The analysis has shown a predominance of IoT, BDA and Cloud, with a synergic implementation of AM and Autonomous Robots (A Rob) in specific cases.
Indeed, IoT improves decision making, real time monitoring and communicating, responsiveness, proactivity, productivity, efficiency, quality controls and flexibility at the process level.
BDA contributes to performance improvements, real time problem solving, superior qualities development, forecasting and planning, operational frameworks, predictive models development, decision making and planning.
Cloud enhances collaboration, coordination, integration, quick and independent access to data from any part of the SC, decision making and planning.
Therefore, the I4.0 technical adoption impacts 3 main fundamental aspects:

- production and resource management (recycling of waste, high-efficiency systems, product design, manufacturing and remanufacturing processes);
- stakeholders (predictive analysis, coordination and collaboration);
- information (monitoring, controlling, and transferring of data).

The most significant technological approaches and practices encountered in the analysis have been reported afterwards to enhance practitioners' interest and know-how and foster a further development.

Firstly, the research domain (Fernández-Caramés et al., 2019) provided the design and evaluation of a UAV (Unmanned aerial vehicles) system that, together with BDA, supports industries in automating inventory tasks and traceability. Different tests were performed in a real industrial warehouse, concluding that the system is able to collect inventory data remarkably faster in comparison to traditional manual tasks and estimate the items position thanks to their tags signal strength.

A circular model, instead, to reuse scrap electronic devices integrating reverse logistics and AM was recommended by Nascimento et al. (2019). To enable the transition from linear to CBMs, which reuse wasted materials, 5 prominent needs were identified: appropriate product LC planning, integrated LC options, better alignment between maintenance, reuse and recycling strategies, the proposal of an integrated management method, considering maintenance plans and operations, standardisation and adaptability of systems.

A novel, working, reliable, low-cost and scalable solution for asset tracking, supporting global asset management for I4.0 was proposed by Frankó et al. (2020). The solution uses high accuracy indoor positioning, based on Ultra-Wideband (UWB) radio technology, combined with RFID-based tracking features. The UWB use ensures the accuracy of the system even for warehouses of small and medium sized companies without significant computation requirements. In this way, the cost remains low, while the solution is still highly scalable due to the UHF-RFID technology.

A hybrid model based on recurrent neural networks (RNN) to enhance safety and transparency in food SCs was introduced by Khan et al. (2020). Long short-term memory (LSTM) and gated recurrent units (GRU) were used as a prediction model and the genetic algorithm (GA) optimization was jointly included to optimize the parameters of the hybrid model.

Through this method and, thus, the deployment of IoT and Blockchain technologies, the food industry benefits in three main areas: provenance, payments and management.
On the other hand, electric vehicles and traction batteries were used as an example to prove how I4.0 can be integrated into the recycling process (Kintscher et al., 2020). The case involved the development of a marketplace, connected to a robot, to exchange information. The robotic system is capable, indeed, of analysing the condition of the battery and transmitting a holistic approach for an information exchange architecture between the several actors of the SC.
An end-to-end solution for reverse SCM based on cooperation between different IoT communication standards was proposed by Garrido-Hidalgo et al. (2019). The CSC framework was addressed in a case study based on the Audi A6 Li-ion EVB (electrical vehicle batteries) pack. It is composed of a forward flow of products from suppliers to customers and, once reached their EoL, these are removed from their electrical vehicle and shipped to the RLI.
Through a comparative analysis (latency, investment, flexibility, data rate, communication range, battery life and reliability) of IoT standards; RFID for short-range, BLE for local and LoRaWAN for long-range communication were selected.

The mentioned technologies foster and enable the circular development with a LC thinking approach, enhancing the circularity and waste minimisation principles. Indeed, the most discussed practices of the development phase have regarded 3Rs, WM, M&EE and CD.

Certainly, the technical adoption and circular practices implementation require several characteristics that are essential to a successful result and need to be acknowledged by practitioners and approaching firms. Firstly, strong Internet connectivity, technical infrastructures (B15) and information systems (B17) are essential to register, share, storage and analyse huge amounts of collected data.
Moreover, to optimise the effort, resources and final outcome, technical platforms should be compatible (B18). In this way, the transitional process can proceed smoothly thanks to the flexible integration and interface of the old and new system.
A summary to advise and support approaching firms is presented in Table 14.

Why?	How?	What?	
Encountered practical gaps	**Proposed practices and approaches[5]**	**Adopted I4.0 technologies and CE strategies**	
B8: Lack of skilled workforce B15: Lack of technological resources and infrastructures B16: Lack of compatibility and integration of technical platforms B17: Lack of information systems and data management	UAV (Unmanned aerial vehicles) system that, together with BDA, supports industries in automating inventory tasks and traceability (Fernández-Caramés et al., 2019).	IoT BDA Cloud AM A Rob	3Rs WM M&EE CD
	Circular model to reuse scrap electronic devices integrating reverse logistics and AM (Nascimento et al., 2019).		
	Methodology for asset tracking, based on UWB radio technology and RFID, supporting global asset management for I4.0 (Frankó et al., 2020).		
	A hybrid model based on recurrent neural networks (RNN) to enhance safety and transparency in food SCs (Khan et al., 2020).		
	End-to-end solution for reverse SCM based on cooperation between different IoT communication (Garrido-Hidalgo et al., 2019).		

Table 14: Development phase summarising table

4.4.3 Measurement

As reported in the preliminary steps, even the measurement phase is characterized by insights about the 3 transversal categories (*CSC best practices, challenges and barriers and I4.0 enabling technologies*). Moreover, the outcome is referred to the *CSC performance tools and indicators* category outputs, thus practitioners are provided and can benefit from innovative tools, indicators and frameworks.
However, the previously highlighted lack of global standard and performance measurement (B3) characterizes the third phase with a poor discussion and presence of quantitative and qualitative measures in the research field. The performances tracking is useful not only for an external point of view, but also for an internal one, to monitor the initial plan and eventually suggest adjustments through circular and continuous improvements. Therefore, enrichments and focus on these aspects are still needed.
The majority of reported indicators are referred to WM, 3Rs and M&EE practices and, thus, to environmental efficiency and waste reduction. Among other, the LCA has proved to be a useful tool for SCs willing to become circular since it is able to determine the entire environmental impacts and suggest circular approaches, as

[5] Environmental and economic aspects slight predominance.

highlighted in the framework by Julianelli et al. (2020) and Shoaib-ul-Hasan et al., (2021).

Regarding the discussion about I4.0 technologies implemented in the measurement phase, references are scarce. However, a majority of IoT, BDA and Cloud is evident even in this case. The importance, indeed, of information sharing, connectivity and transparency is primary for the performance assessment and improvement of a transitional firm. Among other, Gružauskas et al. (2018) highlighted how the adoption of IoT, BDA, Cloud and A Rob technologies in the agri-food sector is fostering the competitiveness advantage in the long run limiting trade-offs between sustainability and cost-effective performances. The obtained results showed that, by implementing the autonomous vehicles strategy along with the consolidation, warehouses CO_2 emission level can be decreased of 22% accompanied by a reduction of logistics costs. In the same industry, a conceptual framework to examine food loss and waste issues within food SCs was proposed by Luo et al. (2021). The approach includes various methods such as stochastic programming, simulation, LCA and empirical analysis.
The willingness to optimise and minimise wastes has been stressed by others. A new KPI, indeed, capable of measuring the impact of energy consumption on the Nakajima's 6 big losses (breakdowns, setups, minor stoppages, speed loss, quality defects and start-ups) was developed by Morella et al. (2020).

A deficiency of a systematic and comprehensive evaluation of the 3 TBL layers is present, in fact only few papers adopted a holistic or social approach of investigation, while the majority concentrates on environmental aspects as the numerous emissions indicators.
In this sense, Genovese et al. (2017) compared the performances of traditional and circular production systems across a range of indicators like direct, indirect and total lifecycle emissions, waste recovered, virgin resources use and carbon maps. The paper asserted than an integration of CE principles within SSCM can provide clear advantages from an environmental point of view.
The environmental gains, in terms of carbon emissions, achieved through some CE principles in the context of sustainable, green and CLSC were demonstrated by Nasir et al. (2017), using the case study of a construction industry.

Moreover, practitioners should be informed that many of the tools proposed in the literature are often qualitative and very generic in the formulation, as the case of Xie et al. (2020) proposing visibility, leagility, personalization, information governance, SC warning, green, innovation and learning indicators to enable the monitoring and evaluation of SC performance.
In addition, the adoption of a coordination index among the SC actors for an effective benchmarking of the SC performance in the I4.0 era was provided by Singh et al. (2019). In total 32 factors were considered using the graph theoretic approach to evaluate the coordination of an Indian organization SC.

Practitioners should concentrate more on this last measurement phase to enrich the propositions portfolio enhancing a monitored CSC and, thus optimal outcomes.
In this sense, recently some scholars, (Rocca et al., 2021), have defined a novel CE Performance Assessment (CEPA) methodology that, together with classic LCA and LCC (LC cost) methods, is able to exploit quantitative assessments of CBMs.
CEPA outputs consist in a set of specific KPIs, mainly based on the Material Flow Analysis, regarding resources LC circularity and the quantification of economic and environmental benefits related with CE.
A summary to advise and support approaching firms is presented in Table 15.

Why?	**How?**	**What?**	
Encountered practical gaps	**Proposed practices and approaches[6]**	**Adopted I4.0 technologies and CE strategies**	
B3: Lack of global standards and performance measurements	CO_2 emission level and logistics costs reduction thanks to the I4.0 adoption strategy (Gružauskas et al., 2018).	IoT BDA Cloud	3Rs WM M&EE
	Conceptual framework, including the LCA, to examine food loss and waste (Luo et al., 2021).		
	KPI capable of measuring the impact of energy consumption on the Nakajima's 6 big losses (Morella et al., 2020).		
	LC emissions, waste recovered, carbon maps indicators to compare traditional and circular production systems (Genovese et al., 2017).		
	Carbon emissions reduction achieved through CE practices (Nasir et al., 2017).		
	Coordination index among the SC actors (Singh et al., 2019).		
	CEPA methodology, LCA and LCC to exploit quantitative assessments of CBMs (Rocca et al., 2021).		

Table 15: Measurement phase summarising table

[6] Environmental and economic aspects significant predominance.

5 Discussion

The presented literature analysis together with the final model proposition are significantly contributing to the research field. In addition, not only academics can benefit from this work, since practitioners and managers are provided with practical approaches and insights able to support and guide them during the practical implementation and everyday management. Therefore, the value of the findings is threefold.

Firstly, the knowledge is enhanced thanks to the significant, systematic and effective literature review, which analyses almost 200 selected articles, which contributed, during the entire articulation of the thesis, to the gaps' detection and the model development. Academics are provided with a list of the possible theoretical gaps that could occur when approaching CSC (Section 4.2.1). Indeed, the scarcity of practical references (G1) and systemic approaches (G2) were identified as the preeminent research lacks.
To compensate these gaps, the work offers an initial study with a practical and systemic direction building a CSC model to guide interested practitioners.
Hopefully, this will pave the way to other future contributions and increase the level of attention and interest devoted to CSCs.

The newness and difficulty of implementing CSCs from an initial linear model has shown to be an issue for approaching firms. Companies, indeed, are looking for practical guides and support to be prepare and aware in optimally facing the transition. Thanks to the model, a systematisation and categorisation of methods, approaches, guidelines and warnings is provided in order to guide practitioners in adopting the optimal digital technologies and circular strategies during the entire CSC transition.
In this way, the major practical impediments and barriers, identified in Section 4.2.2, can be overcome and the CSC transition is able to proceed smoothly.
Moreover, the absence of previous studies offering a practical model further highlights the value of the work.

Finally, findings have also managerial implications since the work helps managers in the decision-making process throughout the CSC transition.

Firstly, managerial actors are updated and informed with sustainable insights and new approaches available. This contributes to the generation of awareness among the industrial sector creating the recognition of the importance that sustainability aspects have nowadays.
Secondly, being now informed and theoretically aware, managers have the instruments to face the circular change and lead the internal transition of the company. In addition, the practical adaptations and the circular paradigm will enhance the reputation, quality and advancement of the firm itself.
Finally, the work offers a practical and solid support to realise the transition. Indeed, know-how, practices and guidelines are provided to guide approaching companies in each phase of the transition. Moreover, the numerous case studies allow a full comprehension and identification during the implementation.

6 Conclusions

The analysis has concentrated on an integrated context covering 3 main areas of interest: CE, CSC and I4.0. In this sense, the investigation purpose was to acquire insights about existing CSCs that are implementing a circular approach thanks to CE practices and I4.0 technologies. The results come from a heterogenic literature base which takes into account various industries. However, all of them seem to share a generic and theoretical or a very case specific approach. The literature analysis and the theoretical gaps identification have, indeed, highlighted and confirmed a scarcity of practical and systematic studies in the domain.
This characteristic disorients interested practitioners and approaching firms since they lack a practical support during the circular transition.
Therefore, this paper tries to overcome the presented issue by offering and suggesting a model which may serve as a guide to practitioners.

The literature analysis and the subsequent CSC categories definition have provided some useful and interesting outputs. Firstly, the outcome suggests a predominance of contributions studying the impediments of a CSC development, highlighting the difficulty encountered by approaching firms and the willingness to find solutions able to overcome them. On the opposite side, papers addressing measurable outputs and CSC indicators are still lacking in the domain. This nascent circular paradigm has not developed quantitative means to monitor and track the obtained outputs yet. Therefore, future advancements are needed.
Regarding the different analysed aspects of I4.0 technologies, the outcome has shown a prevalence of IoT, BDA and Cloud technologies among the 9 defined, thanks to their beneficial impacts on production efficiency, resource management, stakeholders' coordination and collaboration and information management.
On the other hand, the most promising CE strategies have been identified in 3Rs, WM and M&EE since their beneficial power in terms of costs and waste reduction.
In addition, the analysis confirmed a predominance of economic and environmental aspects and impacts, leaving aside the social sphere, according to the TBL. This latter indication is, however, something to be carefully aware since, as reported afterwards, practical barriers related to social issues has resulted to be significant during the adoption.

The gaps analysis has demonstrated the synergic importance of political, financial, technical, social and organizational commitment in order to achieve a smooth circular transition. While political and financial aspects matter in the decision and in the undertake of a process oriented to a circular paradigm of SC; organizational, technical and social barriers have proved to be impactful during the implementation and the transition to a CSC. For this reason, these latter have been used in the model proposition as warnings to be aware of during the practical adoption.
Indeed, management support, strategic planning, mitigation of the fear of change, compatibility of technological infrastructures, information systems and skilled workforce are some of the main requirements for an optimal CSC, whose lack may hinder the entire process.

The acquired findings have been employed to create a model that synthetises and presents some guidelines, practices and approaches able to support approaching firms in the different phases of the circular transition.
In this sense, the proposition has been structured in 3 main subsequent and circular phases: conceptualization, development and measurement, which are related to the main steps of the transitional process.
In this sense, managerial insights as PSS, structural flexibility, closing resource loops and co-creation strategies have been listed as business practices for the conceptualization phase.
In the development phase, technological applications of IoT, BDA, Cloud, AM and A Rob enhancing automation, safety, transparency and communication have been defined in detail.
Finally, the model provides tools and indicators like LCA, LCC, emissions and waste level, carbon maps and coordination index to control and monitor the performances of the entire process. However, the identified scarcity of specific quantitative and social indicators is raising a future research need.

The proposed model tries to synthetise the main findings of the previous analysis and to integrate them with a practical and systemic view.
The value of the model is threefold since it enlarges the knowledge around CSC providing a complete and accurate literature review analysis, it contributes to the CSC practices building a practical guide to sustain the transition and it supports managers

dealing with sustainability aspects and in the decision-making process around the CSC adoption.

This work could be seen as an initial step to pave the way to future contributions oriented to the presented approach and willing to compensate the highlighted gaps. Doing so, the domain will be strengthened with deeper knowledge from which approaching firms could benefit.

The future increasing attention will be able to overcome the limitations of this work. Indeed, time issues, possible flawed methodology and author subjective judgements are decreasing the value of the paper.

Moreover, the CSC model proposition suggests a further development with an industrial validation of the latter. This step is needed in order to have a proof and a confirmation of the model effectiveness and accuracy. Therefore, future research could interview interested companies to get feedbacks about the insights and findings of this thesis.

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