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PhD Thesis

Exploring New Trajectories for Sustainable Supply Chain: Towards an Integrated Framework

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LIST OF ACRONYMS

Concepts	Acronyms
Industry 4.0	I4.0
Supply Chain	SC
Sustainable Supply Chain Management	SSCM
Lean Supply Chain Management	LSCM
Sustainable Supply Chain	SSC
Triple Bottom Line	TBL
Systematic Literature Review	SLR
Literature Review	LR
Web of Science	WOS
SCImago Journal Rank	SJR
Green Supply Chain Management	GSCM
Corporate Social Responsibility	CSR
Circular Economy	CE
Energy Efficiency	EE
Information Technologies and Innovation	IT&IN
Production Management Paradigms	PMP
Supply Chain Operation	SCO
Resource-Based View	RBV
Just in Time	JIT
Visual Stream Mapping	VSM
Total Productive Maintenance	TPM
Sustainable Total Quality Management	STQM
Artificial Intelligence	AI
Augmented Reality	AR
Big Data	BD
Cyber Physical Systems	CPSs
Internet of Things	IoT
Virtual Simulation	VS

*Acronyms are listed in order of appearance

INTRODUCTION

The growing emphasis on the evolution and diffusion of sustainability and related enabling practices has invested the entire global economic panorama. This because companies are under pressure to comply with internal policy guidelines and specifications, as well as the evolving needs of individual customers (Wellbrock et al., 2020). In parallel, in recent years, we are witnessing the transition of industries towards the *Smart Factories* model through the gradual introduction of Industry 4.0 (I4.0) technologies into processes. The I4.0 model, however, cannot ignore the issue of all-around sustainability considering aspects that are not only economic but above all environmental and social. This sustainability-I4.0 dichotomy in some cases must be intersected with some models already present within the Supply Chain (SC) structure such as the lean approach. To be competitive in this context, SCs must combine management paradigms to reach a high level of performance. The Lean Supply Chain Management (LSCM) refers to the elimination of non-value-added activities to enhance firms' performance (Womack et al., 1990). According to this model, waste reduction is implemented through managerial strategies that affect all members of the SC from suppliers to consumers (Yang et al., 2011). Recent interest in environmental issues has led companies to change their operational approaches to comply with new environmental regulations and to respond to the growing demands of customers for sustainable products and services (Kaswan and Rathi 2020). Sustainable Supply Chain Management (SSCM) is an important organizational model to achieve corporate profit and increase market share, based on the reduction of risks and environmental impacts while improving the overall sustainable efficiency of SCs. Previous studies have shown how these two paradigms (LSCM and SSCM) are aligned and intersect each other (Alves & Alves, 2015; Azevedo et al., 2017; Martínez et al., 2017). Carvalho et al. (2010) have asserted that the two paradigms have the common objective of maximizing customer satisfaction by reducing waste along with the SC. More recent studies, on the other hand, have deepened the link between the lean paradigm and I4.0 (Buer et al., 2018; Ejsmont & Gładysz, 2020; Sanders et al., 2017). The integration of these two concepts has led to new definitions such as: "Lean 4.0" and "Digital Lean Manufacturing". Given the increasing complexity of operations, lean practices are not enough to address competitive pressure. The integrated paradigms aim at more flexible, fast, customized, interconnected, and transparent management of production and distribution systems. As part of the link between I4.0 and sustainability, some studies evaluate the different possibilities of digital technologies in improving green practices (Ghobakhloo, 2020; Stock and Seliger, 2016). This thesis aims to close the circle and find the connection points between the three paradigms of I4.0, SSCM, and LSCM. To date, no papers fill this gap.

The thesis is structured in four chapters. The first starts with a novel systematic review of the literature on sustainability in SC. Thanks to the review process, different research streams connected to sustainability were identified. The second chapter analysed in detail the connection between I4.0 and sustainability. In the third chapter, the sustainable practices in the SCs context are depicted. Finally, in the fourth chapter the relationship between I4.0, lean and sustainable SCs is analysed, and the integrated framework is defined. The framework is tested by conducting a multiple case study in the automotive sector. Finally, conclusions and future research directions are presented.

CHAPTER I: ANALYSIS OF THE LITERATURE

Summary

In this chapter, an analysis of the extant literature related to sustainability in SCs is performed. This section starts by presenting the main features of the methodology adopted to conduct the systematic review (Centobelli et al., 2021). All the elements presented in this chapter are the first stage for the development of the analyses presented in the subsequent chapters.

1.1 Overview

In recent years, the debate on sustainability in the SC domain is in the spotlight, and it has recalled the interest of an increasing number of researchers and practitioners. This is the result of a series of massive changes that began in the seventies and have become increasingly rapid and disruptive from the last decade (Kinder, 2003; Womack & Jones, 1996; Zhang, 2006). In the 1970s, the literature was influenced by the growth poles theory (Perroux, 1961). The SC was analysed as a star-shaped system crossed by dyadic customer-supplier relationships (Berthomieu, 1983). In the 1980s, according to the theory of the firm as a set of contracts (Klein, Crawford, and Alchian, 1978), the co-operative game theory of the firm (Aoki 1984), and the transaction costs theory (Williamson, 1985), the SC is presented as pyramidal-shaped system. The latter was characterised by information and knowledge sharing processes between customer and first-tier suppliers (Lamming, 1993). In the 1990s, the literature was influenced by the theories of strategic alliances (Contractor and Lorange, 2002) and the SC became a pyramidal-shaped system coordinated by the customer (Colombo & Mariotti, 1998). In the early 2000s, the literature was also affected by the extended enterprise and virtual enterprise theories (Kinder, 2003; Kornelius and Wamelink, 1998) and the SC became a globalised system (Gelderman and Semeijn, 2006; Levy and Grewal, 2000). In the 2010s, the literature was affected by sustainability and circular economy theories (Seuring & Müller, 2008; Vachon & Klassen, 2006). The SC became a complex circular system where a relevant role is played by both efficiency and sustainability issues (Schrettle et al., 2014). Many authors also stressed that Sustainable Supply Chain (SSC) offered new opportunities and represented a new view for sustainable manufacturing (Yu & Ramanathan, 2015; Rathore, et al., 2020; Gouda & Saranga, 2020). After an initial period when the environmental outlook dominated the sustainability literature, the Triple Bottom Line (TBL) is becoming the prevailing perspective. Policy makers at a special United Nation summit on 25 September 2015 defined the 2030 agenda for sustainable development and sustainable development goals and declared that "*for sustainable development to be achieved, it is crucial to harmonize three core elements: economic growth, social inclusion and environmental protection. These elements are interconnected, and all are crucial for the well-being of individuals and societies*". The question of how to quantify sustainability has sparked heated debate among researchers, policymakers, and other stakeholders. The adoption of the 2030 agenda, which includes the sustainable development goals, targets, and indicators, has enriched this discussion (Liu et al., 2018). The 2030 Agenda was adopted in order to ensure that everyone has a better and more sustainable future. It seeks to address the primary issues that the society confronts, realizing that eradicating poverty necessitates measures that promote economic growth while also addressing a variety of social needs like as health, education, and gender equality. Given this background, the topic of SC sustainability is becoming one of the most prolific research topics in the field of management literature with many papers published every year. This body of literature includes primary studies (e.g., conceptual, or empirical papers) and secondary studies (i.e., literature reviews). In recent years, the number of secondary studies focusing on sustainability in SCM domain increases significantly. Therefore, it emerges the need of designing novel tertiary methodologies to select, aggregate, categorise and analyse the findings provided by secondary studies. With these premises, this chapter aims to design a tertiary-systematic review methodology to provide a comprehensive and updated overview on the topic of SSC starting from the results of the previous secondary studies published in the body of literature. The traditional Systematic Literature Review (SLR) approach can be explained as an aggregation of primary research studies that use and describe specific, explicit, and hence repeatable methodological procedures to locate, assemble, critically assess, and synthesize all important concerns on a certain research topic. Starting from the standard methodology of SLR, the objective is to conduct a systematic review of reviews to evaluate the evolution of literature gaps over time, as well as the specific answers to the research questions formulated by previous secondary studies. The systematic review aims to provide a dynamic research compass for both academicians and practitioners. The results show that there is a close correlation between perspectives of analysis and research gaps identified in the reviews. Most of the perspectives adopted by previous studies are mainly methodology-based or generic and not focused on specific topics. Furthermore, the formulation of the research proposals highlights the need for new integrated paradigms, models, tools, and metrics that relate SCs' sustainability with apparently distant subjects such as I4.0, lean practices, collaborative processes. A further contribution is related to the methodological aspects: the phase of definition of the research agenda is carried out in reverse. Starting from the prioritisation of the research gaps, research directions connected to them were identified. This method highlights how the research gaps become a starting point and no longer a result. In addition, another innovative aspect of the defined methodology is linked to multidisciplinarity and replicability. This methodological approach can be extended to different research areas when the high number of primary and secondary studies on a specific topic does not allow to conduct comprehensive systematic or structured reviews. Furthermore, this methodology allows researchers to easily identify emerging research areas and cluster papers that look at a specific perspective of analysis. On the other side, this tertiary study is of interest to practitioners as it provides a dynamic agenda that allows them to understand how the research on sustainability issues is evolving.

1.2 Methodology

Literature Reviews (LRs) are defined as secondary studies analysing the findings of primary studies, whereas primary studies provide the analysis of data in a research study. LRs have been introduced as a research methodology to manage the growing number of scientific publications on a given topic. These regularly analyse, evaluate, and synthesise existing works to help researchers to keep track of scientific advances in a research field (Glock & Hochrein, 2011; Tranfield, Denyer, & Smart, 2003). LRs aim to aggregate primary studies related to a specific research question. Like secondary studies – which collect primary studies and evaluate the aggregated results - tertiary studies analyse LRs. These become necessary when saturation in the number of reviews realised on a specific topic was reached. Therefore, it is necessary to understand the real evolution of the research gaps identified by the LRs over time (Govindan & Hasanagic, 2018; Mishra et al., 2017; Yun et al., 2019). Despite there are two previous tertiary studies conducted on the topic of SSCM (Carter and Washispack, 2018; Martins and Pato, 2019). These contributions mainly focus on the evolution of the secondary studies via formal analysis (e.g., review protocol, review type, keywords) and categorise the objectives addressed by the reviews concerning the TBL perspective. On the contrary, in addition to the well-known descriptive analysis, this research aims to develop a novel tertiary-systematic methodology to evaluate the evolution of literature gaps that emerged over time. Besides, this analysis gives specific answers to the research questions formulated by previous secondary studies published in the body of literature, to provide a research compass for both academicians and practitioners.

Compared to other literature review approaches (e.g., narrative, systematic, bibliometric, and meta-analytic), this methodology allows researchers to integrate the strengths and overcome the limitations of other literature review approaches. In conclusion, concerning the tertiary study methodology, it emerges that some research topics are characterized by a high publication output and suffer from the fact that the high amount of published research makes it very difficult (if not impossible) to easily have an overview of the entire domain. For the same reason, systematically reviewing the entire domain in a single literature review is often prohibitive. Tertiary studies may support structuring and synthesizing over investigated research areas considering as unit of analysis literature reviews instead of a prohibitively large number of primary studies. It is not available in the literature a threshold in terms of the number of papers published beyond which researchers can decide if a tertiary study is necessary. Tertiary studies provide a compact and comprehensive overview of the state-of-knowledge in a specific research area and unveil general deficiencies of published literature reviews on the subject under consideration. Tertiary studies are thus valuable sources for finding potential areas for future research. In the area of SSCM, a prohibitively large number of primary works and a high and an increasing number of secondary research contributions motivated our tertiary study. A broad and comprehensive review of the SSCM using primary studies is not possible due to the massive number of papers that have been published on this topic. Only a tertiary study can review this research stream in such a broad manner. In line with Abedinnia et al. (2017) and Garousi & Mäntylä (2016), this approach allowed to analyse in detail the entire domain of SSCM, conducting a systematic approach which would not be possible with a systematic or bibliometric literature review that analyses primary studies. As a result, also for a researcher or practitioner interested in growing their background in a given field, it is laborious to go through all published primary but also secondary studies to gain a high-level view of the research landscape. This high-level view is well captured in tertiary studies. These studies aid new researchers and practitioners in identifying the topics that have been addressed, the gaps and potential future research topics of the area investigated. In this sense, tertiary studies help researchers and practitioners by reducing the individual effort of gathering and summarizing relevant literature. Therefore, the added value of the proposed tertiary study is to be found in the methodological approach. The methodology consists of three steps presented in Figure 1.1 and Figure 1.2.

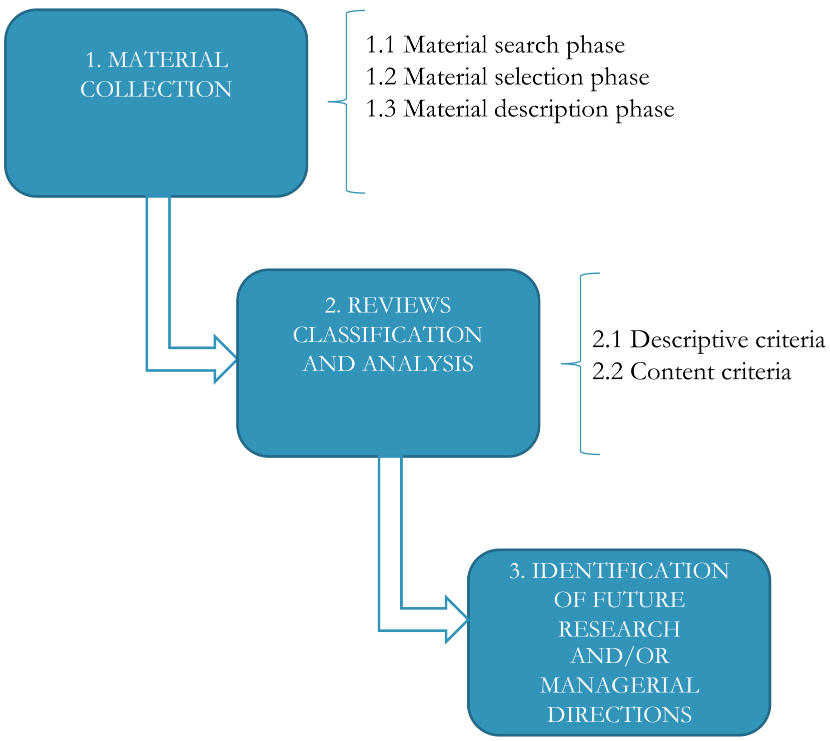

Figure 1.1 Tertiary-systematic study review sequence

1. MATERIAL COLLECTION
MATERIAL SEARCH PHASE
Identification of academic databases Identification of search strings Removing duplications Filters (source type, year, language) Initial sample: **290** articles
MATERIAL SELECTION PHASE
1st exclusion criterion (based on title and abstract reading) (-179) 2nd exclusion criterion (based on full-text reading) (-33) 3rd inclusion criterion (based on snowball approach) (+16) Final sample: **94** articles
MATERIAL DESCRIPTION PHASE
Evolution of reviews over time Journals and subject areas

↓

2. REVIEWS CLASSIFICATION AND ANALYSIS
DESCRIPTIVE CRITERIA
Review Protocol Objective
CONTENT CRITERIA
Focus/Topic areas Perspectives

↓

3. IDENTIFICATION OF FUTURE RESEARCH AND/OR MANAGERIAL DIRECTIONS
Identification of research gaps First-tier gap classification Second-tier gap classification Gaps prioritisation Identification of future research directions

Figure 1.2 Tertiary-systematic study review protocol

The first two phases were adapted from previous contributions (Hochrein & Glock, 2012; Kitchenham et al., 2010; Seuring & Gold, 2012). These steps prepare the ground for the subsequent analysis (i.e., phase 3) which represent the main contribution of the methodology. Specifically, the relevant papers on the subject under consideration are identified. These papers undergo a funnel skimming process to obtain the final sample for the following descriptive analysis. It is essential to point out that the results of all the phases in which exclusion and classification processes are necessarily come from the parallel work of two experts in the field plus a third one in case of uncertainty.

The descriptive analysis is intended to give a broad-spectrum view of the subject matter. Once evaluated the evolution of papers over time as well as journals and subject areas. Subsequently, papers have been evaluated considering the perspectives of a review protocol used to conduct their research (i.e., search string, time range, database(s), inclusion-exclusion criteria, number of papers pre-screening and post-screening). At the end of the descriptive analysis, the content analysis begins, which aims to detail the content of the individual articles. The papers' content has been analysed considering both topic areas and the perspectives of the authors. The analysis of the contents lays the foundations for the first innovative step of the methodology, namely the analysis of the degree of coverage of the perspectives and the related topic areas. The latter is performed by calculating the frequencies of each perspective within the sample of works (i.e., the occurrence) and comparing them with the frequency of the perspectives by topic area (i.e., the degree of coverage). These data allow to build a graph that can be divided into four quadrants that classify perspectives based on the level of both occurrence and degree of coverage. This analysis will facilitate the subsequent identification phases of the research proposals as it highlights the less adopted perspectives in the literature and strongly transversal.

Finally, the third phase of the methodology constitutes the most innovative element which distinguishes the proposed methodology from the traditional LR. Generally, a LR paper ends with the definition of a set of research questions linked to the analysis of the papers. Thus, the results are strongly polarized from the authors' point of view by their background and experiences. On the contrary, the procedure proposed to define research gaps is structured in five main phases. In the first phase, a classification of the research gaps is carried out. The gaps are identified through a triangulation process that involves the analysis of the full text of the papers by two researchers, plus a third one in case of uncertainty, who identify the gaps found by previous secondary studies. A final list representative of the gaps in the literature on the topic under consideration is obtained. However, these gaps must be further analysed according to the typology. This consideration leads to the second step of the third phase and the classification of these gaps into three categories: context-based gaps, methodology-based gaps, and content-based gaps. The gaps related to the first two categories can be associated with any area of research from engineering to statistics to social sciences. Typical gaps identified are represented, for instance, by the need to carry out studies in other countries or industry sectors to compare findings or expand the knowledge on a given topic. On the contrary, content-based gaps contribute to the construction of a vivid and useful research agenda for practitioners and researchers. These are specific gaps related to the topic of the review work. For this reason, they cannot be generalized like methodological and contextual ones. To focus on the gaps that represent a real lack in the literature, a further methodological step has been defined. This consists of the division of the content gaps into two subgroups: primary gaps and contemporary gaps. The first group includes gaps related to basic concepts in the literature but evolving over time, such as practices, drivers, and barriers affecting SSCM. The second group comprises gaps that derive from new issues that have spread over time (e.g., resilience, TBL). This classification allows to obtain a map of the gaps considering the occurrence and evolution of the gaps identified in each category over the years. Starting from this analysis, a further methodological step was proposed for the prioritisation of the gaps based on the degree of coverage over the years and their occurrence. Finally, it is possible to draw up the research agenda, which presents important gaps that may be filled by future researchers (step 3.5).

1.3 Material collection

1.3.1 Material search phase

Data were collected from the Web of Science (WOS) database. Many prior studies used this database as a reliable and high-quality data source for conducting literature reviews (Johnsen, Miemczyk, and Howard 2017; Rebs, Brandenburg, and Seuring, 2019; Strozzi and Colicchia, 2015). As for the search strings used to retrieve the LRs to be analysed, they were identified through a brainstorming process that involved researchers and company experts on the topic. The following search strings were used separately to collected data from WOS:

- TOPIC ("sustainab*" OR "triple bottom line") *AND* TITLE ("supply chain" OR "supply system*" OR "supply network"); document type: review.
- TOPIC ("sustainab*" OR "triple bottom line") *AND* TITLE ("state of art" OR "literature" OR "state of the art" OR "review" OR "overview") *AND* TITLE (("supply chain" OR "supply system*" OR "supply network”)); document type: article or review.

The asterisk was used at the end of some keywords to cover a broad range of results. For example, the asterisk after the keyword “sustainab*” was used to include all the possible results focusing on sustainability issues (e.g., sustainability and sustainable) (Nakamba et al., 2017). To ensure the quality of the papers analysed conference proceedings and book chapters were excluded from the hits, and only peer-reviewed publications were included in the final sample (Denyer and Tranfield 2009). In addition, no filters have been included to reduce the data range considered. The data collection phase was conducted in April 2019. The papers retrieved using the different search strings (136 papers were retrieved from search string 1 and 254 papers were retrieved from search string 2) were analysed and duplicated papers removed. The total number of LRs to be examined at the end of this phase was 290.

1.3.2 Material selection phase

In this phase, inclusion and exclusion criteria were defined to identify the final sample of papers to be analysed in the following steps. Three criteria of inclusion or exclusion were defined to select only the articles regarding the specific aim of the paper. The first exclusion criterion is based on reading the title and abstract of articles. Specifically, the title and abstract of each article have been analysed by two researchers and, in the case of uncertainty, by a third researcher to exclude papers that do not perform a literature review or do not review the topic under investigation. According to the first criterion, 179 *papers* were excluded. The second exclusion criterion is based on full-text reading. It aims to remove papers not focused on the topic under investigation or in which the literature review is just a marginal part of the paper. To this end, the full texts of the remaining 111 were read by two researchers. According to the second exclusion criterion, 33 papers were excluded.

Finally, the *snowball approach* (i.e. inclusion criterion) was adopted to retrieve additional relevant reviews (Hussain, Khan, & Al-Aomar, 2016; Khan et al., 2019; Rogers, 2003; Strozzi & Colicchia, 2015). Therefore, after reading the full text of the relevant papers, 16 additional literature reviews analysing sustainability issues in the field of the SC were included in the final sample. As a result, 94 papers were considered for the following phases.

1.3.3 Material description phase

Figure 1. analyses the evolution of reviews over time, considering the year of publication and the number of citations received by each review. The results show that 94 secondary studies identified in the previous step were published between 2007 and 2019. Data collection phase was conducted at the beginning of April 2019, and therefore only six papers published in 2019 were retrieved. The first literature review on the topic included in our sample was published in 2007 by Srivastava (2007), and it reached the highest number of citations (1,573). Only five reviews were published between 2008 and 2011, and the highest number of reviews published on the topic (25) was recorded in 2017. Figure 1. also shows that in the last five years there was a growing number of secondary studies focusing on sustainability issues in the SC, and it proves that this is a promising and evolving topic in the current literature. As for the number of citations received, Figure 1. shows that there are two peaks in 2007 and 2012, with 1,573 and 2,169 citations, respectively.

The 94 selected papers were analysed in terms of the number of papers published per journal and subject areas covered. Forty unique journals were identified (Appendix A). *Journal of Cleaner Production* contributes with eighteen articles published (19% of the total number of reviews), followed by *Supply Chain Management-An International Journal* with nine articles, *Sustainability* with eight articles, *International Journal of Production Economics,* and *International Journal of Physical Distribution & Logistics Management* both with six articles. The contribution of other journals is lower than 5%.

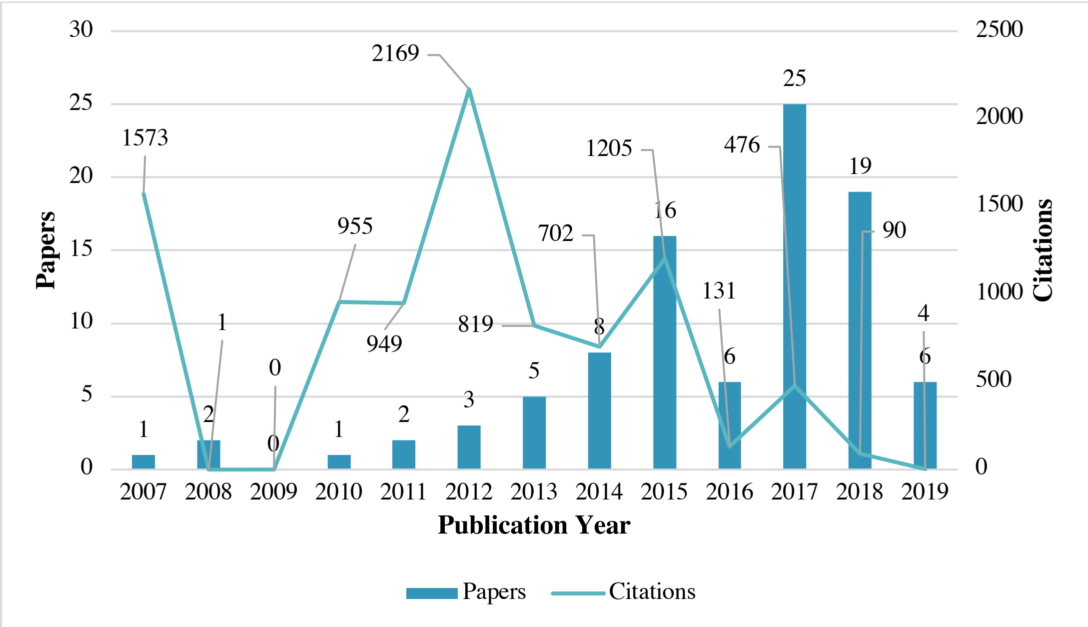

Figure 1.3 Number of papers and citations received in relation to publication year (data collected in April 2019)

To identify the subject areas covered by journals, the functionalities provided by the platform *SCImago Journal Rank (SJR)* have been used. The subject areas considered were: *"Decision Sciences", "Business, Management and Accounting", "Environmental Science", "Social Sciences", "Computer Science", "Engineering", "Arts and Humanities", "Psychology", "Agricultural and Biological Sciences", "Energy", "Mathematics", "Economics Econometrics and Finance"*. The multidisciplinary of the identified subject areas, ranging from psychology to agriculture, emphasises the significance of the topic under investigation that represents a crossroad research field for the scientific community.

1.4 Reviews classification and analysis

1.4.1 Descriptive criteria

This section presents a descriptive analysis of the selected material. According to Seuring & Gold, (2012), the objective of this phase is to evaluate the formal characteristics of the material and provide the background for subsequent content analysis.

The final sample of 94 papers will be examined considering the steps performed to conduct the review (i.e., review protocol) and the main objective of the review.

To analyse the research protocol used in the review process and, therefore, assess the reproducibility of the results, different perspectives have been considered and discussed: search string(s) used for data collection phase, academic database(s) used for data collection phase, time range analysed, selection criteria, number of papers pre- and post-screening. Providing information on the exact search string, database(s), time range adopted, and respective outcomes, the reliability and validity of the results may be enhanced. Appendix B reports the result of the protocol analysis.

The results show that 83% of reviews report the exact search string adopted in the database(s) and 89% of reviews specify the database(s) used to collect data. The time range analysed was declared from 86% of papers. The selection criteria (i.e., inclusion and/or exclusion criteria) used in the search were indicated from 89% of reviews. The most frequently used exclusion criteria were the selection of papers written in the English language and published in peer-reviewed journals, 51% and 50% papers, respectively. The last element considered for the evaluation of the protocol was the number of primary studies selected for the following analysis before and after the screening phase. Only 63% of secondary studies also report the number of papers that resulted from the pre-screening phase. On the contrary, almost all the LRs (90%) report the final number of papers analysed.

Four of the most frequent purposes achieved by researchers in conducting LRs were identified to classify the main objective of the reviews (adapted from Hochrein, Glock, Bogaschewsky, & Heider, 2015; Seuring & Gold, 2012):

- *State of Art (SA).* It is the objective considered for all those reviews that aim to summarize the body of existing research on a specific topic, and do not have other purposes than reviewing the literature.
- *Research Agenda (RA).* It represents the aim of all the papers that identify a list of gaps in the existing body of knowledge or future research opportunities.
- *Taxonomy (TA).* It is adopted by all the papers that classify factors (e.g., practices, models, theories, barriers, drivers) according to a specific perspective.
- *Research Framework (RF).* It includes reviews that aim to define a conceptual map or extend an existing framework.

Reviews may have more than one objective listed above. Table 1.1 presents the evolution and classification of the review's goals over time. The results show that 25% of reviews attempt to perform SA. A significant percentage of secondary studies (23%) has the aim to perform SA and identify RA. Another common choice is first to perform SA and successively define a RF – 10% of the reviews analysed - or a TA – 9% of the reviews analysed. Only 11% of secondary studies have triple objectives, and only one review expressively adopts all the objectives (Jia et al., 2018).

1.4.2 Content analysis criteria

In this section, the review content was analysed in terms of review focus, topic areas, and perspectives considered. The process of content analysis consists of coding papers according to different characterising elements (such as the topic area) and the sustainability perspective addressed by the authors. The coding process allows researchers to define a research agenda that allows easy identification, indexing, or retrieval of content relevant to research questions.

Table 1.1 Review objectives

Publication Year	SINGLE OBJECTIVE				*Total*
	RF	SA	TA	RA	
2007-2010	0	0	0	0	***0***
2011-2014	0	4	0	0	***4***
2015-2019	3	19	4	1	***27***
Total	***3***	***23***	***4***	***1***	***31***

Publication Year	DOUBLE OBJECTIVES						*Total*
	RA - RF	RA – TA	SA - RA	SA – RF	TA - RF	SA - TA	
2007-2010	0	0	0	0	1	2	***3***
2011-2014	1	0	7	3	1	0	***12***
2015-2019	5	2	14	6	4	6	***37***
Total	***6***	***2***	***21***	***9***	***6***	***8***	***52***

Publication Year	TRIPLE OBJECTIVES				*Total*
	RA - TA - RF	SA - RA - RF	SA - RA - TA	SA - TA - RF	
2007-2010	0	0	1	0	**1**
2011-2014	0	1	1	0	**2**
2015-2019	2	2	1	2	**7**
Total	**2**	**3**	**3**	**2**	**10**

Publication Year	FULL OBJECTIVES	*Total*
	SA - RA - TA - RF	
2007-2010	0	***0***
2011-2014	0	***0***
2015-2019	1	***1***
Total	***1***	***1***

Sustainability dimension

This study aims to review the sustainability issues in SC. Therefore, the first issue investigated in the content analysis is the sustainability lens connected to the environmental, social, and/or economic dimensions considered by the reviews selected (Figure 1.4). Almost half of the publications considered environmental, social, and economic sustainability (i.e., triple bottom line – TBL) as perspectives. These studies integrate social variables – such as population, income, job creation, human health, and noise, environmental variables – such as energy, materials, water usage, and economic factors related to the efficient use of resources and achieving a return on investment, financial performance, cost reduction, competitive advantage, and economic benefits (Rumelt, 1974, Zhao and Chen, 2014, Abduaziz et al., 2015). Figure 1.5 shows that there is an increasing number of papers focusing exclusively on one sustainable dimension (mainly on the environmental dimension) or papers focusing on TBL.

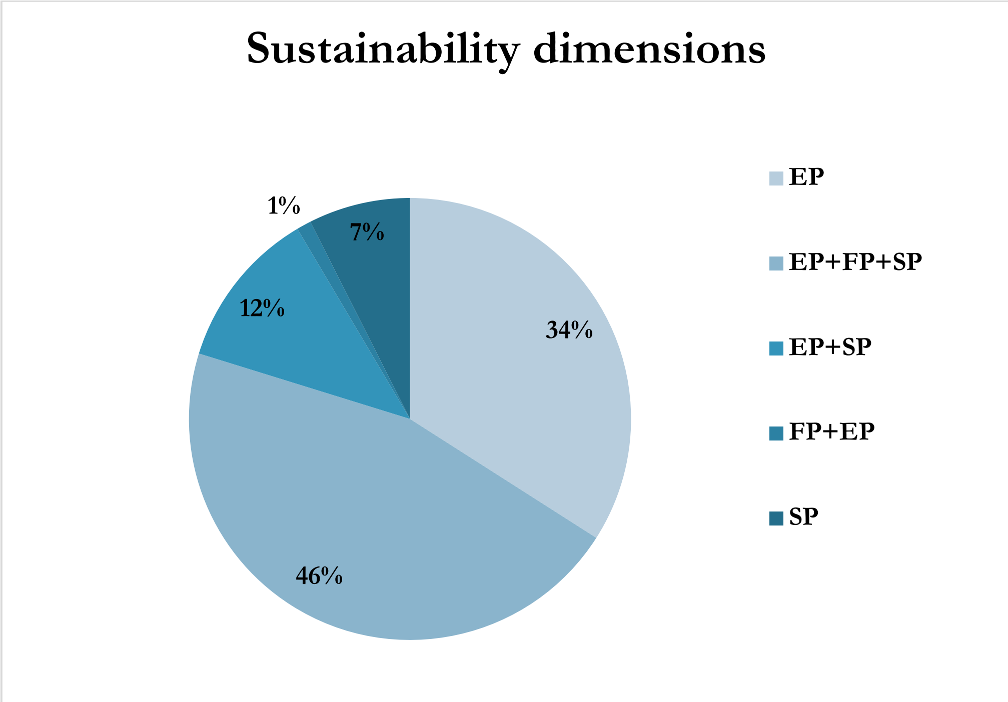

Figure 1.4 Papers by sustainability dimensions

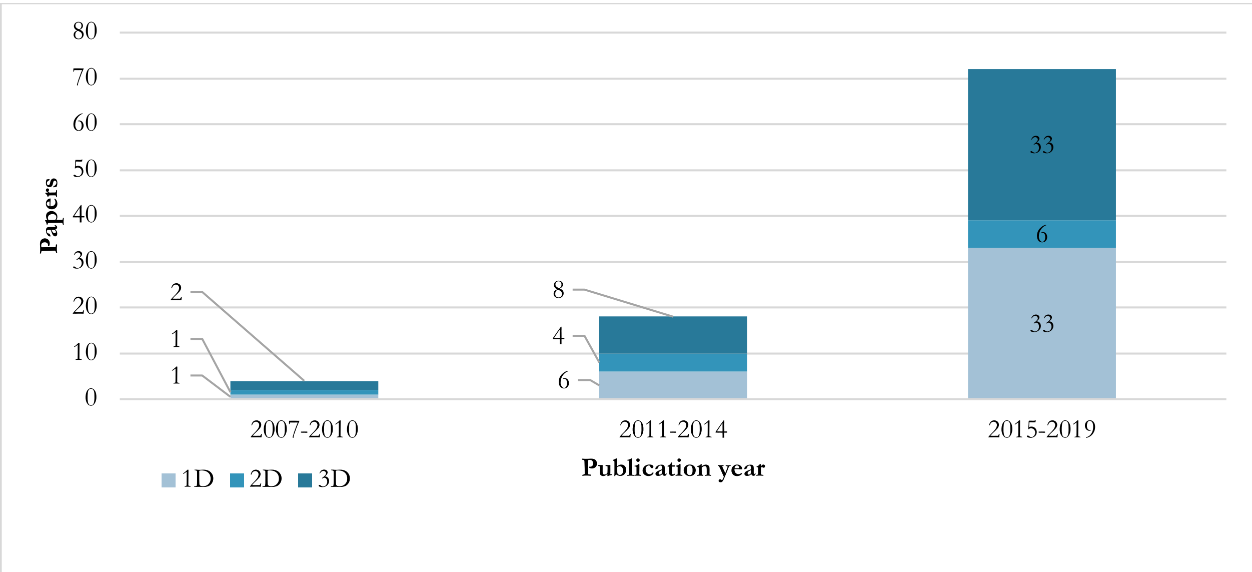

Figure 1.5 Development of sustainability dimensions

(**1D** - one dimension; **2D** - two dimensions; **3D** - three dimensions)

Successively, the reviews have been analysed considering their focus. According to Mayring (2000) and Krippendorff (2013), before the analysis of the first 50% of selected papers, it was defined an initial set of topic areas based on the sustainability focus and experience with the context. After the analysis of the first 50% of papers and the application of procedures of inductive category development, the initial set of topic areas have been revised. Additional topic areas concerning the more specific theme addressed have been included. With these premises, the content analysis of selected papers makes it possible to identify eight main different topic areas: 1. Green Supply Chain Management (GSCM), 2. Sustainable

Supply Chain Management (SSCM), 3. Corporate Social Responsibility (CSR), 4. Circular Economy (CE), 5. Energy Efficiency (EE), 6. Information Technology and Innovation (IT&IN), 7. Production Management Paradigms (PMP), and 8. Supply Chain Operations (SCO).

1. *Green Supply Chain Management (GSCM)* represents the focus of 25.5% of papers. This area includes papers analysing exclusively environmental sustainability issues of the SC. The GSCM concept evolved over years, and different similar conceptualisations emerged – i.e., sustainable supply network management (Cruz and Matsypura, 2009; Young and Kielkiewicz-Young, 2001), supply and demand sustainability or corporate social responsibility networks (Cruz and Matsypura, 2009; Kova, 2004; Yang et al., 2020), SC environmental management (Lippman, 2001; Sharfman et al., 2009), SC environmental management (Lippman, 2001; Sharfman et al., 2009), green purchasing and procurement (Gunther and Scheibe, 2006), environmental purchasing (Zsidisin and Siferd, 2001), integration of environmental concerns into the inter-organisational practices of SCM (Sarkis et al., 2011).

2. *Sustainable Supply Chain Management (SSCM)* area includes papers related to the TBL concept or integrating environmental and social issues (Seuring & Müller, 2008). A total of thirty-five reviews belong to this area. Until 2015, SSCM and GSCM were the two most investigated topics, and their publication trend is similar (Figure 1.6).

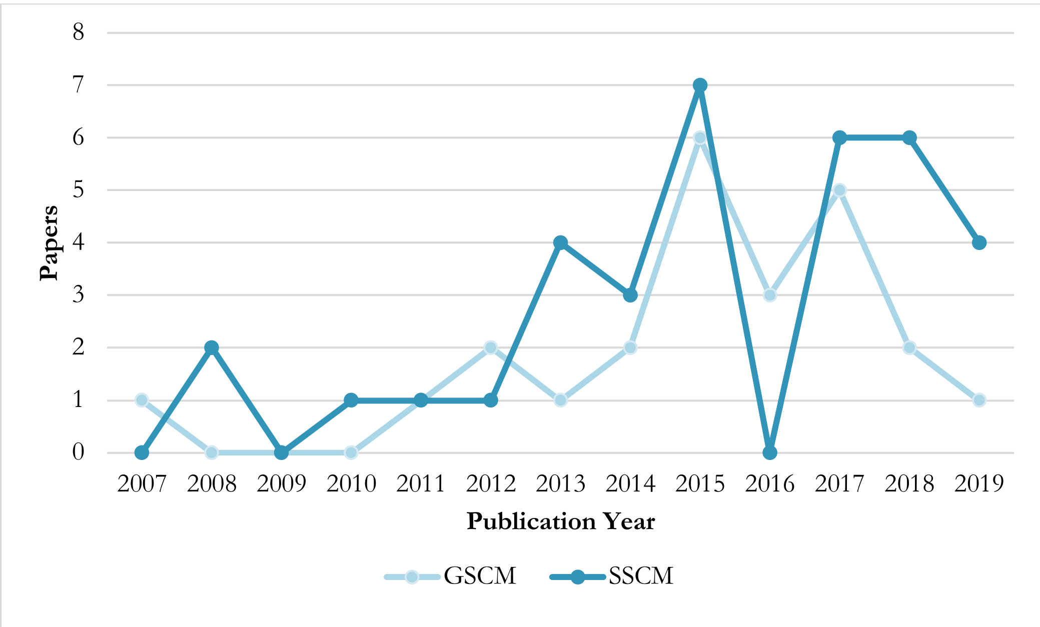

Figure 1.6 Papers per topic-area (**GSCM**, **SSCM**)

After 2015, new topics started to emerge, and additional topic-areas have been identified (Figure 1.7). There are emerging concepts imported from other research fields like big data and predictive analytics (Hazen et al., 2016), life-cycle assessment, solid-waste management, and facility location problems (Eskandarpour et al., 2015), risk-management, network design and disruption risks (Pires Ribeiro and Barbosa-Povoa, 2018).

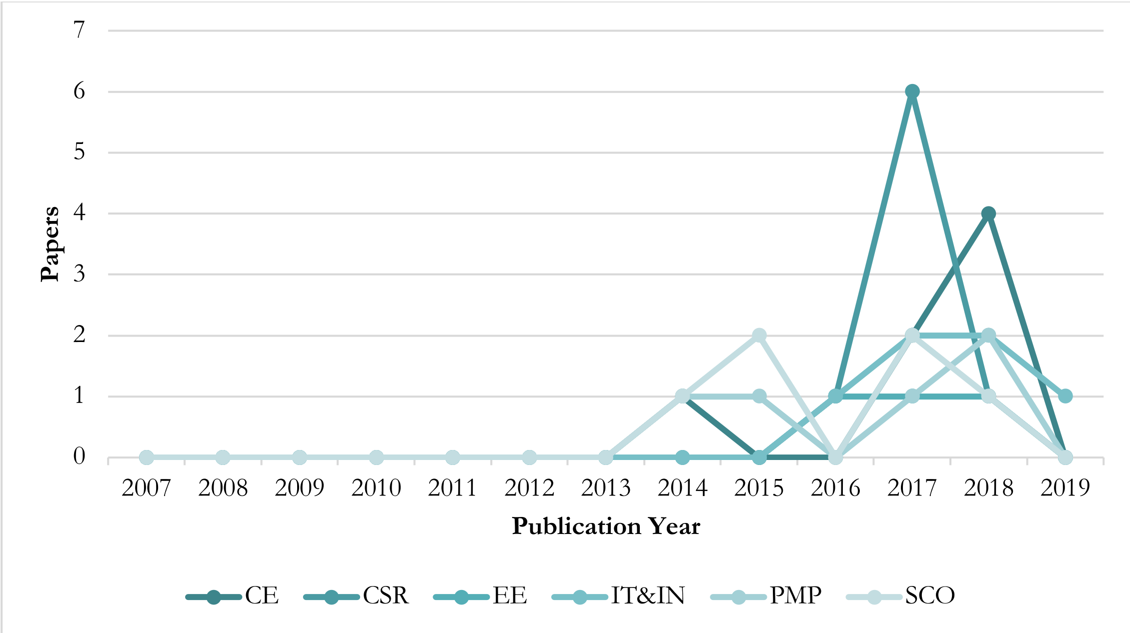

Figure 1.7 Papers per topic-area (**CE**, **CSR**, **EE**, **IT&IN**, **PMP**, **SCO**)

3. *Circular Economy (CE)* can be defined as an economic model wherein resourcing, purchasing, production, and reprocessing processes are designed to consider environmental performance, human well-being and to respond to environmental constraints (Murray et al., 2017; Durán-Romero et al., 2020, Ferasso et al., 2020; Johansson and Henriksson, 2020) . All the seven papers assigned to this topic-area deal with issues related to reverse logistics and closed-loop SC for the creation of systems where waste to disposal processes is minimized exploiting reusing, repairing, remanufacturing, and recycling processes.

4. *Corporate Social Responsibility (CSR)* is the fourth area identified and comprises eight reviews that examine how corporate social sustainability is investigated in the SCM domain. According to Anisul Huq, Stevenson, & Zorzini, (2014), social sustainability can be defined as a holistic concept to be integrated with the other two dimensions of TBL, recognising stakeholders within and beyond the SC, and attempting to ensure long-term benefits for society. Only after 2015 researchers reviewed papers analysing the links between the social sphere and the SC.

5. *Energy Efficiency (EE)* comprises three papers dealing with the identification of energy efficiency and environmental sustainability initiatives adopted in SC. The concept of EE emerged in the sustainability literature in recent years since it represents an essential resource for economic and social development, providing substantial benefits for different stakeholders (Marchi & Zanoni, 2017).

6. *Information Technologies and Innovation (IT&IN)* is the area involving six reviews focused on the various phases, key themes, and pivotal practices in the evolution of information systems and innovation processes, as well as the relationship between IT, innovation, SC, and sustainability.

7. *Production Management Paradigms (PMP)* area includes five reviews evaluating the state-of-the-art of research into the links between organisational paradigms, SC management, and sustainability issues. Lean manufacturing is considered one of the most influential paradigms in manufacturing (Forrester et al., 2010). As empirical evidence suggests, it improves the competitiveness of organisations (Tiwari, Sadeghi, and Eseonu, 2020) by reducing inventories and lead-times, and improving productivity and quality (Abdul Wahab et al., 2013).

8. *Supply Chain Operation (SCO)* area includes six reviews focused on specific SC operations (e.g., purchasing, manufacturing, sourcing, product development).

Perspectives

According to Cooper (2010), the review perspective is commonly considered as the point of view through which authors examined and synthesised the focus of the papers analysed. After reading the full text of the papers, eighteen different perspectives of analysis have been identified (Table 1.2). The results show that the most analysed perspectives are *factor affecting*, *sustainability dimensions, operations, and theories*.

Table 1.2 Perspectives per topic-area

Perspectives	**Topic Area**								**Total**
	SSCM	GSCM	CSR	CE	SCO	IT&IN	PMP	EE	
Factors affecting	x	x	x	x	x	x	x	x	8
Sustainability dimensions	x	x	x	x	x	x	x		7
Operations	x	x	x			x	x	x	6
Theories/Theoretical lenses	x	x	x	x	x	x			6
Industry sector	x	x	x	x		x			5
Performance measure	x	x	x	x				x	5
Modelling approach	x	x			x		x		4
Collaboration	x	x			x				3
Methodology/Research design	x	x			x				3
Strategies		x	x					x	3
Configuration	x			x					2
Definitions	x	x							2
Governance mechanism	x	x							2
Keyword		x	x						2
Supply chain actor's links and connections	x			x					2
Supply chain processes					x		x		2
Decision Levels	x								1
Research framework and elements	x								1
TOTAL	15	13	8	7	7	5	5	4	

Once the list of perspectives adopted in previous LRs has been identified, the process of analysis of such perspectives is carried out. This methodology allows to cluster the perspectives and represent them in a graph, based on two main indices: the *degree of coverage* (obtained considering the ratio between the areas covered by a perspective and the total of areas identified in the previous section) and the *occurrence* of each perspective (defined as the ratio between the LRs that adopt each perspective and the total of LRs included in the sample). Through this analysis, it is possible to classify the perspectives into four clusters: (C1) specific and rare; (C2) specific and recurrent; (C3) broad and rare; (C4) broad and recurrent. Figure 1.8 reports a clear and concise picture of the main perspectives of analysis adopted in sustainability research.

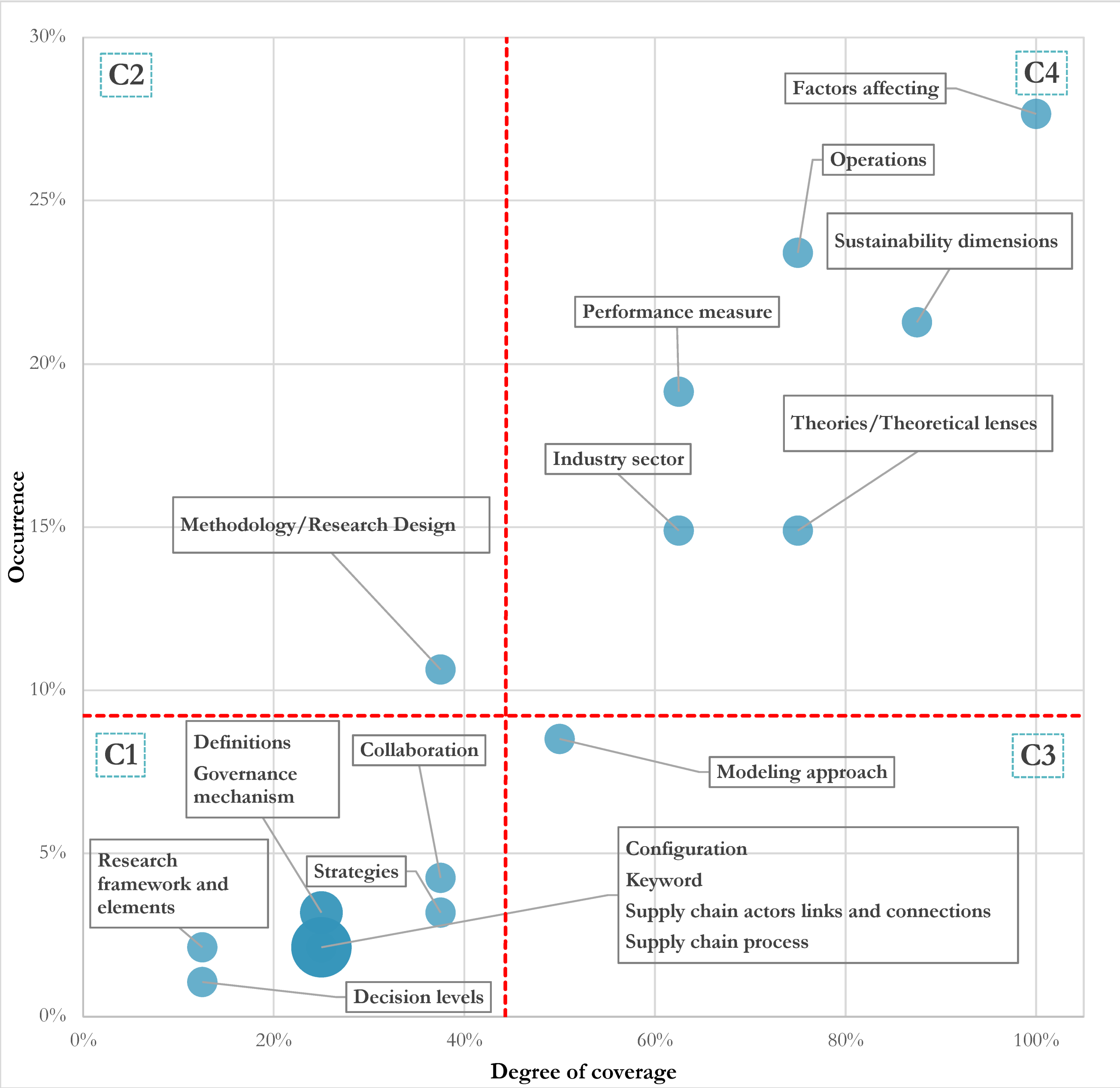

Figure 1.8 Analysis of perspectives adopted by previous reviews

Specifically, on the x-axis the degree of coverage has been reported whereas on the y-axis the occurrence. A circle represents each perspective within the graph. The width of the circle considers the number of perspectives characterized by the same coordinates. The four quadrants delimited by the red dotted lines are identified considering the median values of the dimensions reported on the axes to mitigate the effects of outliers.

The first cluster includes all the perspectives that are poorly treated in the literature and have a low level of interdisciplinarity. Therefore, these perspectives have not been analysed by many reviews and are linked to one or few topic areas. The second group includes perspectives with high values of occurrence and, therefore, widely treated in literature but with a low degree of interdisciplinarity. The cluster C3 includes cross-topic perspectives, not frequent in the literature. Finally, the cluster C4 includes the most widely investigated perspectives in terms of both occurrence and coverage.

Among the eighteen perspectives identified, cluster one contains the largest number of perspectives. Within cluster 1, it is possible to prioritize the perspectives considering the increasing degree of coverage and occurrence. As a result, the prioritisation of cluster one is the following:

1. *Decision levels*
2. *Research framework and elements*
3. *Configuration*
4. *Keywords*
5. *Supply chain actor's links and connections*
6. *Supply chain process*
7. *Definitions*
8. *Governance mechanism*
9. *Strategy*
10. *Collaboration*

The prioritisation process facilitates the following process of analytical extraction and definition of the research proposal carried out in the next section. The Cluster 2 includes a single perspective (i.e., *methodology and research design).* Also*,* Cluster 3 includes a single perspective – *modeling approaches* – that is interdisciplinary but adopted by a limited number of papers. Finally, the Cluster 4 includes the most used perspectives with a high level of interdisciplinarity, such as *performance measures, industry sector, operations, factor affecting, theories and theoretical lenses.*

The research proposals that will be defined in the following section will be identified starting from the perspectives belonging to cluster 1 since it includes the topics scarcely analysed by researchers and in few topic areas.

1.5 Identification of future research and managerial directions

In this section, the third step of the proposed methodology is presented. The analysis of the research gaps will lead to the definition of the research agenda outlined in the next paragraph. This process is carried out systematically following a five-step process:

- Identification of research gaps.
- First-tier gap classification.
- Second-tier gap classification.
- Gaps prioritisation.
- Identification of future research directions.

1.5.1 Identification of research gaps

In the first step, the most relevant research gaps reported in the literature and mentioned by authors have been collected by two researchers in parallel, plus a third one in case of uncertainty. This analysis has been based on full paper evaluation and not merely on reading abstract or specific paragraphs.

1.5.2 First-tier gap classification

Starting from the list of gaps identified, they were firstly categorised into three main categories:

- Context-based gaps
- Methodology-based gaps
- Content-based gaps

The first two categories include gaps that cannot be linked to a specific topic. These gaps are transversal to many research themes, so they are often identified in the literature. These can be found in all the areas identified and in both empirical and conceptual papers.

Specifically, the *context-based gaps* are easily defined as they identify the possibility or need to analyse the same topic taking into consideration different contexts. The context-gaps show the need to expand the research in other sectors, consider a different country (e.g., emerging economies) or a different industry as a unit of analysis. *Methodology-based gaps* relate to the suggestions of adopting other methodologies and compare findings.

More in detail, the need for new conceptual frameworks, theories, and business models to integrate the sustainability dimensions inside organisations have been identified. Fall under this category also gaps related to empirical analysis with qualitative and quantitative approaches adopting both primary and secondary data, longitudinal analysis, and data triangulation methodologies. Updated simulation and mathematical models appear to be also necessary for a different context (Min and Kim, 2012; Srivastava, 2007). The map related to context-based gaps and methodology-based gaps (Figure 1.9) shows the publication year on the x-axis, while the different gaps divided by category (context-based; methodology-based) on the y-axis. The circles in the graph represent the temporal trend of the gaps over time. Specifically, the width of the circle identifies the frequency with which the authors have found the specific gap.

As can be seen from Figure 1.9, context-based gaps do not emerge until 2013. This result may be linked to the increasing number of papers on the theme of sustainability which require a broader diversification from the contextual point of view. Analysing the upper part of the map (i.e., evolution of methodology-based gaps), it is possible to notice two gaps that have an almost constant trend over time - the development of new theoretical models and new research methodologies. This result is not surprising because the evolution of the sustainability topic over time leads to the definition of new theoretical models and methodologies. Except for data triangulation which appears only in 2017, in recent years the need to build new frameworks, business models, simulation models, and longitudinal analyses is growing. The analysis of these gaps, although important to give a general picture on the topic of sustainability, does not require a further phase of prioritisation since, given the nature of these gaps, they will not contribute to the definition of the research agenda developed in the next section.

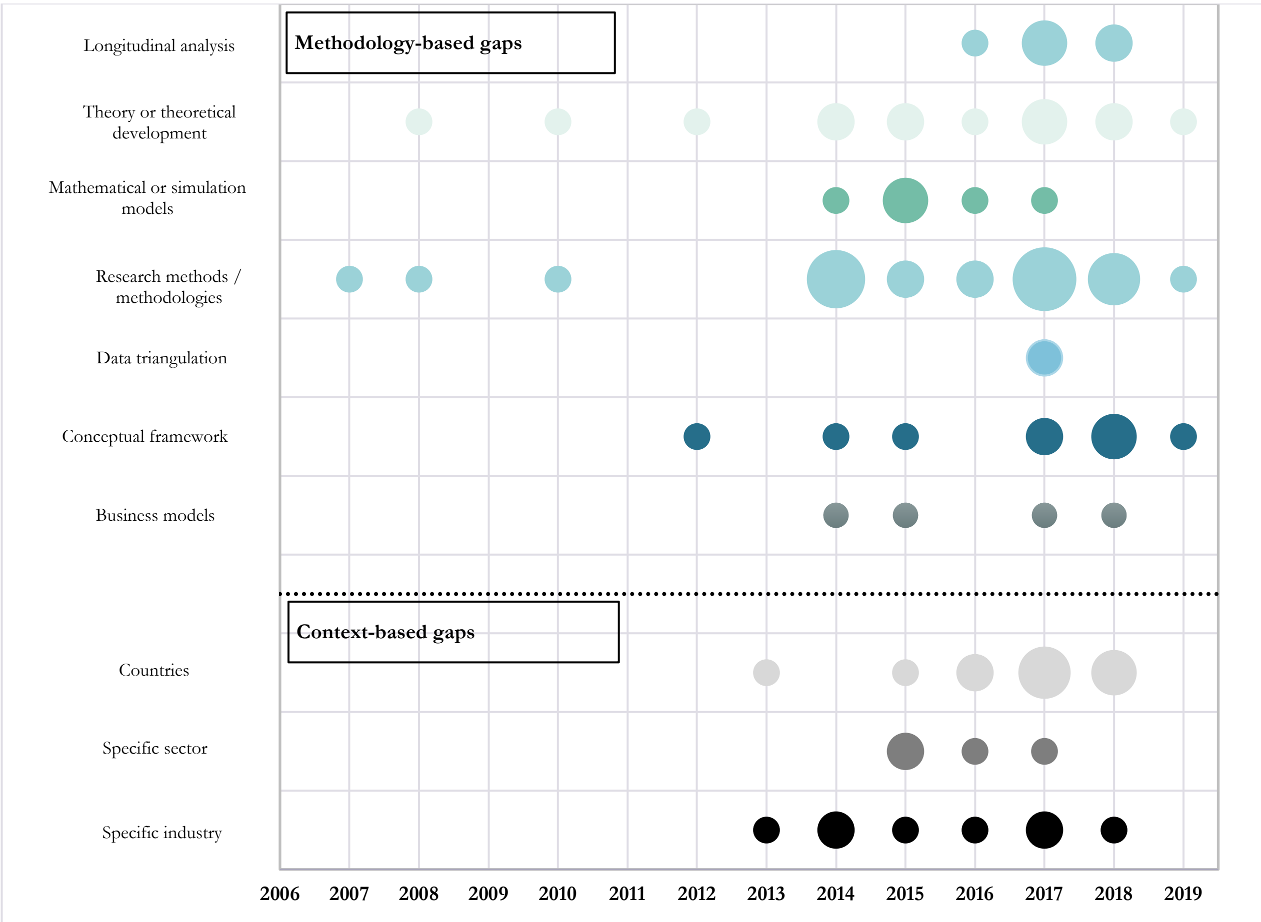

Figure 1.9 Analysis of methodology-based and context-based gaps

1.5.3 Second-tier gap classification

The third category identified refers to *content-based* gaps. These gaps refer to a specific theme and cannot be generalized on a broad spectrum. Two subcategories were defined to have a more exact and detailed view of the latter category:

- Primary gaps.
- Contemporary gaps.

Primary gaps refer to research directions connected to basic perspectives such as practices, drivers, performance assessment that result to be rather constant over the years. In this category there are the need for new sustainability performance measures and assessment, the identification of new factors affecting sustainability in SCM, such as drivers and barriers to achieving sustainability practices and sustainable strategies.

Contemporary gaps refer to specific topics or perspectives of analysis that may emerge contexts or years.

From this categorisation, it emerges that the sustainability concept evolved over the years and, nowadays, the main goal of all companies is to integrate all the three sustainability dimensions – economic, environmental, and social sustainability – and this aspect still requires investigation. Despite the number of papers addressing social sustainability issues is growing in recent years, several studies identified the analysis of social dimension as a research gap. This may be caused by some concerns in measuring and collecting data for social sustainability measures.

Most of the papers acknowledged the complexity of pursuing a sustainable SC and observe that an efficient and sustainable SCM requires the involvement of all the SC network actors. The collaboration between internal and external stakeholders – including governments and NGOs but also company employees – still needs attention and could be further investigated.

Our findings also show that the potential of new ICTs and, more generally, of new technologies may support companies in achieving sustainability goals. In this line, the Fourth Industrial Revolution – mainly known as I4.0 – is completely revolutionising production processes. Therefore, the impact of I4.0 on sustainability issues represents an interesting area to be further investigated in the following years. Hence, especially as concerns environmental sustainability in manufacturing industries, the production processes and logistics flows assume a crucial role and studies related to closed-loop SC, reverse logistics, and lean aspects are always needed.

Following the subdivision, the second map of the gaps represented in Figure 1.10 was built. As for the map in Figure 1.9, this also presents the evolution of the gaps over time according to the category. The analysis of the map allows to identify the hot topics that will be the starting point for the construction of the research agenda that will be discussed in the next sections.

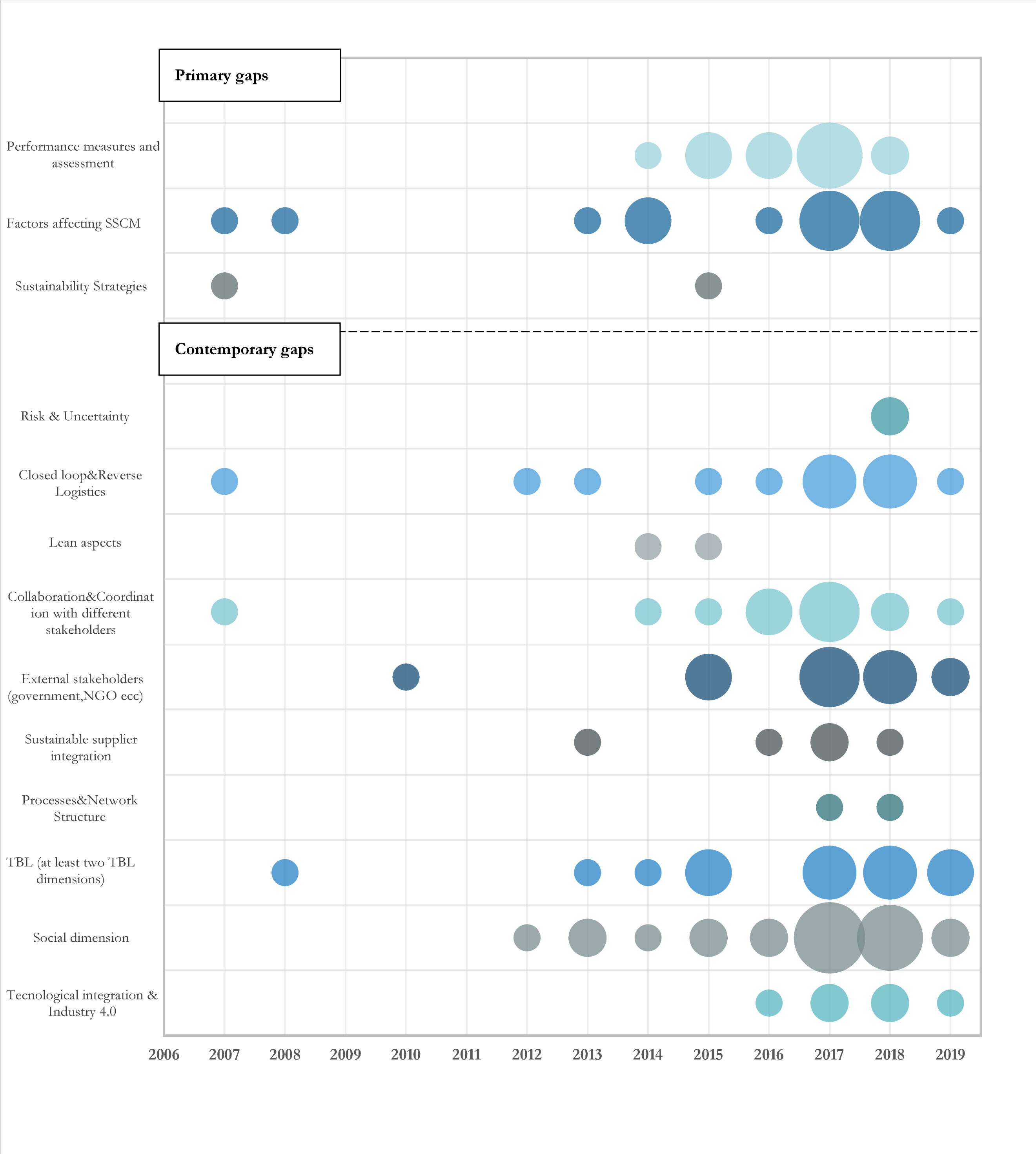

Figure 1.10 Analysis of content-based gaps

1.5.4 Gaps prioritisation

To facilitate the definition of the research agenda and related research questions, analysing the evolution of the gaps, it is possible to introduce the step related to the prioritisation of the research gaps. The prioritisation is carried out considering the recurrence of the gap in the years and the degree of frequency in the most recent years. Specifically, a gap that evolves over a wider period but is less recurrent in recent years has a lower degree of importance than a gap found more recently and more recurrent in recent years (e.g., in our analysis, TBL has a higher degree of importance than social dimension). In this way, it is possible to define the following prioritisation of contemporary gaps:

1. TBL.
2. Social dimension.
3. External stakeholders' involvement.
4. Closed-loop & reverse logistics.
5. Collaboration and coordination with different stakeholders.
6. Technological integration & I4.0.
7. Risk and uncertainty.
8. Supplier perspective.
9. Process & network structure.
10. Lean aspects.

In the same way, prioritisation has been carried out for primary gaps as follows:

1. Factors affecting SSCM management
2. Performance measure and assessment
3. Sustainability strategies

The prioritisation process has highlighted the most recurrent and challenging gaps in the last few years that have not yet found a comprehensive answer and can be addressed in-depth by future researchers. From the practitioners' point of view, this map clarifies the issues that still represent a challenge for research and on which it would be fruitful to invest.

1.6 Discussion

The last step of the methodology consists in the definition of the research agenda. The formulation of the different research proposals has been structured considering the less frequent and less transversal perspectives of the literature. Previous analysis showed that the perspectives and the research gaps identified in the reviews analysed are strictly related. Our analysis reveals that most of the perspectives of analysis adopted by previous studies are mainly methodology-based or generic and not focused on specific subjects. Specifically, all these perspectives can be applied to several contexts, even very far from sustainability in the SCM domain. This is the case of most of the perspectives of analysis belonging to cluster C4. This is also the case of perspectives of analysis like activities, barriers, drivers, empirical papers, industry sector, qualitative and quantitative approaches, which also represent methodology-based gaps and primary gaps. It is almost the same for other generic perspectives of analysis like factors or performance measures. Indeed, *performance measures* is the most used perspective of analysis to classify the papers in literature reviews. This demonstrates that despite most authors of primary studies put their efforts in proposing new measures to analyse sustainability performance, the complexity of the environment and context in which companies operate require new and innovative indicators to assess sustainability performance. On the contrary, specific perspectives of analysis cannot be adopted in multiple contexts. Specific perspectives, like leadership, decision level, and collaboration, represent original perspectives of analysis which will require more attention by future researchers. Except for some contemporary gaps, like TBL and social dimension, it was found that contemporary gaps are still a prolific research avenue. The prioritisation process of contemporary gaps highlighted the real research lacks. Based on the findings resulted from the gaps map in Figure 1.10, a series of recommendations have risen, which form the basis of our research agenda reported in Table 1.3.

Table 1.3 Research agenda

Gaps typology	Gaps	Research Proposals
Contemporary	TBL	Integrate TBL and digitisation by highlighting the impacts of enabling technologies on the three perspectives of economic, environmental, and social sustainability. Identification of holistic models that consider the interactions between the three different perspectives of the TBL and the decision-making levels (strategical-tactical-operational).
	Social dimension	Evaluate whether CSR efforts by companies are perceived by their customers and how to respond to pressures for global integration and local responsiveness.
	External stakeholders' involvement	Evaluate how external stakeholders can influence relationships between sustainable supplier development practices and customer performance. Examine the different roles stakeholders can play (e.g., community actors, associates, non-governmental managers, and employees) to implement sustainable supply networks. Define evaluation and management measures of stakeholders for monitoring the effectiveness and efficiency of SSC systems.
	Closed loop & reverse logistic	Evaluate how reverse logistics and closed-loop SCs can be used to implement sustainable green SC practices. Deepen the theme of green network design in reverse logistics to evaluate the performance in terms of individual activities of a green SC such as green logistics, green production, green supply processes. Make use of data analysis and data mining techniques to evaluate current CE practices regarding environmental impact to reduce inefficiencies and bottlenecks.
	Collaboration and coordination with different stakeholders	Identify tools for the development of collaboration and coordination between stakeholders. Evaluate how blockchains impact collaboration between different actors of the network to reach a high level of sustainability performance. Define metrics for assessing the level of awareness of employees in the implementation of sustainable practices. Evaluate how the use of I4.0 technologies for sustainable management impacts internal stakeholders' involvement.
	Technological integration & I4.0	Develop models for the integration of I4.0 technologies (Big data & Analytics and IoT) in the context of SSCs.
	Risk and uncertainty	Define risk and resilience metrics that should be incorporated into the sustainable supply network to support management decisions.
	Supplier perspective	Develop conceptual models to examine and define the process to adopt sustainable practices in the supply network structure. Integrate the perspectives of internal and external processes in designing SSCs.

	Process & network structure	Expand the discussion on the supplier selection process, considering both parameters related to the TBL, and other factors related to digitisation, relationship, and risk management. Assess how relationships between suppliers and customers change following the introduction of sustainable practices.
	Lean aspects	Design models for measuring the degree of compatibility between lean and green strategies. Develop new integrated paradigms that consider the Lean, Sustainable, and I4.0 aspects.
Primary	Factors affecting sustainable supply chain management	Investigate the interaction between factors affecting SSCM and supply network structure/complexity.
	Performance measure and assessment	Design "easy-to-use" decision performance measures to support companies in assessing intangible factors affected by sustainable initiatives.
	Sustainability strategies	Development of new strategies to raise the awareness of SC partners to sustainability issues.

1.7 Formulation of research questions

The research proposals derived from contemporary gaps highlight the need for new integrated paradigms, holistic and conceptual models. The latter integrates the concept of SCs' sustainability with aspects apparently heterogeneous and strictly different from this research field such as I4.0 technologies, decision-making level (i.e., strategical-tactical-operational), risk and uncertainty. It also emerges growing attention to social aspects through the definition of sustainable consumption models, as envisaged by objective n.12 of the 2030 agenda of sustainable development goals drawn up by the United Nations. Another relevant point is linked to the role of external and internal SC stakeholders (e.g., government, suppliers, customer, NGOs) and their influence in creating sustainable networks. Furthermore, a relevant issue highlights the need to transform the traditional linear SC configurations into closed ones to facilitate the adoption of sustainable and circular SC operations practices. It is also necessary an impact and degree of compatibility assessment of CE and lean practices. Finally, in the prioritisation of primary gaps, factors affecting SSCM were found first. This gap emphasizes the need to investigate the interactions between the different factors analysed in the literature and the complexity of the SC network/structure. Performance measures and assessment gap identifies the call for new easy-to-use metrics for assessing intangible factors deriving from the adoption of sustainable models such as the level of customer awareness, the degree of involvement of internal stakeholders the level of resilience. Finally, as for sustainable strategies, it emerges the importance of implementing strategies capable of developing SC partners' awareness of sustainability issues.

It is therefore noted that despite the substantial literature on the topic of sustainability in the SC, there are still numerous areas that need to be further explored. The thesis therefore has the objective of responding to some of the research needs that emerged. In particular, with reference to the primary gaps, three gaps emerged from the prioritization. I have put my focus on the first two gaps that are considered the less analysed. Specifically, the first related to the factors that influence the sustainability of the SCs and the second related to the identification of performance measures. Based on the forgoing, l formulated the following research questions:

1. What are the main metrics adopted to evaluate the impact of I4.0 in the context of SSCM?
2. What are the practices that affects sustainability along the whole SC?

Once these two gaps were addressed, I focused on contemporary gaps. Given the number and complexity of the gaps identified, I tried to identify a model that could include the crucial aspects of the sustainability in SCs from a broader perspective. This because, from the categorization of the reviews according to the topic area, a scarcity of studies on production management paradigms emerged. Furthermore, this aspect was crossed with some of the gaps identified among contemporary gaps. Precisely, the attention was focused on those gaps that could be integrated and analyzed within a single organizational paradigm and among these I4.0, TBL and lean aspects have been chosen. In fact, these gaps were evaluated synergistically and led to the definition of the following research questions:

3. How can I4.0 technologies support lean and sustainable practices?
4. What is the impact of the integration of I4.0 technologies, lean and sustainable practices on the performance of the whole SC?

The four identified questions guide the discussion throughout the thesis. In particular, the next chapter focuses on the analysis of the metrics used to assess the impact of I4.0 technologies on sustainability. Subsequently, a model is proposed that identifies the practices that enhance the sustainability of SCs. Finally, by integrating some of the aspects identified in chapters 2 and 3, the discussion moved on to the formulation and testing of the integrated framework.

CHAPTER II: UNVEILING THE RELATIONSHIPS BETWEEN SUSTAINABILITY AND INDUSTRY 4.0 TECHNOLOGIES

Summary

This chapter highlights the main sustainability metrics associated with digital technologies. Specifically, the digitalization process enhances the connection of products and factories, the value chain, and users to achieve a production cycle as sustainable as possible. The new technologies developed allow companies to foster innovation and entrepreneurship, increase the market share, reduce energy waste, recover, and reuse the material, etc. Thus, this study aims to find a connection between I4.0 and sustainability by identifying and categorizing the main performance measures of the impact of I4.0 technologies in the sustainable environment.

2.1. Introduction

Sustainability represents one of the most addressed issues of the last decade. This concept has evolved over the years. Initially, the term sustainability referred only to environmental features related to the reduction of carbon footprints, CO_2 emissions, water waste etc. Nowadays this concept has acquired a new meaning linked to the TBL (Choi and Ng, (2011); Ford and Despeisse, 2016). The latter was firstly introduced by Elkington in the late 90s (Elkington, 1998). In line with the TBL, organizations must be economically viable, environmentally friendly and socially responsible to be considered sustainable (Carter and Rogers, 2008). Although sustainability has acquired a broader meaning, there is a widespread tendency to link this topic with the impact of certain systems or activities on the environment in its respective sphere of influence. Despite the apparent prevalence of the environmental factors, the social and economic aspects of sustainable development are equally important within the sustainability of companies. Nonetheless, environmental aspects of sustainability dominate the stand-alone research, on the contrary measuring its interaction with social and economic performance is less developed (Batista et al. 2017). Companies tend to assess their impact on the economic conditions by adopting various metrics such as the Global Reporting Initiative´s (GRI) sustainability indicators and Dow Jones sustainability index (Calabrese et al. 2019). Parallel to the trend of organizations to comply with sustainability standards, in recent years we have seen the transition of organizations towards the model of *Smart Factories*. This phenomenon is better known as I4.0. Previous contributions consider I4.0 the epitome of the digitalization of manufacturing (Sung 2018; Telukdarie et al. 2018). This transition deals with the accumulation of technology incorporated into successive generations of advanced tools and techniques (Szalavetz 2019). According to Kagermann, Wahlster, and Helbig (2013), the main ideas of I4.0 have also become a strategic initiative of the German government which has included this concept in the "High-Tech Strategy 2020 Action Plan". Similar strategies have also been implemented in other industrialized countries, e.g., USA, China, United Kingdom, and others (Kumar et al., 2020). Nowadays, the fourth industrial revolution aims to achieve faster innovation in manufacturing processes with greater efficiency of the value chain (Ben-Daya, Hassini, and Bahroun, 2019). I4.0 allows flexibility and customization of products and services and, consequently, increases the maximization of profitability (Schmidt et al. 2015). The strong emphasis on digitalisation has prompted researchers to analyze the I4.0 - sustainability dichotomy (Ghobakhloo, 2020; Stock and Seliger, 2016). As part of the link between I4.0 and sustainability, these studies evaluate the different possibilities of digital technologies in improving green practices. The implementation of I4.0 in the sustainable context is favouring important changes at the organization level. In this perspective, numerous authors have expressed the need for studies on the impacts of these technologies on the TBL (Ivanov, Dolgui, and Sokolov, 2019; Prause, 2015), (Quezada et al., 2017). Specifically, few studies focus on the identification of metrics to assess the impact of I4.0 on sustainability. This chapter aims to fill this gap and find the connection points between sustainability and I4.0 technologies. This objective is addressed through the definition of a taxonomy of the main sustainability metrics related to digital technologies.

2.2 Theoretical Background

2.2.1 Industry 4.0

In the last decade, the economy has been witnessing the digital transformation of the industry. The fourth industrial revolution is now considered a successful phenomenon, rather than a pure media event (Ardito et al. 2019; Buer et al., 2018). Even before the introduction of the I4.0 concept, Rifkin (2011) identified the Internet and green energies as the key elements of the new industrial revolution. The former allows easy access to information and easy trade in goods and services and the latter reduces the energy impact on the environment.

Following the introduction of the term I4.0 in 2011, the digital transformation has immediately captured the attention of industrialists and governments around the world (Ghobakhloo et al., 2021; Nascimento et al., 2019). Following the presentation of the German government plan, numerous initiatives were promoted by various government entities for the redefinition of modern production, aimed at a radical improvement and a deepening of the vision described, guided by the strengthened link between science, technology, and industry. Liao et al. (2017), in their systematic review of the literature, have reconstructed the government plans that arose in less than ten years, and which therefore aim to exploit all the potential promised by the fourth industrial revolution. In 2011 the United States (USA) define a novel program called "Advanced Manufacturing Partnership (AMP)" to support manufacturing companies. In 2012, the German government approved the "High-Tech Strategy 2020" action plan, to allocate funds reserved for technological development. In 2013 the French government defined "La Nouvelle France Industrielle", an action plan consisting of more than 30 sectoral initiatives for industrial revitalization. In 2013, the United Kingdom government presented the "Future of Manufacturing". This plan aims to provide a policy for the growth and resilience of United Kingdom manufacturing over the coming decades. In 2014, the European Commission presented the new contractual Public-Private Partnership (PPP) on the "Factories of the Future (FoF)". In the same year, the South Korean government announced the "Innovation in Manufacturing 3.0" program for the development of Korean manufacturing. In 2015, the Chinese government issued the "Made in China 2025" plan together with the "Internet Plus" plan, which prioritizes different sectors in the manufacturing industry to accelerate computerization and industrialization in China. In the same year, the Japanese government adopted the 5th foundation plan for science and technology, in which special attention was paid to the manufacturing sector for the realization of its world-leading "Super Smart Society". In 2016, the Singapore government committed nearly $ 20 billion to its Research, Innovation and Enterprise (RIE) 2020 plan. Following the European elections in May 2019, the European Union set several priorities that shape the political and policy agenda until 2024.

Among the various priorities, the concept of Industry 5.0 was introduced as a natural continuation of I4.0 capable of providing a vision of industry that aims beyond efficiency and productivity reinforcing the role and the contribution of industry to society. Given this background, all companies in the world can only take an interest in the digital transition. In that, the adoption of I4.0 technologies allows the conversion of common machines into self-aware and self-learning equipment to improve performance and overall value chain management (Javaid and Haleem, 2019; Vaidya, Ambad, and Bhosle, 2018).

I4.0 ensures that manufacturing integrated with information technology, the result of this collaboration action translates into the development of “intelligent” factories that are highly efficient in the use of resources capable of adapting rapidly to the changing needs of stakeholders, to meet company objectives (Wittenberg 2016). The advent of the fourth industrial revolution has also redefined the integration of the physical world into the organization and the cyber world through technologies such as artificial intelligence, analytics, cloud technology, internet of things, etc. (Bassi, 2017; Fonseca, 2018; Xu and Duan, 2019). Digital transformation has not only changed the way an organization operates but the market is also transformed by considering the entire value chain (Oesterreich and Teuteberg 2016). Regarding macroeconomics aspects, I4.0 has developed a profound impact on factories, public and private sectors, economies, etc. Digital solutions are therefore the most important tool to overcome the crisis triggered by Covid and, at the same time, relaunch competitiveness.

Digitalization is one of the main levers on which the European Commission is aiming to complete the Action Plan, while the new 2021-2027 Union programming is about to start. The central issue is that of the digitalization of industrial processes. A paradigm change that involves the digital integration of all business sectors, starting from the analysis of customer needs and the potential of the market, passing through design to get to production, and then extend to logistics and sales, and the after-sales service, in a constant flow of data that connects machinery, people and systems. It is an opportunity to integrate new production processes, new strategies, new professional figures internally, giving space to innovation, freeing up creativity and allowing you to optimize costs, speed up management, improve efficiency. There are developing countries that are already adopting I4.0 solutions, such as China and India. The latter are completely changing their strategy. In the past, they were characterized by a cost of labour. This is no longer possible as I4.0 requires highly specialized operators.

Although I4.0 is one of the most discussed topics among practitioners and academics in recent years, no single and commonly accepted definition of this concept has been developed (Buer et al., 2018; Mrugalska and Wyrwicka 2017). Researchers and industrialists have divided opinions on which elements constitute I4.0, how these elements are related and where I4.0 technologies apply. Previous contributions show over 100 different definitions of I4.0 (Moeuf et al. 2018). According to the authors, the definition that well reflects the idea of I4.0 is the one proposed by Leyh, Martin, and Schaffer, (2017): "I4.0 describes the transition from centralized production to very flexible and self-controlled production. Within this production, products, all affected systems, and all stages of the engineering process, are digitized and interconnected to share and transmit information and to distribute this information along vertical and horizontal value chains and beyond in broad networks". From this definition, it is clear that I4.0 must be integrated with paradigms already adopted in organizations such as the sustainable one.

2.2.2 Sustainability

Sustainability is a broad concept that addresses most aspects of the human world (Beier et al., 2017). Sustainability is not limited to the environment, but also concerns economic and social resources (Choi and Ng, 2011; Ford and Despeisse, 2016). Environmental sustainability concerns the balance of environmental systems, the consumption and supply of natural and ecologically intact resources (Glavi and Lukman, 2007). Economic sustainability is about long-term economic growth while preserving environmental and social resources. Economic sustainability is not that far from the balance between natural resources, social well-being, and ecosystems (Choi and Ng, 2011; Cricelli and Strazzullo 2021). Social sustainability is the process of recognizing and managing corporate, environmental, economic, and technological impacts on people. Social sustainability aims to create a community where everyone is protected from discrimination and has the same human rights as well as basic services (Dempsey et al., 2011). Sustainability in general is seen as a movement to ensure better and more sustainable wellbeing for all. Although sustainability is a relatively new concept, it has its roots in movements such as conservationism or socio-economic justice (Caradonna, 2014). The concept of sustainability has gained more and more importance in the SC in the last two decades (Pieroni et al., 2019). In fact, the constant increase in competition globally has prompted companies to adopt sustainable practices (Shibin et al., 2018).

Sustainability runs through all processes, starting from the generation of the idea to the delivery of the final product, to the customer (Bastas and Liyanage, 2018). SSCM can be described "as managing the activities, operations, resources, information and funds of the SC, with the aim of maximizing profitability of SCs, as well as social well-being and, at the same time, minimize negative environmental effects"(Hassini et al., 2012, Shi et al., 2017). It focuses on preserving the environment and improving the socio-economic dimension for long-term sustainable development (Ahi and Searcy, 2013, Formentini and Taticchi, 2016, Fahimnia et al., 2017, Linton et al., 2007, Leppelt et al., 2013), pushing companies to improve their performance along SCs (Lin and Tseng, 2016). Implementing sustainable initiatives and programs strengthens the expertise and cooperation between partners by improving their environmental performance, minimizing waste and saving costs (Linton et al., 2007). This reaffirms the need to combine economic, environmental, and social aspects to achieve better sustainable management of the SC.

2.3 Methodology

The theoretical basis of this study that led to the definition of a taxonomy of metrics discussed in the next sections was based on a deductive approach grounded on a large amount of scientific literature and secondary data analysis (Shepherd & Sutcliffe, 2011). A comprehensive narrative literature methodology is used to develop the taxonomy, which comprehensively describes and captures the impact of I4.0 on sustainability of SCs. This approach is particularly useful when the research aims to provide a broad perspective on a given topic from a theoretical and contextual point of view. Narrative reviews are useful in linking together many studies with different but complementary perspectives on a given topic for the integration and comprehensive presentation of theoretical background. The research conducted in this chapter aims to combine knowledge from various perspectives, as a result, narrative synthesis is particularly useful as it allows authors to tell a story based on accounts of previous literature. Narrative reviews usually address a wide variety of perspectives within a given subject, but they do not often specify or include a section describing guidelines about the search strategy (e.g., keywords, database, inclusion/exclusion criteria) (Collins and Fauser, 2005; Henry et al. 2018). On the contrary, systematic review approach reports in great detail materials and methods used to conduct the search, ensuring a rigorous appraisal of validity, the objective or quantitative summary, transparency, rigour, and the evidence-based inferences (Cook et al., 1997). However, for some topics, the systematic review's

strengths can become limitations. The primary issue is that the systematic review requires a well-defined scope and perspective of analysis, as well as the definition of rigorous procedures which, in some cases, may limit researchers in defining the sample of articles.
As a result, broad research topics like sustainable metrics linked to I4.0 technologies would require a wider scope of a systematic review which is in my perspective more aligned to be analysed through a narrative approach. The 32 papers analysed were collected using the following search string:
((“Industry 4.0” OR “digital technologies” OR “smart factories” OR “smart manufacturing” OR “smart production”) AND (“triple bottom line” AND “sustainability”))
Figure 2.1 shows the evolution of papers and citations over the years, while Figure 2.2 highlights the distribution of papers according to the journals.

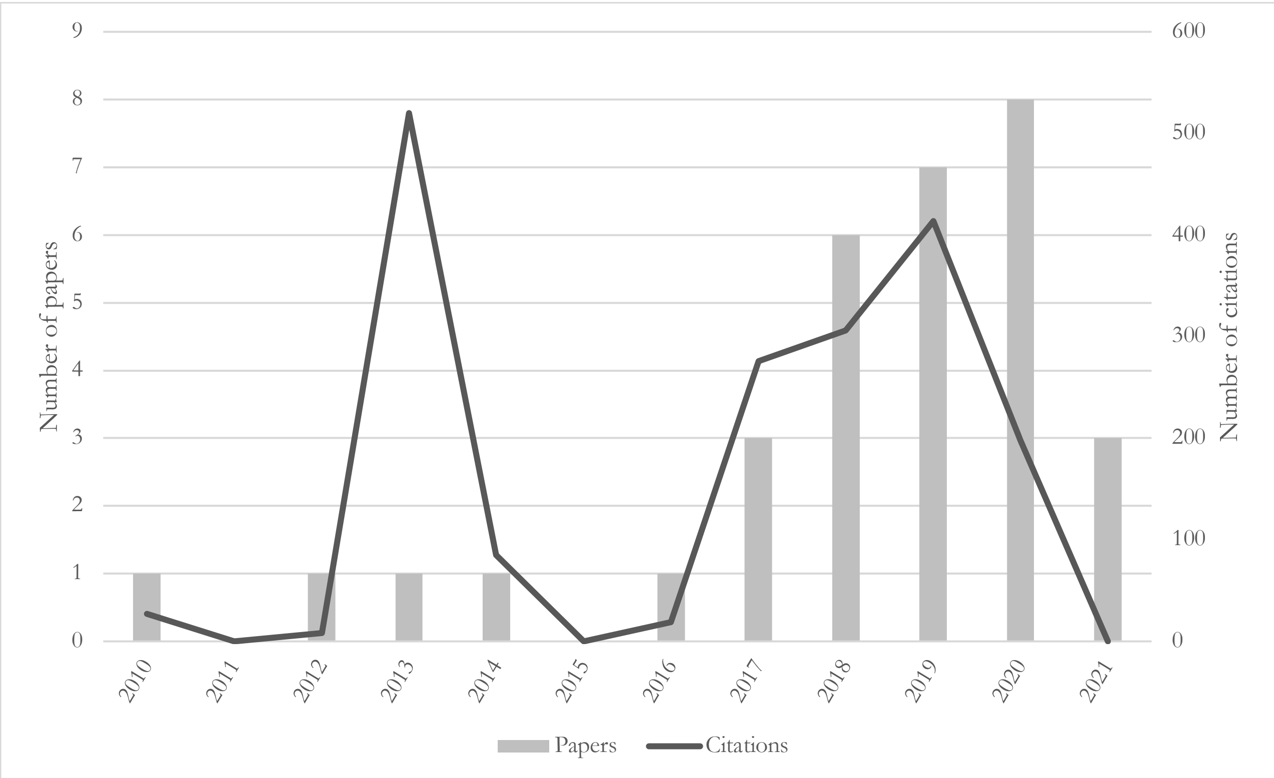

Figure 2.1 Number of papers and citations per year of publication

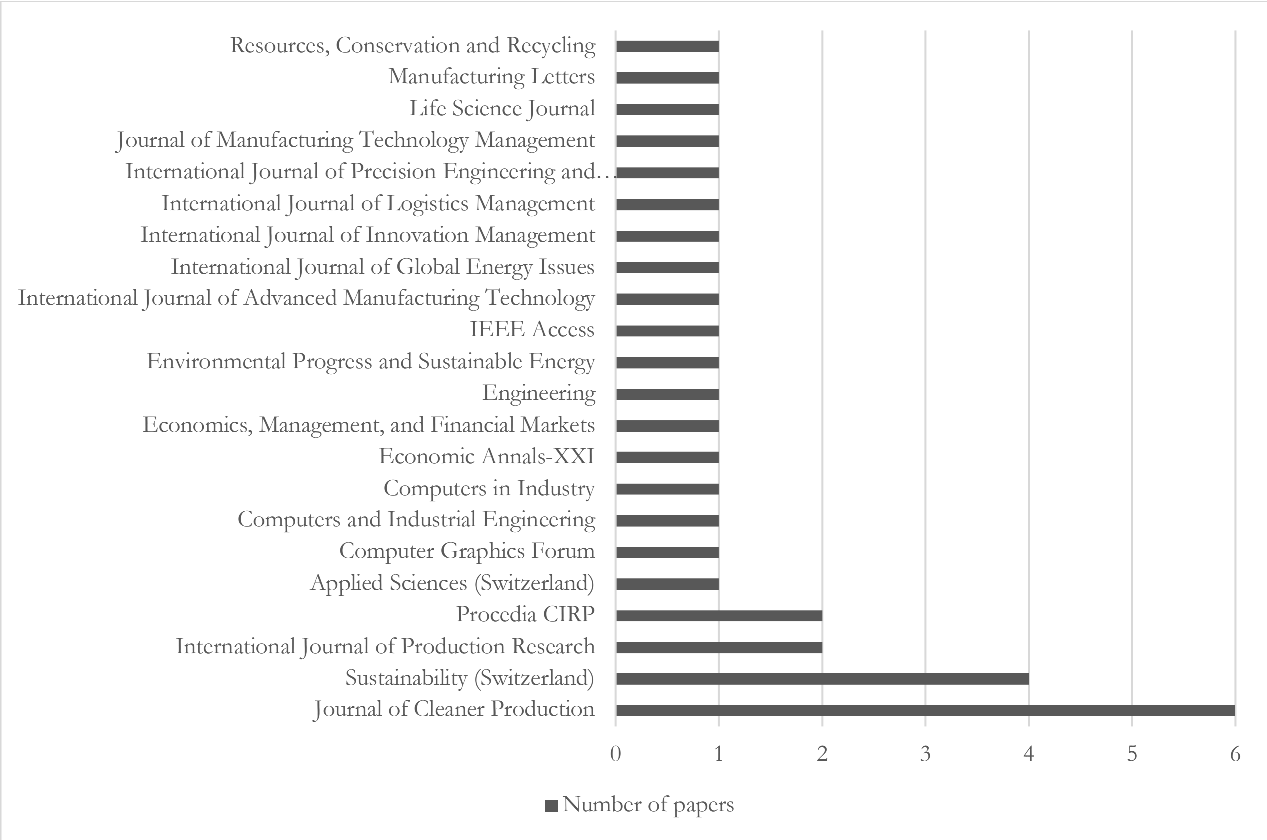

Figure 2.2 Number of papers per journal

2.4 Taxonomy development

Based on the most acknowledged contributions on the topic under investigation, 21 unique different metrics were identified and distinguished in two different areas as shown in Table 2.1. Specifically, direct metrics have an impact on the sustainability of the company, on the other hand, indirect metrics impact the global sustainability of the environment in which operate.

Table 2.1 Classification of sustainability metrics

Sustainability metrics	Definition	Direct	Indirect
1. Competitiveness	Ability to develop and maintain inclusive wealth without compromising the ability to maintain or increase present wealth levels in the future.	x	
2. Customization	Customer involvement in the product design process, customization and information flow between customer and manufacturer		x
3. Economic development	Wealth growth with a positive impact on the community		x
4. Efficiency	Point at which an organization can no longer produce/offer more of one product/service without diminishing the output of another.	x	
5. Extension of product/equipment life cycle	Increase of product/equipment lifecycle even further		x
6. Fostering innovation and entrepreneurship	Massive infrastructure development and massive increase in access to information		x
7. Market share	Increase the portion of a market that is controlled by a single firm or product	x	
8. Reduction of material consumption	Reduction of the number of raw materials and goods in process that are used to produce products during a period like a week, month, quarter		x

9.	Process quality	Extent to which an acceptable process has been created and followed in order to produce the artefacts, including measurements and quality standards	x	
10.	Production costs reduction	Reduction of costs incurred by a company as a result of producing a product or offering a service that generates income. Labour, consumable manufacturing supplies, and general overhead can all be included in production costs.	x	
11.	Productivity	Rate of output per unit of input is a measure of the effectiveness of productive effort	x	
12.	Profitability of investments	Increase in company's ability to provide a return on an investment depending on its resources in comparison to an alternative investment	x	
13.	Reduction of delivery times	Reduction of the amount of time that a company takes to get goods ready for delivery	x	
14.	Reduction of energy consumption	Reduction of the amount of energy or power used		x
15.	Reduction of inventory inaccuracy	Reduction of the absolute difference between physical and information system inventory, divided by the average physical inventory	x	
16.	Reduction of production mistakes and accidental damages	Reduction of machine breakdown or stoppage of production that cause accidental damages.	x	
17.	Reduction of transportation costs	Reduction of the expenses related to the transportation of raw materials, finished products, and employees		x
18.	Reduction of waste costs	Reduction of raw material, labor and waste management costs		x
19.	Reduction of water consumption	Reduction of the amount of water that may be used for production (fabrication, washing, cooling, boiling, etc.)		x
20.	Resources recovery	Ability of using wastes as an input material to create valuable products as new outputs		x
21.	Sales growth	Ability to increase the percentage in sales over a given time period	x	

Following the classification, the metrics were associated with I4.0 technologies. More in detail, the in-depth analysis of the existing literature revealed 11 technologies, each associated with both direct and indirect metrics (Table 2.2).

Table 2.2. Sustainability metrics according to industry 4.0 technologies

Industry 4.0 technologies	Sustainability metrics	References
Additive manufacturing	Customization Economic development Efficiency Extension of the product/equipment life cycle Market share Process quality Productivity Profitability of investments Reduction of delivery times Reduction of water consumption Reduction of inventory inaccuracy Reduction of production costs Reduction of transportation costs Reduction of waste costs Reduction of transportation cost	(Godina et al. 2020; Mehrpouya et al. 2019; Niaki, Torabi, and Nonino 2019; Taddese, Durieux, and Duc 2020; S. Tiwari, Wee, and Daryanto 2018; Turner et al. 2019)

Artificial intelligence	Competitiveness Customization Economic development Extension of the product/equipment life cycle Fostering innovation and entrepreneurship Market share Reduction of water consumption Reduction of production mistakes and accidental damages Reduction of waste costs Resources recovery	(Braccini and Margherita 2018; Kolmykova et al. 2020; Mhlanga 2021)
Augmented reality	Customization Efficiency Process quality Reduction of energy consumption Reduction of production costs Reduction of waste costs Reduction of water consumption Sales growth	(Alahmari et al. 2019; Carbonell Carrera and Bermejo Asensio 2017)
Big data	Competitiveness Customization Economic development Efficiency Extension of product/equipment life cycle Fostering innovation and entrepreneurship Market share Process quality Productivity Reduction of water consumption Reduction of material consumption Reduction of production costs Reduction of production mistakes and accidental damages Reduction of waste costs Resources recovery	(Bag et al. 2020; Braccini and Margherita 2018; Goyal et al. 2016; Kamble, Gunasekaran, and Gawankar 2018; Kolmykova et al. 2020; R Kumar, Singh, and Lamba 2018; Y. C. Liang et al. 2018; Shin, Woo, and Rachuri 2014; Sineviciene et al. 2021; Yuan, Qin, and Zhao 2017)
Blockchain	Economic development Efficiency	(Fraga-Lamas and Fernández-Caramés 2019; Tozanlı, Kongar, and Gupta 2020)
Cloud	Efficiency Process Quality Productivity Reduction of water consumption Reduction of material consumption Reduction of water consumption	(Jena, Mishra, and Moharana 2020; Kamble, Gunasekaran, and Gawankar 2018)
Cyber-physical systems	Process quality Productivity Reduction of production costs Reduction of water consumption	(Y. C. Liang et al. 2018; Popescu, Valaskova, and Majerova 2020; Sebastian Thiede 2018)
Internet of things	Competitiveness Customization Economic development Efficiency Extension of product/equipment life cycle Fostering innovation and entrepreneurship Process quality Productivity Profitability of investments Reduction of water consumption Reduction of material consumption Reduction of production costs Reduction of production mistakes and accidental damages Reduction of waste costs Resources recovery Sales growth	(Belaud et al. 2019; Braccini and Margherita 2018; Kamble, Gunasekaran, and Gawankar 2018; Kolmykova et al. 2020; Mastos et al. 2020; Müller and Voigt 2018; Reif et al. 2010; Y. Zhang et al. 2018)

Radio frequency identification	Efficiency Reduction of inventory inaccuracy	(Cui et al. 2017; Kiel, Müller, and Arnold 2017)
Robotics	Competitiveness Process quality Reduction of production costs Reduction of water consumption Reduction of production mistakes and accidental damages Reduction of waste costs	(Braccini and Margherita 2018; Popescu, Valaskova, and Majerova 2020),
Simulation	Competitiveness Customization Efficiency Extension of product/equipment life cycle Market share Process quality Productivity Reduction of water consumption Reduction of material consumption Reduction of production costs Reduction of production mistakes and accidental damages Reduction of waste costs Resources recovery	(Moon and Mclean 2017; Widok and Wohlgemuth 2011)

2.5 Discussion

The analysis of the existing contribution allows to identify a list of metrics that measure the potential benefits of I4.0 technologies on sustainability. The union between sustainability and I4.0 represents a billion-dollar economic opportunity that, through strategies in terms of interconnection and cooperation capacity of productive resources. It will cause an increase in competitiveness and efficiency and will favour the development of new business models to the point of completely revolutionizing the entire industrial sector. The transition to a sustainable industry model must be guided by a company digitalization process that enhances the connection of products and factories, the value chain, and users to achieve a production cycle as sustainable as possible. The new technologies developed allow the company to save capital, reduce energy waste, recover, and reuse the material, mixing traditional knowledge and new skills, recover more traditional areas to promote new development. From the point of view of the direct effect, the use of technologies such as the internet of things and artificial intelligence increases the efficiency and flexibility of production by facilitating communication with stakeholders (e.g., customers, suppliers, distributors) (Jin et al. 2017). In addition, I4.0 allows the transition to mass customization, optimizing customer requests, reducing waiting times and increasing customer satisfaction (Cai et al. 2019). In the long run, these technologies also positively impact company profitability through the optimization of material flow, reduction of time to market, space optimization, efficient use of resources, reduction of waste, lower inventory costs (Belhadi et al., 2020; Dalenogare et al., 2018). Furthermore, I4.0 favours the creation of new open business models. From the indirect impact point of view, digitalization offers several opportunities to reduce the waste of natural resources and the consumption of materials (Ford and Despeisse 2016). Besides, while it eliminates many low-skilled jobs, it also creates new job opportunities (Brougham and Haar, 2018). Ghobakhloo et al. (2021) have highlighted that in many cases the technology acts as a catalyst, for least developed countries, to accelerate the process of economic modernization. I4.0 is changing the way companies produce, consume, trade and live. This phenomenon has affected all the economic sectors from medical to energy (Huang et al. 2017). The use of technologies facilitates the development of products that respect the global economy (Khorram Niaki et al., 2019).

The digital transformation is changing the way human resources work (Longo, Nicoletti, and Padovano, 2017). The simplification and automation of processes, with consequent improvement of the decision-making process, improve the efficiency of human resources (Sivathanu and Pillai 2018). The use of smart tools allows employees and managers to communicate in a more free and interactive way, reducing the communication gap between leadership, middle management and employees (Corral de Zubielqui, Fryges, and Jones, 2019). The use of artificial intelligence, augmented reality and data analysis can offer personalized professional development schemes or learning programs based on the experience and personality of each employee. Automation, interoperability, contribute to production efficiency, also improving control measures (Lee, Bagheri, and Kao, 2015; Reis and Gins, 2017). Robots, automated vehicles, intelligent machines, simulation are replacing humans in numerous activities such as inventory monitoring, quality control and product distribution (Zheng et al. 2018). Experts expect I4.0 to eliminate most of the jobs with medium-low qualifications that will be compensated by creating new job opportunities in the IT, mechatronics and engineering areas (Ghobakhloo, 2018). Greater productivity, better process stability, product customization and reduction of waste and delivery times are among the other sustainability opportunities offered by the modular approach of intelligent manufacturing (Bag, Gupta, and Kumar, 2021). In conclusion, this study extensively analyzes the sustainable implications of the use of I4.0 technologies. Through the classification shown in Table 2.2, it is noted that some technologies have been studied in detail and numerous metrics have been identified for the assessment of sustainability. Other technologies such as radio frequency identification, blockchain and cyber-physical systems are instead little analyzed and in this sense, few sustainability metrics have been identified. In addition, has emerged a scarcity of studies that evaluate the use of technologies in a combined way.

2.6 Conclusion

In recent years, sustainability and I4.0 have become crucial aspects of the global economy. In the literature, numerous studies focus on the environmental aspects of sustainability with a focus on digital technologies. On the contrary, few studies address the issue of digital sustainability considering also the social and economic aspects. The narrative literature review methodology was used to answer the research question identified in chapter 1.

Indeed, a broad analysis of the existing contributions allows to identify and categorize 21 metrics. The latter were grouped according to the effect on sustainability (direct/indirect) and the digital technologies.

Finally, emerged that these tools are not only changing the concept of sustainability itself, but also the way of designing, assembling, selling, and maintaining products and processes. The use of digital technologies facilitates the implementation of organizational activities, improving productivity, reducing consumption and consequently costs, making modular workstations and flexible production lines. On the other hand, it favours the development of economic sustainability in an indirect perspective of reducing waste, energy, and water consumption. From the point of view of academics, this study represents a starting point for future empirical studies that could exploit the metrics identified. Regarding the managerial contribution, the taxonomy presented can represent a useful tool for the delineation of the characteristics of the technologies, to guide practitioners in the choice of future investments. Some gaps emerge from the literature. There has been growing interest in the application of blockchain technologies, cyber-physical systems, and radio frequency identification but there is a lack of research into the impact of those technologies at the operational level. It is necessary to investigate more carefully the type of digital technology to be implemented concerning the sector or the type of activity carried out by the organization to improve sustainability. Another relevant topic is the analysis of the impact of the combined use of different I4.0 technologies. Specifically, there is a lack of papers that deal with strategies to increase sustainability performance through the combined use of enabling technologies and conduct real application cases. This gap will be addressed in chapter 4.

CHAPTER III: SUPPLY CHAIN PRACTICES ENHANCING SUSTAINABILITY

Summary

In this chapter, a comprehensive overview of SSCM practices is conducted. Sustainable practices have been identified and systematically organized for both primary and support activities of the value chain (Farag et al., 2021). This chapter bring together many different contributions available in the literature and organize them in an interesting and comprehensive taxonomy that will be further exploited for the identification of a conceptual model.

3.1 Introduction

The 1987 report of the World Environment and Development Commission (WCED) also known as the Brundtland Report, introduced, for the first time, the term sustainability. This report sought to express the need to understand sustainability as a combination of environmental, economic, and social influences. In this view, sustainable growth is recognized in these three dimensions. The convergence of economic, environmental, and social problems is readily understood (Phatak and Sople, 2019). In the last few years, the concept of SSCM is raised because of heightened urgency to respond to the pressing global challenges. Global warming and changing biodiversity has brought the world's sustainability towards imminent danger (Tseng et al., 2019; Chofreh et al., 2019). Together with the growing attention towards environmental problems, there is increasing pressure related to CSR. Companies must reconsider their SC when applying sustainable business models. Consequently, SSCM has recently become one of the core elements of transition in the direction of a sustainable and circular market based on the economy (Antikainen, et al., 2019). A system-wide innovation that transforms the entire value-adding processes requires multiple or all aspects of current company business models to accelerate the transformation of businesses, industry, and economies into adapting and successfully implementing a sustainable economy (Stahel, 2014; Antikainen and Valkokari, 2016; Wan et al., 2016). As businesses innovate sustainable business models, it is not enough to consider customers' value proposition (Antikainen and Valkokari, 2016). Instead, businesses must incorporate sustainability into their value plans, considering environmental, social, and economic value (Antikainen, et al., 2019; Geibler 2013). Porter (1985) argues that companies which maximize their SC activities against competition are more likely to exploit useful capacity for sustained competitive advantage. According to Resource-Based View (RBV), businesses can gain sustainable competitive advantage by the introduction of value-creating strategies (Barny 1991; Eisenhardt and Martin 2000; Prajogo, et al., 2008). Porter (1985) also suggests that the value chain for a company is the cumulative sum of the operations that a company does internally. The definition of the value chain implies that the attainment of competitive advantages starts with the attempt to build more profound coordinating skills in conducting those competitively important value chain operations to deliberately leverage certain capacities that improve company strategy and attractiveness. Value chain activities are, of course, necessary to gain a competitive advantage. However, despite the common view that the highest industrial knowledge in value chain operations will deliver competitive dominance, there is still growing empirical work on the position of the various value chain activities. The value chain includes various elements. The SC includes manufacturing, logistics, marketing & sales, customer relationship management, supply, end of life operation, coordination & collaboration, corporate strategy, and top management commitment, and finally R&D (Prajogo, et al., 2008). A mechanism that transforms the input into resources and the product demand into internal and external value-added consumers is one of the key obstacles for business management (Krajewski and Ritzman, 2005). The business is only successful if its operation, facilities, and development companies are focused upon offering benefits that sustain customer satisfaction and engagement as a matter of priority (Gertner, 2013). It is necessary to add to the operation a value chain principle, because processes are resource users and must be properties, not just for the added value, but also for the number of workers, supervisors, facilities, supplies, utilities, land, and resources they use in production work (Krajewski and Ritzman, 2005). The organization should develop a plan with the aid of a value chain, define the ways for the client to pay for and gain from the value (Normann and Ramirez, 1993). Furthermore, the organization must have the skills and capital superior to its rivals to build a competitive advantage (Porter, 1996). SSCM may provide all stakeholders with added value, in addition to leading to societal, economic, and environmental change. To maximize value for money, it would help to consider and then reduce the expense of products, facilities and jobs over the whole life cycle and maximizing resource quality. Environmental performance improvement of solid/liquid waste and pollutants across the sustained SC. By better consistency, reducing waste helps increase operating efficiency (Phatak and Sople, 2019). Sustainable business practices can help develop business capital and improve living standards in markets; unsustainable economic operations can result in environmental destruction which can undermine lengthy stability and economic competitiveness (Hsu and Tan, 2016). The results of literature show that supply versatility to satisfy customer needs, vendor know how to support customer offered services which help the customer directly, and, more broadly, support in launching new products of a focusing business represents the value component added by cross-functional experience (Jääskeläinen and Heikkilä, 2019).

3.2 Theoretical background

3.2.1 Value chain model

Business processes are characterized by different activities organized to realize products or services, creating added value for both organizations and customers. These activities and procedures are necessary to transform raw material into a product or an idea into a service, involving the entire company ecosystem to organize a system capable of delivering the product or service directly to the customer. All of this can be analyzed by breaking down phases and processes into multi processes or relying on the value chain model. Porter (1998) was the first to introduce the concept of the value chain. Specifically, the value chains' theory, developed by Porter, defines the competitive advantage as the result of several interconnected activities from sourcing to distribution of goods and services. According to this model, the industry cannot be considered isolated from the context in which it is embedded. The value chains' model focuses on customer activities as a central principle rather than departments and categories of accounting expenditure. It also connects activities and demonstrates the effect on costs and profits. Consequently, the analysis of the value chain allows identifying the sources of value and losses in the organization. Porter's value chain analysis distinguishes between primary and support activities. Primary activities have an immediate effect on the production, maintenance, sale, and support of the products or services to be provided. These activities consist of the following elements: inbound/outbound logistics, production, marketing and sale, and service. Support activities assist with primary activities and constitute the foundation of the organization. These include firm infrastructure, supply, human resource management, and technology development.

3.2.2 Sustainable value chain model

In recent years, the increased awareness of consumers, the targeted campaigns of NGOs, and the increasingly stringent national or international policies about sustainable processes are forcing the business world to adopt systems for reducing the environmental impact of their operations and monitoring social and territorial aspects. To respond effectively to the evolution of sustainability policies, industrial companies must increasingly consider the entire SC operations. Developing new experiences of sustainability within the entire value chain can therefore have an important impact on the competitive advantage in the markets in which the company traditionally operates. In this scenario, emerges the concept of a sustainable value chain (Marimin et al., 2014). Implementing sustainable value chain practices in both primary and support activities allow companies to pursue both stakeholders and consumers interests. Different stakeholders take part in the value chain operations and affect the overall value of final products and services. Therefore, all of them play a key role to achieve sustainable goals, from the sourcing phase to managing wastes after usage, reducing costs. Adopting more sustainable practices, it is possible to minimize production waste, improve logistics, optimize, and improve production processes, with a significant reduction in costs at the end of the year. On the other hand, it allows companies to operate directly on products, identifying new production methods or new materials that lead to the creation of more eco-friendly products, and able to attract new consumers. In this way, a sustainable company can achieve a leading position in an increasingly fluid market that is increasingly devoted to environmental and social issues. Using these levers, leading companies can stimulate and involve their suppliers in adopting more sustainability-oriented development policies. Summing up, a sustainable value chain model refers to different SC operations beginning with the initial sourcing, through R&D and production, to the final recycling of waste and product abandonment. Specifically, as for the traditional value chain defined by Porter, sustainable value chain activities can be subdivided into primary and support activities. Based on previous studies there have been identified as primary activities: manufacturing, logistics, marketing and sale, and customer management relationship. Besides, supply, end of life operations, coordination and collaboration, corporate strategy and top management commitment, and finally R&D are considered support activities (Anthony, 2019; Hartman and Stafford, 1998; Kung, Huang, and Cheng, 2012). Table 3.1 presents the classification of SSC practices according to primary and support activities.

3.3 Taxonomy of SSCM practices

Primary activities

3.3.1 Manufacturing

The industry-sustainability combination is certainly not new. For decades, this relationship has been developed along the theme of respect for the environment and emissions. Indeed, the need to develop sustainable manufacturing systems arose due to the negative impact on the environment resulting from the excessive exploitation of natural resources and the pollution of ecosystems. Shifting to sustainable manufacturing systems usually implies investing in many different technologies that are typically beyond the traditional technological grasp (Heidrich and Tiwary, 2013). As shown in Table 3.1, most of the literature on sustainable manufacturing practices is characterized by reducing different types of waste and pollution. The effort at implementing sustainable manufacturing systems involves mostly the manufacturing area in the supply network. Specifically, sustainable manufacturing processes include several practices such as material and waste recovery, reduction of CO_2 emissions, reduction of energy consumption, carbon footprint and toxic gas emissions (De los Rios and Charnley, 2017).

In this context, some of the most common strategies are the re-design of sub-components, recycling, and down-cycling (Despeisse et al. 2012). But this is only one of the aspects that hold the combination sustainability-manufacturing together. Therefore, the smaller impact and the smaller footprint on the planet must necessarily translate into a significant reduction in management costs.

Table 3.1 Categorization of sustainable value chain practices

	Factors	Items	References
Primary	Manufacturing	M1. Material recovery (e.g., use wastes as internal resources such as metal swarf and chips)	Despeisse et al. (2012), Thiede et al. (2012), Pajunen et al. (2012), Abdul Rashid et al. (2017), Yang et al. (2010), Luthra et al. (2017), Luthra et al. (2014), Hsu et al. (2016), Vijayvargy et al. (2014), Ameer and Othman (2012), Yusuf et al. (2013), Fairfield et al. (2011), Liang and Liu (2017)
		M2. Energy savings	Fang et al. (2011), Jayal et al. (2010), Despeisse et al. (2012), Abdul Rashid et al. (2017), Hsu et al. (2016), Vijayvargy et al. (2014), Ameer and Othman (2012), Yusuf et al. (2013), Despeisse et al. (2012), Fairfield et al. (2011), Liang and Liu (2017)
		M3. Reduction of CO2 emissions	Abdul Rashid et al. (2017), Vijayvargy et al. (2014), Ameer and Othman (2012), Yusuf et al. (2013), Fairfield et al. (2011), Liang and Liu (2017)
		M3. Reduction of solid waste	Eltayeb et al. (2011), Vijayvargy et al. (2014), Despeisse et al. (2012)
		M4. Waste reduction strategies	Eltayeb, et al. (2011) Vijayvargy et al. (2014), Despeisse et al. (2012), Fairfield et al. (2011), Siegel et al. (2019)
		M5. Reduction of toxic gas emissions into the environment	Eltayeb et al. (2011), Vijayvargy et al. (2014), Despeisse et al. (2012)
		M6. Improvement in manufacturing and machine efficiency	Bi and Wang (2012), Newman et al. (2012), Pusavec et al. (2010), Granados et al. (2009), Kara and Li (2011), Duflou et al. (2012), Millar and Russell (2011), Fairfield et al. (2011), Abdul Rashid et al. (2017), Hsu et al. (2016), Vijayvargy et al. (2014), Despeisse et al. (2012)
		M7. Sustainable total quality management	Baines et al. (2007), Miller et al. (2010), Abdul Rashid et al. (2017), Das, (2017), Yang et al. (2011), Beske et al. (2014); Beske and Seuring, (2014)
		M8. Reduction of carbon footprints	Eltayeb et al. (2011), Luthra, et al. (2014), Yusuf et al. (2013)
	Logistic	L1. The organization redesigns the logistical system	Mwaura et al. (2016)
		L2. Efficient warehouses	Mwaura et al. (2016)
		L3. Use of local products	Mwaura et al. (2016)
	Marketing & Sale	MS1. Use of green label as an indicator of environmental friendliness	Mwaura et al. (2016)
		MS2. Use of market monitoring tools aiming to follow green-competitive practices	De Souza Zampese, Moori, and Caldeira, (2016)
		MS3. Market segmentation looking for customers interested in green specifications (e.g., market research driving to detect green demands in the market)	De Souza Zampese, Moori, and Caldeira, (2016)
		MS4. Adopt pricing strategies based on differentials in green product	De Souza Zampese, Moori, and Caldeira, (2016)
		MS5. Adopting green features in the product advertising (e.g., in sales argument, website, sales materials and advertising in specialized media)	De Souza Zampese, Moori, and Caldeira, (2016)
		MS6. Adopt green features as a way to improve the corporate image	De Souza Zampese, Moori, and Caldeira, (2016)
		MS7. Sponsoring groups and environmental events	De Souza Zampese, Moori, and Caldeira, (2016)
	Customer Management	CM1. Customer management	Pekovic et al. (2016)
		CM2. Information sharing with customers	Pekovic et al. (2016), Vijayvargy et al. (2014)
		CM3. Cooperation with our customers to achieve sustainability objectives	Paulraj et al. (2017), Vijayvargy et al. (2014); Siegel et al., (2019)

		CM3. Cooperation with our customers to improve their sustainability initiatives	Paulraj et al. (2017), Vijayvargy et al. (2014), Siegel et al. (2019)
		CM4. Collaboration with our customers to provide products and/or services that support our sustainability goals	Paulraj et al. (2017), Vijayvargy et al. (2014)
		CM5. Development of mutual understanding of responsibilities regarding sustainability performance with our customers	Paulraj et al. (2017), Vijayvargy et al. (2014)
		CM6. Conducting joint planning to anticipate and resolve sustainability-related problems with our customers	Paulraj et al. (2017), Vijayvargy et al. (2014)
		CM7. Monitoring of Customer satisfaction	Hsu et al. (2016), Ameer and Othman (2012), Yusuf et al. (2013)
Support	**Supply**	S1. Use of biodegradable raw material	Eltayeb et al. (2011), Vijayvargy et al. (2014), Despeisse et al. (2012), Fairfield et al. (2011)
		S2. Reducing the use of harmful raw materials	Eltayeb et al. (2011), Vijayvargy et al. (2014), Despeisse et al. (2012), Fairfield et al. (2011)
		S3. Evaluating supplier certification	Hsu et al. (2016)
		S4. Requiring suppliers with ISO 14000 certification	Eltayeb et al. (2011)Eltayeb, et al. (2011), Ağan (2016), Das (2017), Yang, et al. (2010), Hsu et al. (2016), Vijayvargy et al. (2014), Siegel et al. (2019)
		S5. Suppliers' evaluation	Luthra et al. (2017), Das (2017), Hsu et al. (2016), Vijayvargy et al. (2014), Yang et al. (2010)
		S6. Local sourcing	Das (2017), Yang, et al. (2010); Siegel et al. (2019)
		S7. Suppliers' development	Yang et al. (2010), Das (2017), Rao and Holt (2005)
	End of Life Operations	ELO1. Reuse/Recycle the product at the end of life	Eltayeb et al. (2011), Vijayvargy et al. (2014), Despeisse et al. (2012)
		ELO2. Use of minimum packaging	Mwaura et al. (2016)
		ELO3. Waste recovery (e.g., use coolants and transport solid wastes from the factory for use as resources in other manufacturing processes)	Kara and Li (2011), Duflou et al. (2012), Abdul Rashid et al. (2017), Luthra et al. (2017), Luthra et al. (2014), Hsu et al. (2016), Vijayvargy et al. (2014), Ameer and Othman (2012), Yusuf et al. (2013), Despeisse et al. (2012), Fairfield et al. (2011), Liang and Liu (2017)
		ELO4. Applying to packaging made of recyclable materials	Mwaura et al. (2016)
	Coordination & Collaboration	CC1. Information sharing with suppliers	Das (2017)
		CC2. Cooperation with suppliers to achieve sustainability objectives	Paulraj et al. (2017), Vijayvargy et al. (2014)
		CC3. Providing our suppliers with sustainability requirements for their processes	Paulraj et al. (2017), Vijayvargy et al. (2014)
		CC4. Collaboration with suppliers to provide products and/or services that support our sustainability goals	Paulraj et al. (2017), Vijayvargy et al. (2014)
		CC5. Development of mutual understanding of responsibilities regarding sustainability performance with our suppliers	Paulraj et al. (2017), Vijayvargy et al. (2014)
		CC6. Joint planning to anticipate and resolve sustainability-related problems with our suppliers	Paulraj et al. (2017), Vijayvargy et al. (2014)
		CC7. Suppliers' feedback about their sustainability performance	Paulraj et al. (2017), Vijayvargy et al. (2014)

		CC8. Providing information to the supplier about environmental issues	Eltayeb, et al. (2011), Ağan (2016), Vijayvargy et al. (2014)
		CC9. Supplier-buyer cooperation for environment-friendly raw material	Eltayeb, et al. (2011), Ağan (2016), Vijayvargy et al. (2014)
		Trust among the members of the supply chain	Hsu et al. (2016), Ameer and Othman (2012), Yusuf et al. (2013)
	Corporate Strategy & Top Management Commitment	CSTM1. Training education of purchasing employees and suppliers	Ağan (2016), Ameer and Othman (2012), Yusuf et al. (2013), Yusuf et al. (2013), Liang and Liu (2017)
		CSTM2. Important weight of environmental criteria in corporate decisions	Jassim, Al-Mubarak, and Hamdan, (2020)
		CSTM3. Include environmental concerns as a core value in mission and vision statements	De Souza Zampese, Moori, and Caldeira, (2016)
		CSTM4. Encourage the involvement of all employees in environmental issues	De Souza Zampese, Moori, and Caldeira, (2016)
	Research & Development	RD1. Adopting new manufacturing technologies	Ameer and Othman (2012), Yusuf et al. (2013), Despeisse et al. (2012)
		RD2. Quality management	Jabbour et al. (2015), Das (2017), Yang, et al. (2010), Luthra, et al. (2017), Vijayvargy, et al. (2014), Yang et al. (2011), Yusuf et al. (2013)
		RD3. Corporate environmental management	Liang and Liu (2017), Hsu, et al. (2016), Vijayvargy et al. (2014), Ameer and Othman (2012)
		RD4. Corporate social responsibility	Ağan (2016), Das, (2017), Ameer and Othman (2012)
		RD5. Reduction of material/energy consumption when designing products	Paulraj et al. (2017), Abdul-Rashid et al. (2017), Das (2017), Kara and Li (2011), Pajunen et al. (2012), Vijayvargy et al. (2014), Ameer and Othman (2012), Yusuf, et al. (2013)
		RD6. Attention to reuse, recycle, and/or recovery of material when designing products	Paulraj et al. (2017), Abdul Rashid, et al. (2017), Lee et al. (2001), Vijayvargy et al. (2014), Ameer and Othman (2012), Yusuf et al. (2013)
		RD7. Designing products to use environmentally friendly materials	Paulraj et al. (2017), Abdul Rashid et al. (2017), Zhu et al. (2007), Hsu et al. (2016), Vijayvargy, et al. (2017), Ameer and Othman (2012)
		RD8. Designing products with standardized components to facilitate reuse	Paulraj, et al. (2017), Abdul Rashid et al. (2017), Vijayvargy et al. (2014)
		RD9. Designing products for easy disassembly	Paulraj et al. (2017), Abdul Rashid et al. (2017), Duflou et al. (2012), Hsu et al. (2016), Vijayvargy et al. (2014), Ameer and Othman (2012)
		RD10. Using cycle analysis to evaluate the environmental impacts of products	Paulraj et al. (2017), Abdul Rashid et al. (2017), Mont and Lindhqvist (2003), Vijayvargy et al. (2014), Ameer and Othman (2012)
		RD11. Having formal guidelines for environmental product design	Paulraj et al. (2017), Abdul Rashid et al. (2017), Hirschl et al. (2003), Vijayvargy et al. (2014)
		RD12. Designing processes about sustainability goals	Paulraj et al. (2017), Vijayvargy et al. (2014)
		RD13. Evaluation of existing processes to reduce their impact on the environment	Paulraj et al. (2017), Vijayvargy et al. (2014)
		RD14. Formal designing for environment guidelines for process design	Paulraj et al. (2017), Vijayvargy et al. (2014)
		RD15. Reengineering of processes to reduce their environmental impact	Paulraj et al. (2017), Vijayvargy et al. (2014)
		RD16. Improvement of environmental friendliness in production	Paulraj et al. (2017), Vijayvargy et al. (2014)

The efficiency of production processes and the modernization of plants according to the most modern and high certifications has costs that must be absorbed in a reasonable time. Given this background, in parallel, another branch of sustainable manufacturing concerns redesigns of machine tools and selective control to improve machine efficiency (Granados et al., 2009). Along with these techniques, another method for increasing operational efficiency and simultaneously reducing waste is to adopt lean strategies and more specifically sustainable total quality management practices. Lean and green manufacturing has a significant positive impact on multiple measures of operational performance when implemented simultaneously rather than separately (Miller et al., 2010). Furthermore, sustainable production is a strategy that allows companies to low the consumption of energy, adopts ethical work standards and is a mechanical approach to the creation and distributing of creative goods and services; avoids hazardous contaminants, and creates zero waste that significantly minimizes the greenhouse gas loop of products and services. Zhu and Sarkis (2004) established some of the key drivers behind GSCM application in the Chinese manufacturing sector, such as simple cost reduction to encourage collaboration with suppliers and support the recycling of end-of-life products. On the other hand, while there is a rising environmental consciousness, the adoption of GSCM throughout companies is still sluggish (Phatak and Sople, 2019).

3.3.2 Logistics

Sustainable logistics operations and their effect on emissions and costs are a current strategic challenge in modern SCs (Validi, Bhattacharya, and Byrne 2020). Logistics activities are one of the most significant sources of air pollution and greenhouse gas emissions (Sheu and Li 2014). For this reason, over the years becomes crucial an efficient and effective design of logistics systems. Sustainable logistics practices refer to the movement of a product after the production phase until reaching the final customer in the SC. Therefore, sustainable logistics essentially involves distributors, wholesalers, and retailers.

At a company level, sustainable logistics requires an adaptation of processes and a change in the infrastructure configuration, systems, fleet management (in the distribution field) and the storage of goods (in the intralogistics field). The goal is to find the economic, ecological, and social balance that allows the company to grow in numbers without affecting the environment. Particularly, logistics contributes to determining a company's overall profitability directly affecting both the cost of the SC and the customer experience (Hübner, Holzapfel, and Kuhn, 2016). This has prompted companies to adopt sustainable strategies. These practices range from the use of local sourcing to the rearrangement of warehouses. Specifically, Mwaura et al. (2016) showed that green distribution practices like the use of local sourcing, minimum packaging, green labels, warehouse rearrangement etc. significantly and positively influence firm competitiveness, reduce cost, and improve efficiency. In this sense, logistics is a core component of the management of SCs with many positive socioeconomic impacts: the development of new infrastructures, work generation, poverty reduction of malnutrition and crime and the wealth of humans and nations. Logistics practices, on the other hand, also have many detrimental effects on their natural and social climate. Logistics, for instance, are still largely reliant on fossil fuels and non-renewable, polluting, congestion, bullying, vibration, harm, and accidents (Abbasi & Nilsson, 2016). Logistics, therefore, calls for operations that reduce the negative effects on the environment and facilitate the SSCM transformation. Research gaps remain in terms of understanding how a sustainable value proposal is to be generated and incorporated into a sustainable business model for logistics activities (Antikainen, et al., 2019).

3.3.3 Marketing & sales

In the last few years, the marketing and sales area has adopted green strategies as a means to develop closer relationships with their customers (De Souza Zampese, Moori, and Caldeira 2016). Current trends such as those related to growing concerns about the scarcity of natural resources, environmental degradation, and social inequalities have led consumers to realize the impact that current models of production, consumption, and life are playing on future sustainability (Silvius and Schipper 2010).

With customers looking to play a role in the transformation towards more sustainable lifestyles, companies must respond to this trend by implementing sustainable practices. Therefore emerge the need to integrate environmental issues and strategic marketing (Cronin et al., 2011). Consumers appear to be requesting products with green attributes over what has traditionally been offered. Therefore, to improve promotional activities and sales, industrial enterprises must promote their environmental responsibility. Since customer orientation and attention to sustainability are currently very pressing, companies are shaping new business strategies, changing operations in a green key. Demand practices let weave economic, ecological, and social objectives and establish and maintain long-term profitable relationships with customers. More specifically, these practices aim to increase consumer awareness of the company's sustainability issues and to attract and retain sustainability-conscious customers. The implementation of these practices allows companies to be closer to customers and understand their needs at all stages. Certainly, marketing plays a vital role within the value chain, as it influences the relationship between a brand and its customers in the pre- and post-sales processes. In the pre-production process, the consumer's attention is essential for understanding customer expectations before the design and development of products. It tackles customer support and retention problems in the post-delivery stage. Marketing wants to define what consumers expect from the products or services offered by a business; what the company gives customers actually, and the discrepancy between what customers want and get. Marketing would then devise a strategy to settle this void alongside the company's other operations. Since consumers are the primary source of new ideas on goods, a company's marketing role may offer useful knowledge in this respect in communication with customers (Prajogo, et al., 2008).

3.3.4 Customer relationship management

In today's market, a common choice in managing the SC has been to place the customer at the centre of business strategy. Customer relationship management is based on creating business value by building relationships with key customer segments (Payne and Frow 2005). In particular, it consists of the acquisition, maintenance, and collaboration with selected customers to generate greater value for both the company and the customer (Navimipour & Soltani, 2016). Through customer relationship management employees develop a new form of awareness of the role of customers. They are not only the mere receivers of the value of the product or service provided by organizations but they become co-producers (Itani, Kassar, and Loureiro, 2019; Luu, 2019). In this vision, the involvement of consumers is total and is therefore also related to the corporate culture. In consideration of sustainability issues, it was necessary to align sustainability objectives with customer preferences. According to Jassim et al. (2020), the introduction of customer-centred approaches has begun to redefine the customer management relationship. This area mainly embraces practices based on cooperation between the parties. Among the latter, information sharing, and collaboration initiatives were found that aim at the one hand to raise user awareness on the topic and on the other to increase customer loyalty. The basic idea of customer sustainable initiatives is to integrate economic sustainability, environmental, and social issues in key areas of customer management. The objective of these practices, in the long run, is to make customers part of a global and interconnected sustainable network.

Support Activities

3.3.5 Supply

Nowadays, the sustainable supply concept considers economic, environmental, and social criteria in sourcing decisions at the same time. According to Dunn (1995) and Handfield et al. (1997), the implementation of corporate sustainability is based upon the involvement and aligned effort of several departments. Tate et al. (2010) highlight the importance of the supply function in contributing to an organization's overall sustainability. Given its position at the starting point of the flow of materials and information. The sustainable procurement research stream has two main objectives: firstly, sustainable supplier selection and evaluation, and secondly the attention on the use of raw material. Concerning the first area, Luthra et al. (2017) highlighted several challenges/barriers and benefits of applying a sustainable supplier selection process in SC. In particular, the authors identify criteria and dimensions (e.g., price, profit, and quality of the products, technological & financial capabilities, and occupational health & safety systems) that can help in managing the challenges/barriers in developing sustainability-focused supplier selection criteria and evaluation decisions. Sustainable supplier management generates an improvement in terms of quality, customer relationship, and lean practices (Das, 2017). In addition to these supplier-oriented initiatives, another important procurement branch is linked to raw materials. Indeed, sustainable solutions in the sourcing of raw materials help generate economic growth and reduce the overall transport and post-use costs (Fairfield et al., 2011).

3.3.6 End of life operations

The end-of-life operations area concerns the process of planning, implementation, and control of efficiency (from a point of view of raw material costs, management of the finished product and related information) from the place of consumption of the product to its point of origin, with the value of the product or to properly dispose of the materials. First, End of life operations impacts the management of physical flows linked to the transport and reception of materials. Second, these initiatives impact the quality since, after qualitative assessments, the returned material could be re-entered into the sales channels as a new material, alternatively, it can be subject to a rework or, classified as a second choice or even "bad quality". Each SC must be "set up" adequately to support the end-of-life process efficiently and effectively. In particular, a study carried out by Eltayeb et al. (2011) shows how the adoption of end-of-life operations is directly reflected in the reduction of the costs of materials and packaging. As one of the possible strategies that can be pursued is to use recycled and non-virgin materials.

3.3.7 Coordination and collaboration

Collaboration and coordination strategies are some of the most widely used tools in the literature on the SSC. These techniques make it possible to simplify communication processes and transform organizations from functional to a matrix structure. These streamlined information flows simplify cooperation in implementing sustainable strategies. The sustainability objectives that previously belonged to a single company function become shared and cross-functional. Relevant collaboration and coordination strategies include sharing sustainability objectives and requirements, joining planning to anticipate and resolve sustainability-related problems and providing information on environmental issues (Paulraj et al., 2017; Vijayvargy et al., 2014).

3.3.8 Corporate strategy and top management commitment

The top management commitment and corporate strategy area involve internal processes from the supply to the retail phase. Implementing sustainable policies requires senior management involvement to create a general strategy to guide the organization's efforts to achieve a shared goal. The support of top management was considered an important factor for the successful integration of a standard, as it deals with evaluating the certifications of external and internal partners (Hsu et al., 2016). The high level of senior management participation in the management system improves the horizontal flow of information and, therefore, generates greater awareness of the sustainable impact of management. Furthermore, the involvement of top management can encourage investments in training courses on sustainability for the various members of the network and new cutting-edge manufacturing technologies for resumption reduction (Ameer and Othman 2012, Yusuf et al. 2013; Despeisse et al. 2012).

3.3.9 R&D

R&D practices mainly involve practices related to the design of innovative solutions, processes, and products. Specifically, the design of a product based on sustainability criteria consequently allows the creation of sustainable processes. Sustainable product design and development has a positive impact on environmental performance (Ahmad et al., 2018a). In particular, eco-design has a significant effect on the product image, brand value, enhanced publicity, green production impacts in terms of cost reduction and an increase in product quality and delivery performance (Abdul-Rashid et al., 2017; Ameer and Othman, 2012; Das, 2017). According to Hsu et al. (2016), emerging economies can benefit from sustainable production processes initiatives in managing their competing goals of profit growth and environmental protection. The design of sustainable processes allows obtaining satisfactory results also in the context of reduction of energy and material consumption. Kara and Li (2011) show that a reliable prediction of unit process energy consumption will enable the industry to develop potential energy-saving strategies during product design and process planning stages. When firms design products and processes following sustainability guidelines, they might trim cost by reducing waste of materials and energy (Paulraj et al., 2017). Continuous product development impacts not only on products and components design but also impact the composition and volume of waste-recycling streams (UNEP, 2013). The introduction of the lifecycle and eco-design procedures are steps towards more sustainable production, as well as a means of increasing the demand for recyclable products via informing customers (Pajunen, 2012). In general, product design and process design represent crucial practices to obtain consistent sustainable results. The most effective way to reduce environmental impacts is through prevention and better planning. Thanks to correctly designed processes, the phases surrounding the procurement of parts and materials and the management of flows can be structured through cooperative eco-design programs (Vijayvargy et al., 2017). Alongside sustainable design practices of products and processes, there is a branch of practices linked to the development of new organizational paradigms related to sustainability as corporate environmental management, and CSR (Ağan 2016; Das, 2017; Ameer and Othman, 2012). In conclusion, R&D management plays a key role. Several researchers measure the innovation success of an organization by evaluating its R&D activities level (Prajogo et al., 2008). Finally, Mikkola (2001) claims that growing technical uncertainty, combined with shorter product lives, causes many businesses to focus on R&D management as a strategical source.

The detailed analysis of the practices of the sustainable value chain has led to the definition of the conceptual model present in Figure 3.1. This last summarizes and reconstructs the concept of the value chain in a sustainable key. In particular, the subdivision of the activities into primary and support activities follows the characteristics of an integrated and circular network that connects the various partners of the SC together. The next paragraph will discuss in detail the peculiarities of the model.

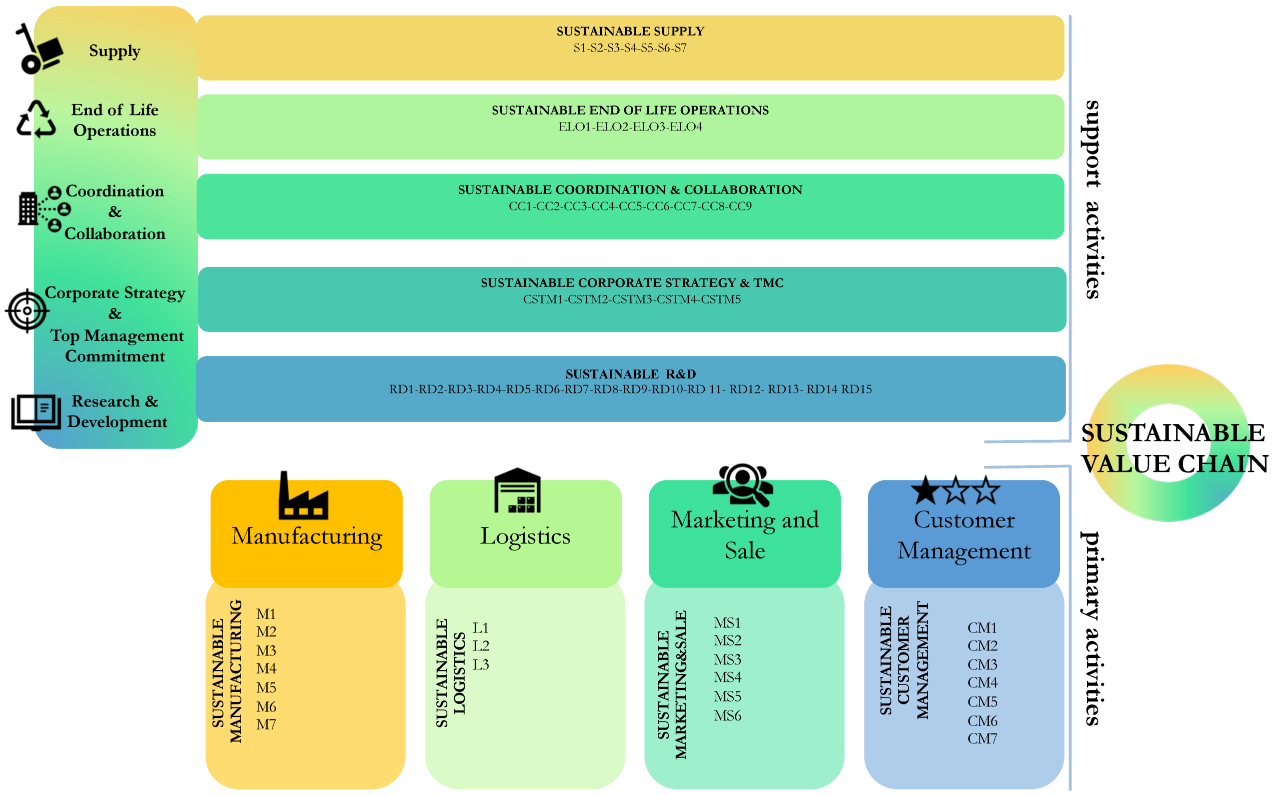

Figure 3.1 Sustainable value chain model

3.4 Discussion

The transition from traditional SC to SSC is often seen by companies as a market problem. However, more considerations influence the introduction of sustainability in SCs. The analysis of several previous contributions reveals that companies can pursue many initiatives to implement SSC practices.

The emphasis on SSCs is also a step towards wider acceptance and sustainable growth since the SC looks at the commodity from the original production of raw materials to distribution and recovery to the end consumer. As a result, companies must establish ever more interactional and cross-functional ties between stakeholders as a gateway to strategic advice and higher productivity. In social and environmental projects, sustainable construction requires green architecture, green procurement, green logistics etc. Through collaboration between internal departments and SCs stakeholders, the GSCM can control their environmental impacts. This helps organizations to expand involvement in environmental and social issues through staff and SC associates, and collaborate with them on strategic planning, and the development of green innovative concepts. Managers should also enable people to build and exchange awareness across the SC and discourage the creation of organizational silos that hinder the free flow of information and knowledge through the SC. Also, they should encourage people. Indeed, if two or more businesses are working together in the SC on social and environmental problems, environmental and social gains can be obtained (Klassen and Vachon, 2003; Niesten and Lozano, 2015; Phatak and

Sople, 2019). For example, the advantages of partnership minimize the environmental footprint and strengthen the SSC orientation (Kleindorfer et al., 2005; Linton et al., 2007; Husted and de Sousa-Filho, 2016). Social accountability and environmental conservation are stressed in the community above profit, according to the literature findings. Past analysis has primarily studied quantitative income and controlled environmental conservation but scarcely engaged in casual social responsibility interactions and consumer relations.

Customer relationship management and social sustainability have been key issues for strategic management, targeted at building and protecting partners to retain power over the long term. In transactional marketing transitions into partnership focus, the promotion of sustainable shared benefit with clients is the cornerstone to managing consumer relationships and the goal of fostering social responsibility. Besides, when the management concerns are the green SC and green customer, businesses are paying more attention to the anticipation of social responsibility by stakeholders. Promoting social responsibility is influenced by core practices and comparative benefit in customer relationship management. The vision for sustainable competitive advantage would be shared if benign engagement and customer interactions were to actively consider the social justice desires of consumers, increase service satisfaction, and build high-life clients. Strong corporate accountability for the industry sectors seems like a positive impact on market reputation and support to retain the company's competitive advantage. While the common notion that best-in-commerce expertise in key-value chain activities will enable businesses to take precedence over the competition is popular within strategic literature, academic research is still ongoing on the position of the various value chain activities.

To date, the association of core competencies in the individual components of the value chain with competitive generic tactics has not been apparent. It is also concluded that businesses that understand that particular aspects of their value chain are linked with specific success metrics and use these elements correctly have the highest ability to achieve strategic dominance, based on observations from the company's RBV theory and value chain model.

3.5 Conclusions

This chapter includes some major results. First, it indicates that any role in the value chain has a different connection and a specific relevance to various competitive performance forms. This perspective is consistent with previous research and shows that marketing, sourcing, and development roles (as for the customer focus) are linked to the value chain.

A second point indicates that R&D is tied to product innovation. There was also a relevant partnership between supply and innovation. It is also remarkable that recruitment is engineering competence. This highlights the growing role of the SC and sourcing challenges in the values chain of companies and does not appear to be constrained by the strategic course of the enterprise. This analysis indicates that administrators and decision-makers of organizations should concentrate on developing competences in communications, sourcing. It is further recommended that organizations looking for innovation differentiation should concentrate their efforts and investments on R&D and value-chain sourcing skills. Overall, although each of the functions of the value chain is significant, their significance depends heavily on the type of approach used by the organization and by the industry sector in which the company operates. In this vein, the model presented stands as a general model that must be modified and particularized on the basis of the sector and the specific SCs to be considered. In fact, in the following chapter, starting from the results obtained, a new framework will be shaped which takes as its starting point some primary and support activities to which it will connect some specific items of the taxonomy.

CHAPTER IV: CROSSING SUSTAINABILITY AND LEAN SUPPLY CHAINS PRACTICES WITH INDUSTRY 4.0 TECHNOLOGIES: AN EMPIRICAL ANALYSIS

Summary

Based on the results of the previous chapters, some of the main I4.0 technologies and sustainable practices in the SCM domain have been highlighted. This chapter will close the circle by integrating these two paradigms extensively analysed with the lean SC. In this vein, after the analysis of the triadic relation between I4.0 lean and sustainable SC, the integrated framework has been defined that allows responding to the research questions 3 and 4 provided in the first chapter. This framework is lowered into the automotive sector, since it is characterized by intensive use of lean and sustainable practices, but also of I4.0 technologies.

4.1 Introduction

In the last few years, I4.0 technologies are becoming transformative breakthroughs that have piqued the interest of practitioners and academics alike in terms of how they might support and enhance operations (Frank et al., 2019; Benitez et al., 2020). A rising number of studies have examined the digital technologies that are widely referred to as ‘I4.0' (Buer et al., 2018; Culot et al., 2020; Weking et al., 2019), and some have explicitly linked these technologies to process improvement through lean and sustainable approaches (Gillani et al., 2020; Wagner et al., 2017). As a result, in the current years, there is a proliferation of studies focused on the dyadic relationships between paradigms. Among the main contributions, Duarte, and Cruz-Machado (2017a) proposed a theoretical model for the integration of I4.0 into the lean SC that aimed at improving production efficiency. Sanders et al. (2016) stated that integrating I4.0 into the lean process allows for successful results. Kainuma and Tawara (2006) studied the lean and SSC by incorporating the reverse logistics phase. Stock and Seliger, (2016) investigated the opportunities for achieving sustainable production in I4.0. The intersection between lean and sustainability, therefore, leads to several advantages in the SCs, such as, reduction of waste, better collaboration with suppliers, better process management as well as a reduction in costs, greater satisfaction of customer needs, and reduction of lead times (Garza-reyes, 2015a; Duarte and Cruz-Machado, 2013). These principles are also the basis of I4.0, in fact the use of I4.0 technologies helps in the implementation of the lean and SSC, (Roblek et al., 2016) allowing to establish better communication with suppliers, reduce waste, helping customers to be more aware in their choice of products and the company to understand their needs in real time (Germany Trade & Invest - GTAI, 2014), finally making employees have more autonomy and work less (Davis, 2015). In recent years there is, therefore, a trend towards the creation of theoretical and conceptual paradigms that highlights the synergies between I4.0 technologies, lean principles, and sustainable practices. While a common opinion may be emerging, most of this discussion is still conceptual and lacking in empirical evidence. The majority of contributions either provide a conceptual study of the potential relationship between I4.0, sustainable and lean SCs. Few authors have defined and empirically tested an integrated paradigm that considers the lean SC, SSC and I4.0 technologies jointly. This gap was considered as a starting point for an exploratory multiple case study analysis on several global leading automotive companies.

The goal of the thesis was to learn whether and how automotive companies use digital technologies to improve their performance by using lean and sustainable practices. The thesis was oriented in the automotive sector, since the automotive industry has high levels of lean-sustainable implementation (Azevedo et al., 2012) allowing a deep understanding of the integration between the two paradigms. In the same vein, this trend relates to the transaction towards digitization, which is investing this sector, leading it to innovate production processes, invest in intelligent and flexible production and therefore in I4.0 solutions. In this regard, based on what has been discussed, the thesis intends to deepen and detail the analyses in the automotive sector. The following sections will analyse in detail the main features of I4.0, SSC, and lean SC techniques in the automotive sector.

4.2 Theoretical background

This paragraph is started by reviewing acknowledged lean and sustainable concepts and methods in the context of the automotive industry. Next paragraphs proceeded to find the most relevant applications in this sector.

4.2.1 Lean supply chain in the automotive sector

According to Ohno (1998), the history of the lean concept is as old as the automotive industry. The Toyota company developed the lean strategy in the 1950s (Ohno, 1988), which, to date, has spread all over the world, in order to coordinate all activities both inside and outside the organizations (Bevilacqua et al., 2015; Mckinsey, 2017).

The automotive industry is one of the most active industries that adopts continuous improvement strategies to reduce costs and increase product quality to be competitive in its sector (Singh and Singh, 2019). Given the above, several studies have been conducted in the literature to investigate the link between the lean philosophy and the automotive sector. Nordin et al. (2010) conducted a study to evaluate the implementation of lean practices in the automotive industries in Malaysia from which emerged that the driving factors, which push companies to implement a lean paradigm, are continuous improvement, customer satisfaction, the desire to increase the best practices and the desire to increase market share. Kumar, Singht, and Modgil (2020) conducted a study to identify the criteria that influence the implementation of lean philosophy in automotive companies in India. The authors showed that customer, information, and quality management are the practices that have a greater impact on SC performance. Marodin et al. (2017) evaluated the impact of the implementation of lean practices on the operational performance in the Brazilian automotive SC. Results have showed that the companies in the Brazilian automotive supply chain have experienced reduction in lead time and inventory because of the use of lean practices.

From a broad point of view, to maintain the balance between product quality and cost, companies attempt to adopt lean strategies (Habidin and Yusof, 2013; Nachiappan et al., 2009; Duarte and Cruz-Machado, 2017b). In this sense, industries, due to growing competition, have had to reshape their production systems (Chen, 2006; Goh, 2006) and face increasingly demanding challenges. Lean practices have played a crucial role in increasing performance both at an operational and corporate level but above all in increasing competitiveness and profitability by reducing production costs (Elmoselhy, 2013). Companies, to achieve lean objectives, have to compete in different production dimensions such as quality, delivery reliability, response time, low cost, customization, and product life cycle (Kotha, 1995). Quality reflects the level of perfection that is perceived in the products. Reliability of deliveries reflects the degree of confidence in products, delivery, and guarantee of consumer to receive the right product, with the right quality, at the right price, at the right time, in the right place. Response time indicates how quickly the company can respond to customer needs. Low cost is about reducing production costs. Customization consists of the ability to produce different types of products in a cost-effective way and to regulate production volumes. In the end, the product life cycle is about the company's ability to develop new products and ideas (Kotha, 1995). In the literature, most research focuses on measuring the impact of lean practices on operational performance (Marin-Garcia and Bonavia, 2015; Marodin et al., 2017a). In general, the lean philosophy can help companies integrate with suppliers and customers (Marodin et al., 2017b). The exchange of information with suppliers about demand, programs and their performance are very critical, both upstream and downstream, in which it includes: demand in distribution levels, current inventory level and offers of current and future products on the market (Kumar et al., 2020). In the automotive sector, acquisitions are a fundamental function, since these allow adding value thanks to the contribution in the implementation of supplier quality standards, in the negotiation of the best price, in the alignment of purchases with company policies and in the disposal of related products (Huang and Wu, 2016; Krause et al., 2009; Lindgreen et al., 2013). In this regard, the purchasing department plays a crucial role in communicating with suppliers (Kumar, Singh and Modgil, 2020). Companies can create value when product design is integrated into the SC, which will have to balance the company's resources and capabilities. (Khan et al., 2016; Lin and Zhou, 2011). Customer needs drive the market. This is particularly true in the automotive sector, where flexibility and responsiveness have become the key to facing the competition (Elmoselhy, 2013). Customers evaluate the company based on the products offered and their uniqueness (Kumar, Singh and Modgil, 2020). Lean principles therefore help to provide value to the customer, to attract them but also to implement a philosophy of continuous improvement (Liker, 2004; Papadopoulou and Ozbayrak, 2005). On the other hand, lean practices help to adapt lean principles in the workshop (Liker, 2004; Papadopoulou and Ozbayrak, 2005) and consequently to obtain better operational performance (Marodin et al., 2016). The improvement does not only go in the workshop but goes abroad throughout the entire SC, from suppliers to customers (Cagliano et al., 2006; Ozelkan et al., 2007). The practices used by the lean approach are numerous. More in detail the practices that will be the subject of this study are the most adopted in the automotive industry (Valamede and Akkaei, 2020; Sanders et al., 2017; Nordin et al., 2010) and will defined as follow:

- Andon is a signaling systems that allows to quickly communicate to operators engaged in an industrial production process. Specifically, this practice takes place via buttons, flags or automatic systems arranged along the workstations or directly above the machinery and connected to an electronic scoreboard or a lighting column that shows in real time the status of the work, the takt time, the materials already processed, those that were foreseen by the roadmap and the presence of a problem (Saurin et al., 2011).
- -Heijunka is the leveling of the production, to obtain a uniform production flow, reducing the whip effect and therefore the wall waste. It plans to produce goods in upstream processes while maintaining a steady pace downstream as well.
- -Jidoka means automation with human intervention (Liker and Morgan, 2006) therefore the production system uses automation technologies under the supervision of the workers. It consists in giving intelligence to machines in such a way that they can autonomously distinguish normal operations from anomalous ones.
- Just in time (JIT) is one of the pillars of the Toyota Product System, it aims to provide the right product, in the right time, quality, location and cost. It aims to reduce the "problems of overproduction, transportation, delivery times, unnecessary movements and product defects" (Mayr et al., 2018; Sanders et al., 2016). In current logistics systems, JIT objectives are not always met, due

to incompatibility between requested and transported products and unexpected delays during transport (Mayr et al., 2018; Sanders et al., 2016).

- Kaizen is a process of continuous improvement, which must be implemented day by day, with the aim of reducing waste and adding value, reducing delivery times and costs, simplifying activities, and preventing the occurrence of future problems. It is the basis of the lean methodology and requires improvement to take place gradually, systematically and involving the various players in the SC.
- -Kanban is a tool to implement and promotes a continuous material flow with waste-free processes, maintaining a predefined inventory level to ensure continuous material supply (Valamede and Akkaei, 2020).
- Pull Production (PP) is a production logic in which only what the market requires is produced. It is a lean tool that allows firms to reduce waste from production processes as production is scheduled since orders received from customers. Pull, in fact, means pulling and refers to producing at the request of the market. The use of a pull system also allows to reduce surpluses and optimize warehouse costs.
- Total Productive Maintenance (TPM) is an innovative maintenance approach that optimizes equipment efficiency, eliminates failures, and promotes autonomous maintenance (Mayr et al., 2018; Singh et al., 2013). It aims to improve productivity and quality, motivate workers, and contribute to job satisfaction (Valamede and Akkaei, 2020).
- Value Stream Mapping (VSM) is a fundamental lean tool and represents a starting point in a lean implementation process. It includes all SC activities and identifies non-value-added processes (Ellingsen, 2017). This tool is used "to eliminate waste, simplify work activities, reduce processing times and costs, increase production quality" (Wagner et al., 2017).

4.2.2 Sustainable supply chain in the automotive sector

The issue of sustainability is more topical than ever, especially in the automotive industry. Automotive manufacturers are under pressure to comply with internal policy guidelines and specifications, as well as the evolving needs of individual customers (Thun and Hoenig, 2011; Wallentowitz and Leyers, 2014).

In response to these legal and consumer pressures, automotive companies have developed activities that address sustainability, such as considering the end-of-life phase during the design process or reducing vehicle weight in order to improve fuel efficiency (Mayyas et al., 2012).

For the automotive industry, the use of electric motors has become increasingly important, but also the light construction of vehicles and the reduction of CO_2 emissions (Wellbrock et al., 2020). However, it is also necessary to take care of the construction of the interior of the vehicles, which is the part most viewed by the user. In this sense, natural fibers could be used, further contributing to the transition towards sustainability (Pischinger and Seiffert, 2016). In the literature it is possible to find various findings, most of which, however, focus on the environmental dimension (Nunes and Benett, 2010) or are found to be inconclusive. Similarly, another branch of the literature assessed that many producers often focus on the economic component of sustainability, neglecting environmental and social aspects (Bergenwall et al., 2012). Other manufacturers, such as those that produce fully electric vehicles, are oriented on the environmental component (Figge and Hahn, 2012). Nunes and Bennett (2010), for example, compared the environmental initiatives implemented by companies operating in the automotive sector, concluding however that these are inconclusive. Wolff et al. (2020) conducted a study aimed at investigating how the automotive industries can become leaders in sustainability, but which ended with the finding that achieving sustainability objectives remains an unresolved challenge. The impeding factors are "lack of common definitions of sustainability and corresponding objectives, lack of accountability and lack of organizational integration". Azevedo and Barros (2017) performed an analysis aimed at evaluating a sustainable business model for the automotive industry, which integrates the three dimensions of sustainability. The study has shown that in the last decade there has been a marked improvement in the sustainable performance of the SC. Sinha et al. (2015) pointed out that managing sustainability in the automotive industry is only possible through a holistic process approach that starts with the conception and continues through to mass production of the product. Several researchers have also focused on the selection of sustainable materials in automotive manufacturing. For example, McAuley (2003) estimates that a 10% reduction in total vehicle weight results in 3-7% greater fuel savings. Furthermore, the selection of sustainable materials influences many areas relating to resources, recyclability, and biodegradability Mohanty et al., 2002). Zahraee et al. (2018) performed a study to evaluate green suppliers in the automotive industry in Iran, which demonstrated a positive relationship between supplier participation in sustainable initiatives and customer investment; customer needs and participation of suppliers in sustainable initiatives; social responsibility and requirements of the SSC. On the contrary it has been shown that supplier availability and cooperation in relational norms do not have a positive effect on SSCM. In conclusion, adding these contributions with that provided in the previous chapter, the sustainable practices that will be adopted in the definition of the integrated framework were chosen. Specifically, starting from the taxonomy identified in chapter 3 (table 3.1), only those practices most used in the automotive sector have been considered:

- Sustainable Total Quality Management (STQM) is defined as management approach of an organization, centered on the quality and the TBL of sustainability, based on the participation of all its members and aimed at long-term success through customer satisfaction, as well as benefits for all members of the 'organization and for society' (ISO 8402, 1992) (Beske et al., 2014; Beske and Seuring, 2014; Kumar et al., 2014).
- Local sourcing represents one of the key pathways through which automotive companies promote sustainable development. The automotive industry produces differentiated and complex products that translate in numerous purchase orders, components, materials, and other external inputs that account for most of the final cost (Zailani et al., 2018). VanWeele (2010) has shown

that the automotive industry is one of the industrial groups most dependent on suppliers, which is approximately between 60 and 80% of the total cost of production. Given this trend, companies tend to use local suppliers to reduce costs and the impact on the environment.

- Sustainable cooperation with customer includes activities such as education and assistance to end customers to improve their environmental awareness regarding driving and develop ecological initiatives to establish environmental improvement objectives (Abdallah et al., 2012). In general, companies collaborate with the customers to increase the green image of the brand (Zhu et al., 2008; Eltayeb et al., 2011; Zhu et al., 2007; Holt and Ghobadian, 2009; Zhu and Sarkis, 2006).
- Sustainable employee engagement is understood as a two-way relationship between employer and employees, in which the latter engage positively, emotionally, and intellectually for their organization and its success (Tower-Perrin, 2003; Robinson et al., 2004). Employee involvement leads to a number of benefits such as developing a motivational culture, commitment and passion for work(Cheese and Cantrell, 2005), customer satisfaction and loyalty (Harter et al., 2002), higher productivity, profit, safety (Buchanan, 2004; Wagner and Harter, 2006). This is particularly used in the automotive sector since, this practice helps to raise awareness among employees on the issues of sustainability and the impacts on the planet (Saraturn, 2016).
- Supplier certification ISO14001 is one of the most widely used environmental management system standards among companies and especially in the automotive industry. It was introduced in 1996 and updated in 2004 (Environmental management systems - requirements with guidance for use, International Organization for Standardization, 2004). According to Potoski and Prakash (2005), if an organization adheres to the requirements of the standard, it will increase the possibility of reducing its environmental impacts compared to organizations that do not adhere. Many companies in the automotive industry require suppliers to implement ISO14001. A supplier, certified according to ISO14001, indicates that it is ready to integrate environmental aspects into the company's management processes (King et al., 2005).
- Waste and emissions reduction is an important aspect of sustainable production. This involves the entire SCs and is aimed at eliminating or preventing waste from an environmental point of view such as CO_2 emissions, water and soil pollution, efficient use of resources and energy (Vijayvargy et al., 2014). As seen previously, it is one of the most addressed and discussed aspect in relation to the automotive sector.

4.2.3 Industry 4.0 in the automotive sector

According to the Automotive Industry Pocket Guide 2020/2021 (European Automobile Manufacturers Association, "The Automobile Industry Pocket Guide", 2020) the automotive industry employs 14.6 million Europeans, which is a considerable 6.7% of total employment in the European Union. With 2.7 million people working in vehicle manufacturing in 226 EU factories, the automotive industry accounts

for 8.5% of the continent's overall manufacturing jobs. More than 18.5 million vehicles were 'made in Europe' in 2019, equal to 20% of world vehicle production, 5.6 millions of these vehicles were exported worldwide, generating a trade surplus of 74 billions of euros for the EU.
Today there are 313 million vehicles on European roads. In addition to ensuring the free movement of people and goods across the continent, these vehicles represent an important source of public revenue, with tax revenues of over € 440.4 billion. Innovation and technological development are the heart of the automotive sector. Indeed, the automotive industry is by far the largest R&D investor in the EU, with an investment in new technologies of € 60.9 billion. This puts it ahead of global competition by making the mobility transformation cleaner and smarter. Given this scenario, it becomes clear how the I4.0 represents a crucial issue in the automotive domain.
Numerous authors have analyzed the I4.0 technologies in this area (Kolberg and Zühlke, 2015; Mayr et al., 2018; Pereira et al., 2019; Sanders et al., 2016; Kamble et al., 2018). After a detailed screening of previous contributions (chapter 2), only the I4.0 technologies most used in the automotive industry were identified as follow:

- 3D printing is based on additive manufacturing, which forms the final products by building successive layers of materials, thus avoiding the assembly of parts and components (Kamble et al., 2018). To generate a digital model for creating a three-dimensional object in a 3D printer, computer-aided design (CAD) software is used (Kamble et al., 2019).
- Artificial Intelligence (AI) is defined as type of interactive, reality-based display environment that takes the capabilities of computer-generated display, sound, and other effects to enhance the real-world experience (Chae and Goh., 2020). This technology that emphasizes creating intelligent machines that work and react like humans with the help of software design (Ghobakhloo, 2019).
- Augmented Reality (AR) this technology works by overlapping virtual objects with the existing environment. In AR displays, virtual and real information, previously acquired with a camera, is digitally merged, and represented on a screen, creating an interface between employees and digital products or equipment (Mayr et al., 2018; Rüßmann et al., 2015).
- Big Data (BD) refers to a large amount of different data, which is processed into information with a high acquisition speed and greater visibility, improving the efficiency and effectiveness of organizations in decision-making processes (Vaidya et al., 2018).
- Cloud computing provides a unified communication between the technological level (intelligent products and cyber-physical systems) and the highest hierarchical level in an organization. Innovation that increases data sharing beyond company boundaries, improves system performance, makes it more agile and flexible and reduces costs (Ma et al., 2017; Vaidya et al., 2018).

- Cyber Phisical Systems (CPSs) represent the IT part of I4.0 and consist of systems that makes the entire factory adaptable (Ivanov et al., 2016; Wang et al., 2015). In the case of manufacturing, these are machines such as a CNC, lathe, mill or grinder to a processing unit such as a computer (Karakose and Yetis, 2017; Monostori, 2014). In the system, the computer acts as the head and the machine acts as the body, as if there are changes, the computer network makes the decision and implements it with the help of the machine. The system also consists of a feedback loop: when a change occurs in the input parameter, the output is changed to satisfy the alteration in the input (Kamble et al., 2018).
- Internet of Things (IoT): refers to interaction between machine and machine without human intervention (Xu et al., 2014). In the IoT, there is a network of devices where each device has a unique identification through the computer system to which it is connected. The devices connected to the system can be remotely controlled with high accuracy and efficiency. IoT revolutionizes existing production systems and is one of the most important enablers for I4.0. The main function of the IoT is to create networks that support the smart organization or factory (Trappey et al., 2017; Varghese and Tandur, 2014).
- Simulation/Virtual simulation (VS) is computational system-based modeling that promotes real-time data to mirror the physical world into a virtual model that includes machines, products, and humans. This simulation provides a preliminary analysis of all the phases that make up the process, presenting performance estimates for the production indicators (Bahrin et al., 2016).

4.3 Framework definition

Following the selection of the I4.0 technologies and lean and sustainable practices to be linked, the first phase for the definition of the integrated framework is the identification of the macro-areas that set up the SC of the automotive sector. Based on the literature (Ambe and Badenhorst-Weiss 2011) four areas have been identified (Figure 4.1).

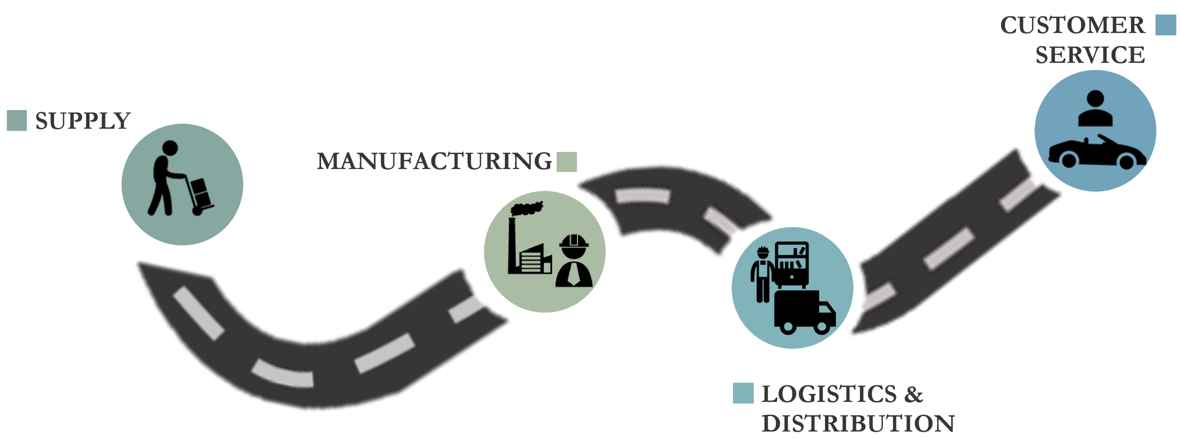

Figure 4.1 Automotive supply chain

The first area identified is the *supply* area. Upstream of the SC, suppliers play a key role as they supply thousands of parts and components to build the vehicle. These parts are received from tier-one suppliers and direct parts manufacturers. Each supplier in turn will use other suppliers, therefore, this area consists of different levels. The time required for each supplier's parts to arrive varies depending on the geographic location. In the case of local suppliers, the part can take place within two days, in the case of suppliers located abroad, it can take several weeks (Iyer et al., 2009).

Subsequently, the vehicles are produced in the *manufacturing* area. The production involves several stages such as bodywork, painting, assembly, and inspection. The various pieces of sheet metal arrive in the bodywork, they are welded and the bodywork and chassis of the vehicle, defined as the body, are created. Subsequently, the body is painted. It is painted in the chosen colour, and several treatments are also carried out to make it more resistant and lasting. The body arrives at the assembly department, where the coupling between the painted body and all the mechanical parts takes place, for which the seats and all the electronics are mounted.

Finally, there is the inspection phase, in which all the checks on the vehicle are carried out. In the *logistics & distribution* phase, each vehicle is picked up from car transporters and delivered to dealers. Dealers play a key role in the *customer service* area, as they are responsible for selling the vehicles produced to customers. Automotive companies have different categories of customers. There are the retail consumers, who represent the largest customer segment, thanks to which companies make the largest profits. The second category of customers is employees or suppliers. Indeed, automotive companies allow employees or relatives to purchase a limited number of vehicles per year to which a discount is applied. Either way, they need to get approval before purchasing. The third category is the fleet, in which rental companies, commercial fleet and government agencies can be distinguished. Each rental company signs a contract with each automotive company for the annual volume of each model requested. A commercial fleet refers to private companies that provide company vehicles to their employees. Government agencies enter contracts with automotive companies to receive vehicles for a limited period (Iyer et al., 2009). Dealers act as a meeting point between the company and customers, therefore one of the major responsibilities attributed to them is to guide the customer's demand. Dealers must invest sufficiently in the facility so that they can operate efficiently and meet or exceed their sales targets. It is also essential that a dealer has an adequate mix of stocks so that the customer is enticed to purchase. A positive customer experience during the sales process will also lead to higher quality (Iyer et al., 2009). In this way that the customer is encouraged to purchase.

4.4 Definition of the hypotheses

In the previous paragraphs, a list of lean and sustainable practices and I4.0 technologies adopted in the automotive sector is identified. Starting from these practices and technologies, a set of hypotheses concerning the combined use of I4.0 lean and sustainable practices in each macro-area of the automotive SC have been formulated. These hypotheses have led to the definition of the integrated framework. This last is presented as a matrix (Figure 4.2). The rows of the matrix represent lean practices adopted in each automotive SC macro-area. The columns of the matrix represent the sustainable practices according to the automotive SC macro-area. Finally, the cells of the matrix are filled with I4.0 technologies that might potentially support both lean and sustainable practices. The following sections will present in detail how the framework was structured.

		SUPPLY	**MANUFACTURING**	**LOGISTICS & DISTRIBUTION**	**CUSTOMER SERVICE**
	SUSTAINABLE PRACTICES / **LEAN PRACTICES**	Local Sourcing Supplier certification ISO14001	Waste and emissions reduction TQM Sustainable empoyee engagement	Waste and emissions reduction	Sustainable cooperation with customer
SUPPLY	VSM JIT Pull Production Kaizen	BD Cloud Simulation CPS AR 3D printing IoT AI	BD Cloud Simulation CPS AR 3D printing IoT AI	BD Cloud Simulation CPS AR 3D printing IoT AI	IoT Simulation AR Cloud CPS
MANUFACTURING	VSM Andon Jidoka Heijunka Kanban TPM Kaizen	BD Cloud Simulation CPS AR 3D printing IoT	BD Cloud Simulation CPS AR 3D printing IoT	BD Cloud Simulation CPS 3D printing IoT	IoT AR 3D printing
LOGISTICS & DISTRIBUTION	VSM JIT Kaizen	BD Cloud Simulation AR 3D printing IoT	BD Cloud Simulation AR 3D printing IoT	BD Cloud Simulation AR 3D printing IoT	IoT AR Simulation 3D printing
CUSTOMER SERVICE	VSM JIT Pull Production Kaizen	BD Cloud Simulation CPS 3D printing IoT	BD Cloud Simulation CPS 3D printing IoT	BD Cloud Simulation CPS 3D printing IoT	IoT Simulation AR Cloud CPS

Figure 4.2 Integrated framework

Hypotheses on lean practices

The hypotheses on lean practices are based on a different previous contribution by Valamede and Akkari, (2020) and Sanders et al., (2017). More in detail, in this phase each lean practice previous identified (section 2.6.1) is placed in the automotive SC area and subsequently combined with specific sustainable practices and I4.0 technologies.

- Andon has been placed in the manufacturing area given its very nature as a visual solution to support production.
- Heijunka is in the manufacturing area as it represents the levelling of production to balance workloads.
- Jidoka has been placed in the manufacturing area since it represents a particular type of automation with the human touch that allows the production process to be interrupted before a failure occurs.
- JIT has been placed in the supply, logistics & distribution, and customer service areas. It requires close collaboration between suppliers, distributors, and customers. Indeed, the supplier will deliver the goods only after the customer has requested them. Furthermore, the logistics & distribution area will adopt this approach to reduce inventory and proceed with the distribution of vehicles more efficiently.
- Kaizen has been placed in all areas of the SC as continuous improvement involves all phases of the SC.
- Kanban has been placed in the manufacturing area as it guides the production process, deciding the quality and quantity to be produced.
- Pull production has been placed in the supply and customer service area since the production rhythm is dictated by the customers and consequently the supplier produces and moves materials only following the customer's request.
- TPM has been placed in the manufacturing area as it refers to activities aimed at guaranteeing the reliability of the machine and therefore the reliability and speed of production quality.
- VSM has been placed in all four areas of the automotive SC, as it is nothing more than a mapping of all the processes that contribute to the realization of the product, starting from the supplier up to the delivery of the product to the customer, passing for the entire SC.

Hypothesis on sustainable practices

As for lean practices, each sustainable practice identified in the previous paragraph was categorized in the automotive SC macro-areas based on different previous contributions (Siegel et al, 2019; Çalik, 2021; Enyoghasi and Badurdeen, 2021).

- Local sourcing has been placed in the supply area as these practices are strictly related to the strategic choice of suppliers to reduce emissions and transportation costs.

- Supplier certification ISO14001 has also been placed in the supply area as regards the choice of suppliers to guarantee attention to the environment and the integration of environmental aspects in the management of processes.
- Sustainable cooperation with customers has been placed in the customer service area, since cooperation with customers makes it possible to carry out reverse logistics processes, sustainable packaging and involves greater attention to environmental and social sustainability.
- Sustainable employee engagement has been placed in the manufacturing area as greater involvement of employees in a sustainable environment allows to reduce waste and create products that are more attentive from the point of view of environmental sustainability.
- STQM has been placed in the manufacturing area as the adoption of quality-oriented systems is adopted in all the manufacturing phases from assembly to final inspections.
- Waste and emissions reduction has been placed in the manufacturing and logistics & distribution area as the elimination of waste is an important aspect of sustainable production and is aimed at eliminating or preventing waste from an environmental point of view such as air pollution, water and soil, efficient use of resources and energy.

Hypothesis on Industry 4.0 technologies

The last step for the definition of the integrated framework was the identification of the potential support that each I4.0 technology could provide to the different lean/sustainable practices positioned in the different areas of the automotive SC.

Regarding lean practices:

- Andon can be supported by CPS as it provides real-time error messages to operators, which will trigger repair actions as soon as the failure occurs, reducing delays due to failures ((Mayer et al., 2018; Mrugalska and Wyrwicka, 2017; Pereira et al., 2019).
- Heijunka can be supported by IoT which has enormous potential in the field of provision for real-time data analysis, reducing fluctuations and the occurrence of bullwhip effect (Pereira et al., 2019).
- Jidoka can be supported by IoT as the production system uses automation technologies under the supervision of workers (Satoglu et al., 2018a). Also, CPS, cloud, and BD improve the overall performance of Jidoka, as this tool better the identification of defects and low-quality parts before delivering (Buer et al., 2018; Lugert et al., 2018; Ma et al., 2017; Satoglu et al., 2018b; Slim et al., 2018; Wagner et al., 2017).
- JIT is supported by BD, cloud, and AR because these tools create a continuous, transparent, automated, and customer-oriented flow of information (Valamede and Akkari, 2020).
- Kaizen can be supported by cloud computing and BD since the data coming from production processes/smart devices are shared in a cloud environment and the analyzed through BD,

contributing to the achievement of results and solutions typical of continuous flow. Furthermore, simulation and AR also act as a support for the implementation of Kaizen by favouring human-machine interaction, allowing employees to acquire new skills and knowledge (Valamede and Akkari, 2020).

- Kanban is supported by BD, which by monitoring the production flow in real-time allows reducing the stocks of materials, and by simulation that allows identifying the optimal parameters for the Kanban. What as more, CPSs allow the transmission of the information contained in the Kanbans through the sensors that send the signals to the enterprise resource systems (Pereira et al., 2019).
- Pull Production can be supported by cloud computing as it provides a better understanding of the customer's needs, by BD as by sharing information in real-time directly in the customer's information system, it reduces communication times and costs, and increases efficiency and added value for the customer. Also, 3D printing could support pull production by streamlining the manufacturing process and reducing delivery costs and lead time (Ahmad et al., 2018b; Davies et al., 2017; Enke et al., 2018; Kolberg et al., 2017; Lugert et al., 2018).
- TPM is supported by cloud which allows managers to monitor machines parameters frequently. Furthermore, TPM is supported by BD which receives data from the cloud to manage maintenance. Besides, simulation and AR techniques improve the training of employees to perform maintenance activities more efficiently and with the right frequency (Kumar et al., 2018).
- VSM practice is supported by BD, cloud, simulation, IoT and 3D printing. Through BD and cloud, VSM will continuously receive new data and information from the entire SC. This information is crucial to detail and to update the maps of processes. Thanks to the simulation, it is possible to create preventive maps, before the production starts, simulating the possible interactions between humans and machines in different scenarios (Valamede and Akkari, 2020; Ahmad et al., 2018b; Camgoz-akdag et al., 2018; Davies et al., 2018; Enke et al., 2018).

Regarding sustainable practices:

- Local Sourcing can be supported by BD as the new data sources improve the exchange of information in the supply network, and the demand-sensing capabilities (Enyoghasi and Badurdeen, 2021).
- Supplier certification ISO14001 can be supported by Cloud, IoT, BD and AI as these technologies help in identifying suppliers with sustainable requirements (Çalik, 2021).
- Sustainable cooperation with customers can be supported by BD since thanks to this tool, information on products, services, customers, and suppliers is readily available, allowing greater accuracy of supply/demand forecasts.

- Sustainable employee engagement can be supported by BD, IoT, and cloud as they act as a support to the health, safety, and awareness of employees, since they are no longer required to perform monotonous and repetitive tasks, they are more satisfied and motivated (Bai et al., 2020; Müller et al., 2018).
- STQM can be supported by AR as observing the products in real-time, improves the collection of data on the life cycle, defect detection, and the satisfaction of product compliance needs (Tao et al., 2018a; Carvalho et al., 2020). Therefore, AR allowing to achieve a better product quality during the life cycle and longer duration. In the same vein, IoT acts as support since it allows better identification of product non-conformities (Tao et al., 2018b). Also, cloud systems allow better control of the product through digital interfaces (Frank et al., 2019).
- Waste and emissions reduction can be supported by BD, AI, and cloud as through the collection, detection, and analysis of data companies can reduce waste and CO_2 emissions and provide infrastructures capable of enabling greater efficiency in the use of materials, energy, toxic materials and less impact on effluents and waste (Schniederjans and Hales, 2016; (Gabriel and Pessl, 2016; Sarkis and Zhu, 2018; Bai et al., 2020). Besides, 3D printing and simulation support waste reduction, as these reduce the need for assembly allowing customization (Stock and Seliger, 2016). This affects the use and efficiency of resources (Enyoghasi and Badurdeen, 2021; Carvalho et al., 2020).

In conclusion, thanks to the intersections present in the framework between lean/sustainable practices and I4.0 technologies it is possible to identify combinations of technologies/practices that can support the global SC performance of firms in the automotive sector in both sustainable and operational terms. The methodology adopted to test these combinations will be illustrated in the following paragraph.

4.5 Case study methodology

The case study is a research approach that allows for the exploration and understanding of complex issues. It can be considered a robust research method especially when a holistic and thorough investigation is needed. This method allows researchers to closely examine the data in a specific context. In most cases, a small geographic area, and industrial sector or a very limited number of individuals are selected as study subjects. The case studies, in their very essence, explore and investigate the phenomenon of real-life through a detailed contextual analysis of a limited number of events or conditions and their relationships. Yin (1984) defines the case study as an empirical investigation that analyses a contemporary phenomenon within its real context, when the boundaries between phenomenon and context are not clear, and in which multiple sources of evidence are used.

As this methodology often receives criticism in terms of its lack of robustness as a research tool, the design phase of the case studies is of paramount importance. Researchers can adopt single-case or multi-case designs depending on the topic under investigation. In multiple case studies, the logic is that of research replication: experience, assertions and theories derived from the study of previous cases constitute the reference framework for the study of subsequent cases, which can also provide empirical evidence that leads to retroacting on the former, shedding light on aspects not yet considered or providing new interpretations of the data. The purpose of the single case study, on the other hand, is to describe and understand the complex structure of relationships that characterize the case itself.

The first important step, in enabling a comprehensive case study, is the definition of a clear research question and important constructs used in that question. The second step is the selection of a population to undertake case analysis. This is followed by the data analysis through different methodologies both qualitative and quantitative. This procedure is completed by integrating the data with the literature. The author needs to compare the found data, hypotheses, and theories with the existing literature in the specific field and with the present search for similarities (increase validity, linking old and emerging theory) and differences (presenting opportunities for new concepts). Furthermore, the quality of the study must find the right closing point. The different steps discussed are summarised in Figure 4.3.

There are several benefits to using the case study. First, the examination of the data is often conducted in the context of its use (Yin, 1984), that is, when the activity takes place. Second, variations in terms of intrinsic, instrumental, and collective approaches to case studies allow for quantitative and qualitative analyzes of the data. Third, the detailed qualitative reports often produced in case of studies not only help explore or describe data in the real world but also help explain the complexities of real situations that cannot be captured through experimental or investigative research.

Despite these advantages, the case studies have received criticism. Yin (1984) discusses three types of arguments against case study research. They often lack rigour. Yin (1984) notes that too many times, the researcher has allowed equivocal evidence or subjective opinions that influence the results and conclusions drawn. Furthermore, the case studies provide very little basis for a scientific generalization as they use a limited number of subjects, some are conducted with only one. Finally, they are often labelled as too long, difficult to conduct and produce a huge amount of documentation (Yin, 1984).

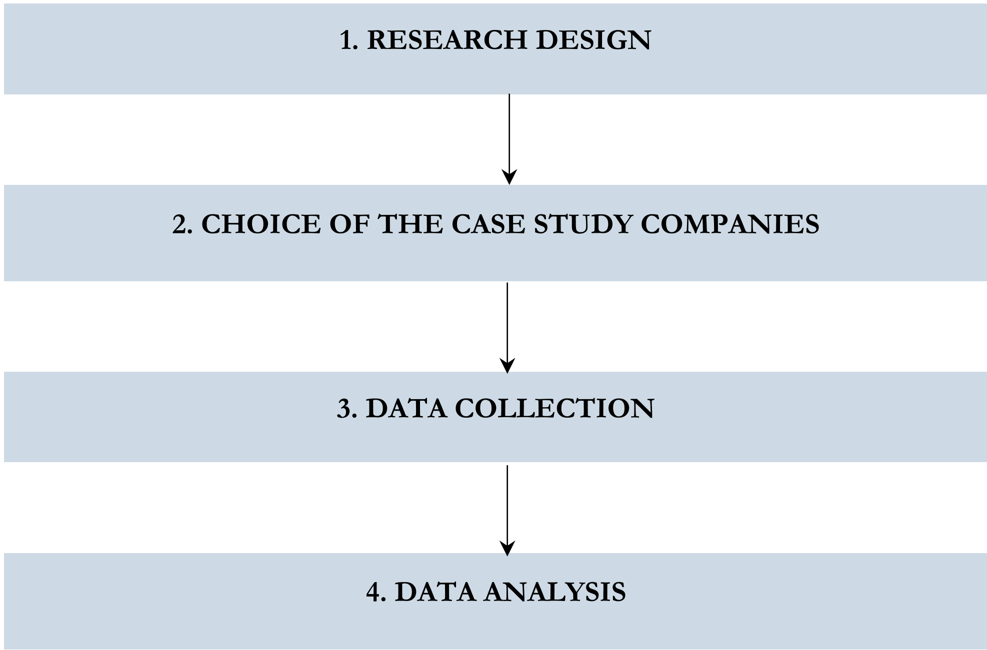

Figure 4.3 Case study steps

4.5.1 Research design

The first step in conducting the case study is defining the research case: this research utilizes a multiple case study design. Clearly defining the research problem is the most important step of the whole project. At this stage, the contents of the literature must be carefully examined, and a careful analysis of the research issues and study objectives must be carried out. The planning phase focuses on identifying research questions or other motivations for carrying out a case study and understanding its strengths and limitations (Yin, 2009). A comprehensive literature review, which improves the validity of the study face, should identify relevant gaps in the literature and link them to research questions.

To fully define the units of analysis and determine the limits on the subject in question, it is necessary to:

- define the precise field of study.
- define the context of the study.
- determine and define, if applicable, the geographical area of reference.
- analyze the literature already available on the research topic.

This phase has been extensively carried out in the previous chapters. Specifically, in chapters 1 the literature was analyzed, and in chapter 2 and 3 were further explored some specific features that support the definition of the hypotheses formulated in the previous sections. The analysis of the literature highlighted the lack of empirical studies on the link between the lean and sustainable SC paradigms and I4.0 technologies. Starting from this result, after a detail analysis of I4.0 technologies, sustainable and lean practices and their mutual connections, an industrial sector was identified characterized by extensive use of both I4.0 technologies lean and sustainable practices. Subsequently, based on the identified sector, the hypotheses were formulated, and the integrated framework was defined to test the link between lean practices, sustainable practices and I4.0 technologies.

The following paragraph will identify the sample on which the framework was tested.

4.5.2 Choice of the case study companies

The choice of the sample of companies to be interviewed is the result of research aimed at identifying companies that had implemented sustainable and lean programs, and that used I4.0 technologies. To ensure that companies have implemented a sustainability program, the GRI "Global Reporting Initiative" standards were assessed, which refer to the environmental, but also the economic and social aspects that every company should respect in order not to leave a negative footprint on the ecosystem. The GRI Standards can be used as a set to draft a sustainability report focused on material issues: economic, environmental, or social. The preparation of a report following the GRI standards provides an inclusive picture of the material issues of a company, their related impact and how they are managed. The company may also use all or part of the GRI standards to report specific data. To make sure that companies have implemented lean programs, although in the literature several indicators allow evaluating this aspect, they are little used, and therefore the websites and strategic plan documents of the leading worldwide automotive companies were consulted to identify the lean initiatives implemented. The same search was performed to retrieve information on the adoption of I4.0 technologies. At the end of this exploratory analysis, the selected companies were seven (Table 4.1).

Company 1 was founded in 1884, is the largest European manufacturer of scooters and motorcycles and is one of the main world players in this sector. To date, the company has three distinct souls such as two-wheelers (scooters and motorcycles from 50cc to 1400cc), light commercial vehicles and the robotics division. In 2019 Company 1 sold 399.600 two-wheeled vehicles and 211.700 light commercial vehicles. Company 1 consists of several industrial centres: in Italy, where there is also the main production plant in the world in which the most famous vehicles are produced, light transport vehicles for the European market and engines for scooters and motorcycles, in India in Baramati and Vinh Phuc (in Vietnam) are placed the other production plants. In addition, it has four R&D centres two in Italy and one in California and Boston. Over the last few years, it has also launched an internalization campaign that has led it to be a world player in its sector. In June 2009 it entered the Vietnamese market and, in March 2012, the plant in Hanoi was inaugurated, an example of quality and excellence, an international best case. In five years, more than 600,000 vehicles have been produced at the Hanoi plant. In April 2012, the Indian plant in Baramati (in the state of Maharashtra) was inaugurated, dedicated to the production of 3 and 4-wheeled light transport vehicles for the Indian market and export, the production of scooters, as well as diesel and turbodiesel engines for the Group's commercial vehicles. The Company 1 Group also operates with a joint venture company in China 45% owned by Company 1. A development plan is envisaged in the area, as announced by the President during the Shareholders' Meeting in April 2017. Across the Atlantic, the Group is present in New York, while on the west coast of the United States, in Pasadena, the Company 1 Group Advanced Design Center research and development hub operates in California. In 2015, in the United States, the Group founded a company to research innovative solutions and technologies in the mobility and transport sector, it is based in Boston. The turnover achieved by Company 1 in 2019 is more than 1,5 million euros with a few employees of 6,222.

The history of Company 2 began in 1933 when it opened a new division dedicated to the production of automobiles. In 1934 the first types of engines were produced. In 1936, the production of the first model of the car began. Company 2 is one multinational Japanese which produces motor vehicles. This is the largest automotive company in Japan, with an estimated production of about 9 million vehicles the year. It dominates the Japanese market with around 40% of new cars registered in 2004, it also enjoys a substantial market share in Europe in the United States. The company produces a large variety of vehicles that are generally valued for quality of materials and good design. In 2011 Company 2 was once again the world leader in sales, with nearly 8.5 million vehicles sold in 2010, an increase of approximately 8% compared to 2009. In 2012 it sold 9.75 million cars, surpassing General Motors and Volkswagen. Company 2 returns to the podium where it was the key player from 2008 to 2010. Company 2 invests a lot of its research on hybrid vehicles based on technology hybrid synergy drive. In 2013, the company sold 3,000,000 hybrid vehicles, which leads to over 5,000,000 hybrid cars in the world. In 2019, it invoiced 29.5 trillion yen, about 220 billion USD.

Company 3 was founded in 1914 in Italy. The first vehicle of Company 3 was built in 1926. Over the years, Company 3 has gone through periods of crisis and recovery. Since 2005, Company 3 has belonged to an Italian group that represents a prestigious brand in the sports and luxury sedan segment present in over 60 countries, where it continues to bear witness to refinement, elegance, and Italian style around the world. In 2013, Company 3 brand was relaunched with the introduction of the new generation of sedan cars, the first in the large sedan segment and the second in the full-size luxury sedan segment. In September 2019, Company 3 announced the project for the new line of electrified vehicles to be produced in Modena, Cassino and Turin.

Company 4 is a car manufacturer founded in Italy in 1947. The company produces automobiles high-end sports and racing and is committed to sports motoring. It is the most titled in Formula 1 world championship. Its origins in sports dating back to 1929, when the founder gave rise to the main division of the Company's 3 racing department, having always been involved in Formula 1 and having raced in the Sports Prototype world championship until 1973. In 2013 and 2014 the brand was recognized as the most influential in the world and in 2015 it was positioned at 295th in the "The most valuable brands of 2015" ranking of the Brand Finance website with a value of 4.8 billion dollars. In 2019 it achieved a turnover of 3,767 billion euros.

Company 5 is one multinational car manufacturer Japanese, founded on December 26, 1933. At its beginning, Company 5 was specialized in the production of four-wheeled vehicles. In the early years, the company concentrated on the supply of vehicles for the army and the licensed production of American (Graham-Paige) and British (Austin) cars. In 1937 the main plant in Yokohama was moved to Manchuria (a territory currently Chinese but at that time occupied by the Rising Sun) to then return home at the end of the Second World War. Today, Company 5 is the second-largest Japanese house after Company 2. It is part of the automotive leading French group. More in detail, Company 5 is the world's largest manufacturer of electric vehicles, with global sales of over 320.000 fully electric vehicles as of April 2018. It produces the best-selling fully electric car and the best-selling plug-in in the world in history. In 2019 it reached 8,174 million vehicles sold with a turnover of 319,1 billion yen.

Company 6 is an Italian automobile manufacturer, founded in 1963. The headquarters and the only production plant have always been in Italy, where over 1,400 employees work. The company, since 1998, is wholly owned by the leading German automotive group. From its foundation until 2002, Company 6 produced an average of 300 vehicles per year. From 2004 onwards, the average number of cars built was over 1.800 units. Company 6 sales are evenly distributed between Europe, the Middle East and Africa, America, Asia, and Oceania. A total of 8,205 cars were sold in 2019 with a turnover of 1,81 billion euros.

Company 7 is a German multinational automotive manufacturing corporation headquartered in Lower Saxony. It designs, manufactures, and distributes passenger and commercial vehicles, motorcycles, engines, and turbomachinery, and offers related services, including financing, leasing, and fleet management. In 2016, it was the world's largest automaker by sales, overtaking Company 2 and keeping this title in 2017, 2018 and 2019, selling 10,9 million vehicles. It has maintained the largest market share in Europe for over two decades. It also ranked seventh in the 2018 Fortune Global 500 list of the world's largest companies. In 2019, Company 7 reached a turnover of 252,6 billion euros with 10,97 million vehicles sold.

Table 4.1 The case study companies

Case Company	Company 1	Company 2	Company 3	Company 4	Company 5	Company 6	Company 7
Main products	Two-wheeled motor vehicles	Passenger sedans / Hybrid vehicles	Luxurious and fast cars	Sport cars	Electric cars	Luxurious and fast cars	Light commercial vehicles
Employee size	6,222	366,283	1,100	4,164	136,000	1,787	671,205
Annual sales	611,300	10,700,000	19,000	10,131	8,174,177	8,205	10,970,000
Area served	Worldwide	Worldwide	Worldwide	Worldwide	Worldwide	Worldwide	Worldwide
Headquarters	Europe, Asia	Asia	Europe	Europe	Asia	Europe	Europe
Revenue (million €)	1,512	231,92	1,603	3,767	88,82	1,810	252,600
Founded	1884	1937	1914	1939	1933	1963	1937
Dates of the interviews	February 2021	February 2021	February and March 2021	March 2021	May 2021	June 2021	July 2021
Informants	CIO & Senior Vice president	Senior Manager – Head of Product Marketing	Senior Manager – Head of Global vehicle control / Product Manager	Head of Technologies	General Manager /CEO division	Head of Production	Sustainability Expert

NB: Data refer to 2019 and were retrieved from the interviews.

4.5.3 Data collection

The aim of this phase is to acquire information on the research topic. The data collection techniques used in the case studies are numerous and have a qualitative and quantitative nature. The data collection phase consists of following the case study protocol, using multiple sources of evidence, creating a case study database, and keeping track of the results collected (Yin, 2009). The data used in the case studies can come from different sources such as documents, archive registers, survey results, interviews and focus groups.

Interviews often represent the primary source of data collection. These are a very effective tool for collecting large amounts of empirical data, especially when the phenomenon of interest is not particularly frequent. Often, however, the data collected in this way are considered distorted, both because the interviewee can falsify them by saying only what he wants to convey to the interviewer, and because the latter could, unconsciously, structure the interview to find the answers best suited to prove their theses. To overcome this problem, it is necessary to adopt a data collection approach that limits the possibility of distortions, interviewing subjects who are well informed on the case in question and who offer different points of view on the phenomenon under investigation.

To avoid biased responses, semi-structured interviews have been adopted. In the semi-structured interview, the levels of structuring, standardization and directivity are lower than in a structured interview (Addeo and Montesperelli, 2007). The interviewer has a track in which the topics are organized into a series of open questions (Pitrone, 1986). The semi-structured interview also envisages the use of a matrix to organize the information collected, for which the questions are submitted in an open form but must subsequently be codified and assigned to a specific category (Fideli and Marradi, 1996). Unlike the structured interview, the semi-structured interview is characterized by less rigidity the interviewer can clarify the meaning of unclear questions, rephrase, or skip potentially reactive questions (Addeo and Montesperelli, 2007). He may also decide to investigate topics that are useful for understanding the interviewee's opinions. The ability to make partial changes to the track, makes it more flexible and dynamic, making interviewees and interviewers more freedom in interaction and communication.

The questionnaire created consists of 17 standard questions, which were administered to each interviewee. Each interviewee was asked to consent to the recording and subsequent publication of the content of the interviews.

The questions are the following:

1) Can you describe your role in the company, also outlining an overview of the SC?
2) Which of the lean practices does your company use among these?
    - Andon
    - Heijunka
    - Jidoka
    - JIT
    - Kaizen
    - Kanban
    - Pull Production
    - TPM
    - VSM
3) In which area of the SC?
    - Supply
    - Manufacturing
    - Logistics & Distribution

- Customer Service

4) Which of the sustainable practices does your company use among these?
    - Local Sourcing
    - Supplier Certification ISO14001
    - Sustainable Cooperation with Customer
    - Sustainable Employee Engagement
    - STQM
    - Waste Reduction
5) In which area of the SC?
    - Supply
    - Manufacturing
    - Logistics & Distribution
    - Customer Service
6) What are the reasons that led the company to implement lean practices?
7) What are the reasons that led the company to implement sustainable practices?
8) Among the following I4.0 technologies, which ones does the company use?
    - 3D Printing
    - AI
    - AR
    - BD
    - Cloud
    - CPS
    - IOT
    - Simulation
9) Are there other I4.0 technologies that your company uses?
10) Could you link each I4.0 technology to the lean practices it supports?

I4.0 Technologies	**Lean Practices**
3D Printing	Andon
AI	Heijunka
AR	Jidoka
BD	JIT
Cloud	Kaizen

CPS	Kanban
IOT	Pull Production
Simulation	TPM
	VSM

11) Could you link each I4.0 technology to the sustainable practices it supports?

I4.0 Technologies	**Sustainable practices**
3D Printing	Local Sourcing
AI	Supplier Certification ISO14001
AR	Sustainable Cooperation with Customer
BD	Sustainable Employee Engagement
Cloud	STQM
CPS	Waste Reduction
IOT	
Simulation	

12)

13) If you were to define, on a scale from 1 (in no measure) to 5 (very much), the level of support that these technologies provide to lean practices, what value would you assign?

	1	2	3	4	5
Andon					
Heijunka					
Jidoka					
JIT					
Kaizen					
Kanban					
Pull Production					
TPM					
VSM					

14) If you were to define, on a scale from 1 (in no measure) to 5 (very much), the level of support that these technologies provide to sustainable practices, what value would you assign?

	1	2	3	4	5
Local Sourcing					
Supplier Certification ISO14001					
Sustainable Cooperation with Customer					
Sustainable Employee Engagement					
STQM					
Waste Reduction					

15) What are the main benefits perceived in term of operational performance achieved by the company in using I4.0 technologies in the context of lean processes? Can you give some examples?
16) What are the main benefits perceived by the company in the use of I4.0 technologies in a sustainable environment? Can you give some examples?
17) What are the main disadvantages of using I4.0 technologies?
18) How does the company respond to the disruption of the pandemic, has it implemented specific strategies?

4.5.4 Data analysis

The data collected were firstly organized and presented in a descriptive narrative and subsequently analysed through Qualitative Comparative Analysis (QCA) (Ragin, 1987) using a fuzzy set. The QCA is a technique that combines quantitative and qualitative methodologies - to identify the combination of I4.0 technologies, sustainable and lean practices that better the performance of automotive companies. Unlike conventional techniques, QCA does not aim to offer a single solution but to explain the complexity of the investigated phenomenon, by comparing configurations of conditions (Marx et al., 2013). QCA is characterised by three "pillars": conjunctural causation (the causal role of a single condition unfolding in combination with other conditions), asymmetric causality (an outcome can have a different explanation than its non-occurrence), and equifinality (multiple paths to the outcome may coexist) (Thomann & Maggetti, 2020). QCA was developed first (Schneider and Wagemann, 2007; Ragin and Rihoux, 2009), however, the practice involves the distinction of three cases (Rihoux et al., 2011):
(1) "csQCA when referring to the original Boolean version of QCA".
(2) "mvQCA when referring to the version that allows multiple-category conditions".
(3) "fsQCA when referring to the fuzzy version that links the fuzzy sets to the analysis of truth tables".
Ragin (2000) was the first to introduce fsQCA, this technique differs greatly from regression-based methods and other conventional statistical techniques. For example, unlike correlation techniques, which try to estimate the net effect of an independent variable on a result variable, fsQCA tries to identify the conditions that lead to a given result. Furthermore, the fsQCA is based on the idea that the relationships between constructs are more understandable in terms of set theory relationships, rather than correlations

(Fiss, 2011). Therefore, the analysis is based on Boolean algebra and aims to identify necessary and sufficient relationships associated with a result of interest. The use of fsQCA can offer several advantages over traditional analysis methods. To capture combinations of conditions sufficient to obtain a result, it uses both qualitative and quantitative evaluations and calculates the degree of belonging of a case to a set thus creating a connection between qualitative and quantitative methods (Ragin, 2000; Rihoux and Ragin, 2009).

fsQCA can be used on samples of different sizes, from very small (<10 cases) to very large (thousands of cases). The dimension allows to analyze the cases separately without going back to them, but also to identify patterns in many cases (Greckhamer et al., 2013). fsQCA can be used with different types of data, such as the Likert scale, clickstream, and multimodal data (Pappas and Woodside, 2021).

The main stages of the fsQCA imply: (1) the definition of the configuration model, (2) the calibration of the conditions and outcomes; (3) analysis of the necessary conditions to achieve the outcome, and finally (4) the analysis of the sufficiency conditions with the construction of the truth table (Ragin, 2008; Schneider & Wagemann, 2012).

(1) The definition of the configuration model implies the identification the antecedent conditions that must be included in the model to explain the result.

(2) The calibration is the process that changes the base variables into conditions or outcome set membership scores (Thiem & Dușa, 2013). In data calibration, fuzzy sets allow researchers to define different degrees of membership in categories, so cases can take any value within the continuous range from 0 to 1 (Ragin, 2008b). A case with a fuzzy membership score of 1 is "fully in" a fuzzy set, a case with a score of 0 is "completely out" of the fuzzy set. A membership score of 0.5 is exactly in the centre, i.e., it is both a member of the fuzzy set and a non-member, this case is called intermediate (Pappas and Woodside, 2021). Data calibration can be direct or indirect. In direction calibration, it is necessary to choose exactly three qualitative breakpoints, which define the level of belonging in the fuzzy set of each case (totally inside, intermediate, completely outside). In the indirect method, measurements must be made because of qualitative assessments. Both methods can be chosen, depending on substantial knowledge of both the data and the underlying theory. The direct method is recommended and is more common (Pappas and Woodside, 2021). To calibrate the data, it is possible to choose different breakpoints, the choice depends on the degree of precision of the fuzzy sets based on the level of detail of the qualitative data. The data lends itself to the choice of a fuzzy set of four values (Basurto and Speer, 2012) as 0, 0.33, 0.67, 1. The values (0, 0.33) respectively indicate a complete and slight non-belonging to the reference fuzzy set; the values (0.67, 1) indicate respectively a slight and complete membership in the reference fuzzy set.

(3) The fsQCA configurational approach implies the analysis of the necessary and sufficient conditions to produce an outcome. A condition is necessary if it is present in all configurations of the outcome,

which means that outcome cannot be achieved without this condition (Ragin, 2008). A condition is sufficient if the outcome depends on it. In QCA, consistency and coverage are the main parameters of fit: the first indicates how much a condition is a subset of an outcome; the second measures how much a necessary condition is relevant for an outcome.

For the necessary condition analysis, the consistency of the necessary condition and the coverage of the necessary condition are the main fit parameters. In line with the literature, the consistency threshold must be close to one: Ragin (2008) suggested a threshold of 0.9, whereas Fiss (2011) recommended 0.75 as a minimum threshold. Coverage threshold should be equal to or larger than 0.5 (Schneider & Wagemann, 2012). The sufficiency condition analysis is based on a truth table, which lists all the possible combinations of the causal conditions and their associated outcome. A subset of the combinations is selected using a consistency cut-off that should be greater than 0.75 (Rihoux & Ragin, 2009).

(4) For the analysis of sufficiency, additional coverage measures are considered as parameters of fit. The proportional reduction of inconsistency (PRI) expresses how much a condition is, at the same time, a subset of the outcome and of the negated outcome; the raw coverage expresses how much the configurations account for the outcome, and the unique coverage expresses how much of the outcome is explained by each path (Ragin, 2006). The analysis of sufficiency produces conservative, parsimonious, and intermediate solution formulas. The conservative solution formula is the most complex since it is based only on empirically observed evidence. The parsimonious solution formula is the least complex solution because it is based on simplifying assumptions. The intermediate solution is often less complex than the conservative solution and more complex than the parsimonious solution (Schneider & Wagemann, 2012).

Descriptive analysis

Before moving on to testing the framework through the fsQCA, the peculiarities of the companies interviewed were examined. In particular, the level of use of lean, sustainable practices and digital technologies was examined. From the analysis of the interviews, it was found that all the seven companies adopted JIT. In many of these, the use of this practice is very thorough, even becoming the founding principle of all activities. This is followed by Kanban and Andon. On the contrary, TPM, pull production and Heijunka are the less used practices (Figure 4.4).

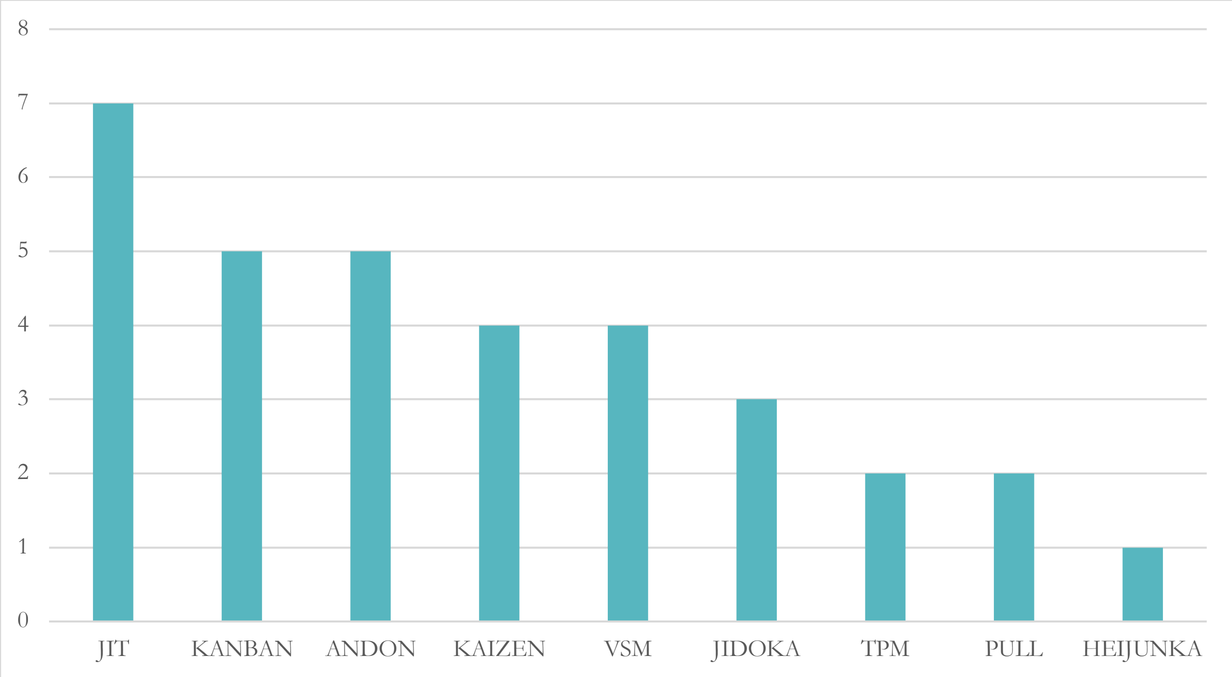

Figure 4.4 Lean practices adoption

A greater difficulty was identified in determining the sustainable practices used by companies, as many informants have not been able to identify the practices used. The analysis revealed that almost all the companies use local sourcing followed by ISO14001 and STQM. Instead, the less used practices are waste reduction and sustainable employee engagement (Figure 4.5).

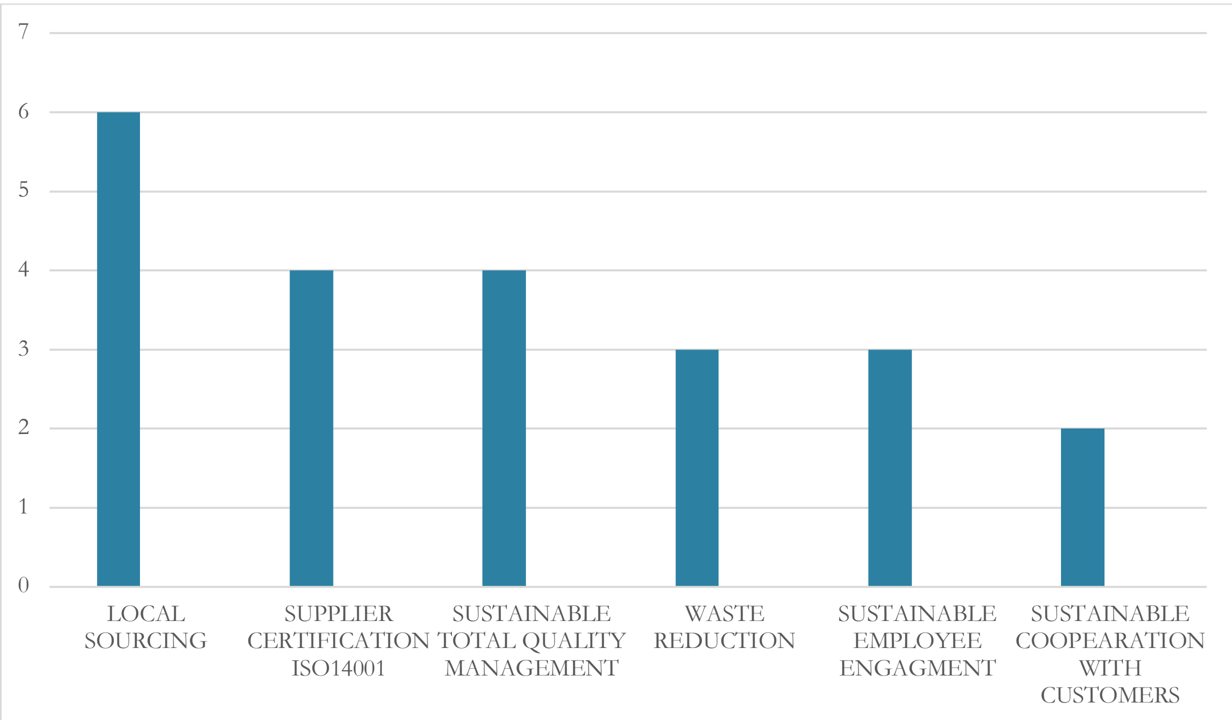

Figure 4.5 Sustainable practices adoption

As for the distribution of I4.0 technologies, the companies showed a moderate/high level of use of technologies. All the companies have faced in recent years or are currently facing a process of digitization and re-engineering of production lines. As can be seen from Figure 4.6 the most used technologies are cloud and simulation. The less adopted technology is AI, CPS and IoT. The scarce use of these technologies is since many managers have identified numerous difficulties in linking, integrating and analyzing data from the different areas of the SC. It has been found that very often the enormous amount of data is not seen as an opportunity but as an obstacle since the digitization process, in addition to investing the machines, should at the same time concern human resources.

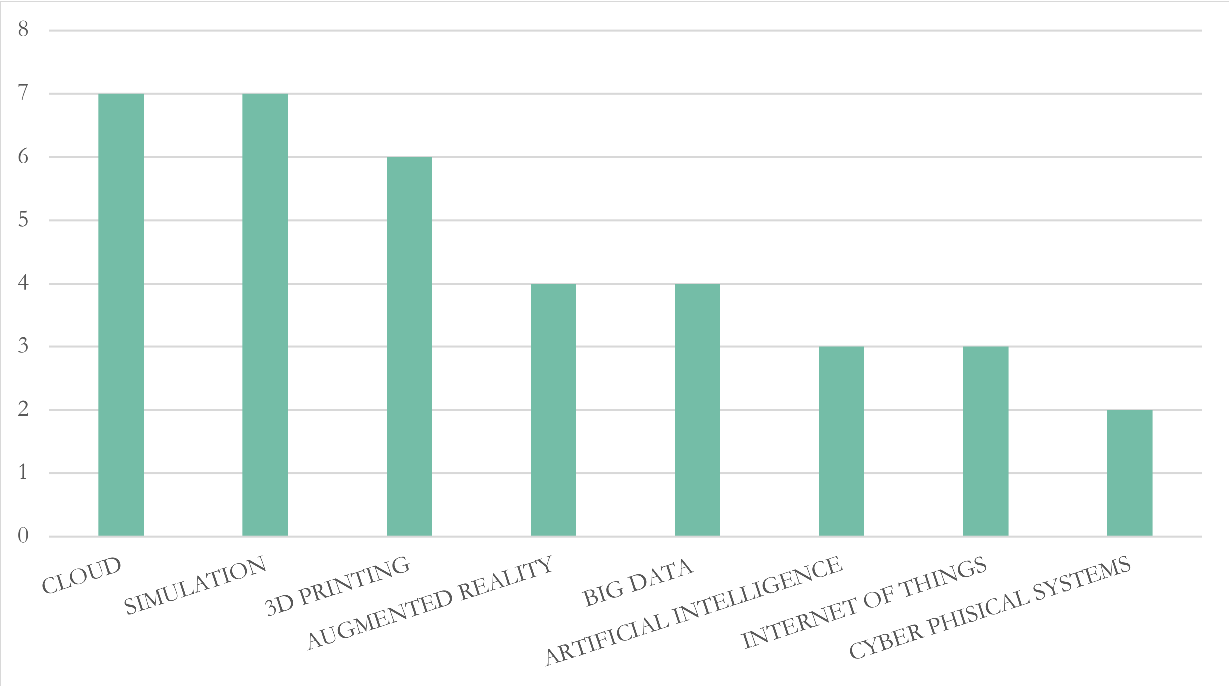

Figure 4.6 Industry 4.0 technologies adoption

Definition of the configuration model

The fsQCA was performed with fsQCA© software version 3.0. It uses combinatorial logic, fuzzy set theory and Boolean minimization to determine which combinations of features may be necessary or sufficient to produce a result.

To respond to the research questions 3 and 4, a framework has been developed (Figure 4.7) that synthesises the results of the previous sections. The framework describes how the global SCs automotive performance both in operational and sustainable terms stems from two sets of variables, the first regarding the support provided by I4.0 technologies to sustainable practices and the second related to the support provided by I4.0 technologies to lean practices. The antecedents (variables) (Table 4.2) and the outcome (performance) (Table 4.3) were obtained based on the answers provided by the informants (questions 11-15) and then summarized in an Excel sheet where, first, was defined whether the I4.0

technologies provide or do not to support lean/sustainable practices. The once this step was completed, the data were calibrated, using a scale of 4 values (0; 0.33; 0.67; 1) where 0 and 0.33 represent total non-belonging / mild non-belonging while 0.67 and 1 represent mild membership / total membership (Basurto and Speer, 2012). More in detail, starting from the interviews, it was possible to translate the answers, assigning one of the four values of the scale, based on the high/low support of technologies for lean/sustainable practices and the effect of this combination on performance. Data calibration was performed adopting a triangulation process that involved one researcher and a company expert to avoid inaccurate results.

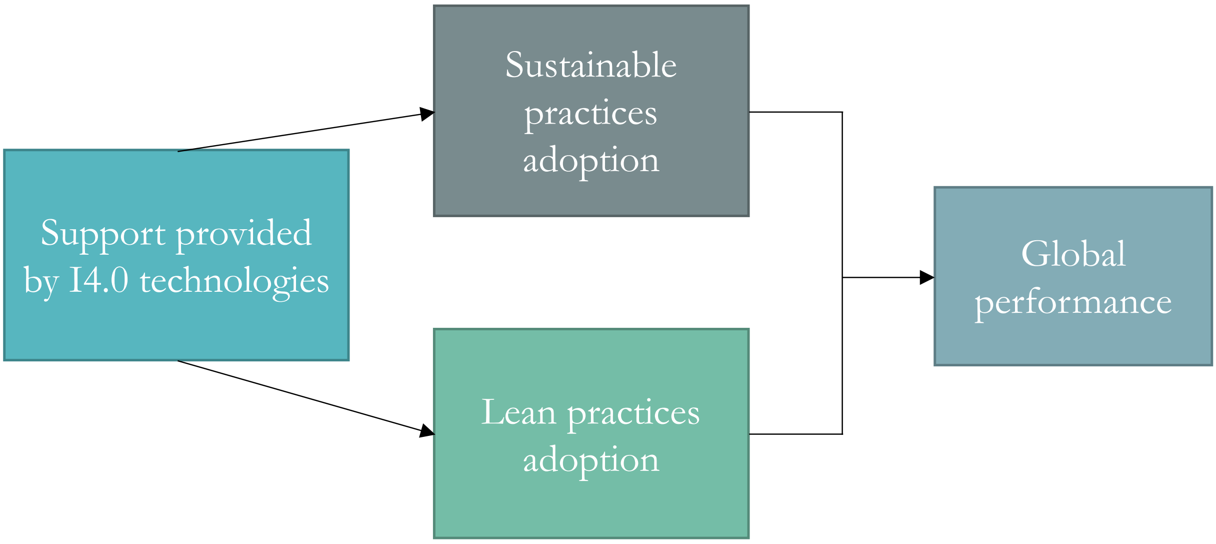

Figure 4.7 Configuration model

Table 4.2 Variable's description

Variable	Description
S_BD_VSM	BD supports VSM
S_BD_JIT	BD supports JIT
S_BD_PULL	BD supports pull production
S_BD_KAIZ	BD supports Kaizen
S_BD_HEIJ	BD supports Heijunka
S_BD_AND	BD supports Andon
S_BD_JID	BD supports Jidoka
S_BD_KAN	BD supports Kanban
S_BD_TPM	BD supports TPM
S_CLOUD_VSM	Cloud supports VSM
S_CLOUD_JIT	Cloud supports JIT
S_CLOUD_PULL	Cloud supports pull production
S_CLOUD_KAIZ	Cloud supports Kaizen
S_CLOUD_HEIJ	Cloud supports Heijunka
S_CLOUD_AND	Cloud supports Andon
S_CLOUD_JID	Cloud supports Jidoka

S_CLOUD_KAN	Cloud supports Kanban
S_CLOUD_TPM	Cloud supports TPM
S_IOT_VSM	IoT supports VSM
S_IOT_JIT	IoT supports JIT
S_IOT_PULL	IoT supports pull production
S_IOT_KAIZ	IoT supports Kaizen
S_IOT_HEIJ	IoT supports Heijunka
S_IOT_AND	IoT supports Andon
S_IOT_JID	IoT supports Jidoka
S_IOT_KAN	IoT supports Kanban
S_IOT_TPM	IoT supports TPM
S_3DP_VSM	3D printing supports VSM
S_3DP_JIT	3D printing supports JIT
S_3DP_PULL	3D printing supports pull production
S_3DP_KAIZ	3D printing supports Kaizen
S_3DP_HEIJ	3D printing supports Heijunka
S_3DP_AND	3D printing supports Andon
S_3DP_JID	3D printing supports Jidoka
S_3DP_KAN	3D printing supports Kanban
S_3DP_TPM	3D printing supports TPM
S_AI_JIT	AI supports JIT
S_AI_PULL	AI supports pull production
S_AI_HEIJ	AI supports Heijunka
S_AI_AND	AI supports Andon
S_AI_JID	AI supports Jidoka
S_AI_KAN	AI supports Kanban
S_AI_VSM	AI supports VSM
S_AI_KAIZ	AI supports Kaizen
S_AI_TPM	AI supports TPM
S_AR_JIT	AR supports JIT
S_AR_PULL	AR supports pull production
S_AR_HEIJ	AR supports Heijunka
S_AR_AND	AR supports Andon
S_AR_JID	AR supports Jidoka
S_AR_KAN	AR supports Kanban
S_AR_VSM	AR supports VSM
S_AR_KAIZ	AR supports Kaizen
S_AR_TPM	AR supports TPM
S_SIMUL_VSM	Simulation supports VSM
S_SIMUL_JIT	Simulation supports JIT
S_SIMUL_PULL	Simulation supports pull production
S_SIMUL_KAIZ	Simulation supports Kaizen
S_SIMUL_HEIJ	Simulation supports Heijunka
S_SIMUL_KAN	Simulation supports Kanban
S_SIMUL_JID	Simulation supports Jidoka
S_SIMUL_AND	Simulation supports Andon
S_SIMUL_TPM	Simulation supports TPM
S_CPS_JIT	CPS supports VSM
S_ CPS_PULL	CPS supports JIT
S_ CPS_HEIJ	CPS supports pull production

S_ CPS_AND	CPS supports Kaizen
S_ CPS_JID	CPS supports Heijunka
S_ CPS_KAN	CPS supports Kanban
S_ CPS_VSM	CPS supports Jidoka
S_ CPS_KAIZ	CPS supports Andon
S_ CPS_TPM	CPS supports TPM
S_BD_LS	BD supports local sourcing
S_BD_SC	BD supports supplier certification ISO14001
S_BDA_WR	BD supports waste reduction
S_BD_STQM	BD supports STQM
S_BD_EE	BD supports sustainable employee engagement
S_BD_CC	BD supports sustainable cooperation with customers
S_CLOUD_LS	Cloud supports local sourcing
S_CLOUD_SC	Cloud supports supplier certification ISO14001
S_CLOUD_WR	Cloud supports waste reduction
S_CLOUD_STQM	Cloud supports STQM
S_CLOUD_EE	Cloud supports sustainable employee engagement
S_CLOUD_CC	Cloud supports sustainable cooperation with customers
S_IOT_LS	IoT supports local sourcing
S_IOT_SC	IoT supports supplier certification ISO14001
S_IOT_WR	IoT supports waste reduction
S_IOT_TQM	IoT supports STQM
S_IOT_EE	IoT supports sustainable employee engagement
S_IOT_CC	IoT supports sustainable cooperation with customers
S_3DP_LS	3D printing supports local sourcing
S_3DP_SC	3D printing supports supplier certification ISO14001
S_3DP_WR	3D printing supports waste reduction
S_3DP_TQM	3D printing supports STQM
S_3DP_EE	3D printing supports sustainable employee engagement
S_3DP_CC	3D printing supports sustainable cooperation with customers
S_AI_LS	AI supports local sourcing
S_AI_SC	AI supports supplier certification ISO14001
S_AI_WR	AI supports waste reduction
S_AI_STQM	AI supports STQM
S_AI_EE	AI supports sustainable employee engagement
S_AI_CC	AI supports sustainable cooperation with customers
S_AR_LS	AR supports local sourcing
S_AR_SC	AR supports supplier certification ISO14001
S_AR_WR	AR supports waste reduction
S_AR_STQM	AR supports STQM
S_AR_EE	AR supports sustainable employee engagement
S_AR_CC	AR supports sustainable cooperation with customers
S_ CPS _LS	Simulation supports local sourcing
S_ CPS _SC	Simulation supports supplier certification ISO14001
S_ CPS _WR	Simulation supports waste reduction
S_ CPS _STQM	Simulation supports STQM
S_ CPS _EE	Simulation supports sustainable employee engagement
S_ CPS _EE	Simulation supports sustainable cooperation with customers
S_ CPS _LS	CPS supports local sourcing
S_ CPS _SC	CPS supports supplier certification ISO14001

S_ CPS _WR	CPS supports waste reduction
S_ CPS _STQM	CPS supports STQM
S_ CPS _EE	CPS supports sustainable employee engagement
S_ CPS _EE	CPS supports sustainable cooperation with customers

Table 4.3 Outcome

OUTCOME_1	Global performance

The global performance is obtained as a synergistic combination of the use of I4.0 technologies to support lean practices on the one hand and sustainable practices on the other. This aspect is crucial as this analysis want to test whether the combined use of lean and sustainable practices and industry 4.0 technologies translates into a significant improvement in the operational and sustainable performance of companies in the automotive sector. In this sense, global performance is evaluated as the sum of both environmental and operational aspects. This is because, the adoption of lean practices translates into lower costs but higher sales and profits (De Giovanni and Zaccour, 2019) which also lead to greater flexibility and efficiency and consequently help to establish a stronger bond with the customer. Sustainable performance, instead, refers to all the three aspects of sustainability such as economic, environmental, and social. A better environmental sustainability performance provides for the lowering of emissions, waste, energy consumption and accidents (De Giovanni, 2017).
In conclusion, this combination investigates the relationship between input and output variables. The outcome is obtained considering the following model:

<u>Model 1:</u> Outcome global performance= f (S_BD_VSM, S_BD_JIT, S_BD_PULL, S_BD_KAIZ, S_BD_HEIJ, S_BD_AND, S_BD_JID, S_BD_KAN, S_BD_TPM, S_CLOUD_VSM, S_CLOUD_JIT, S_CLOUD_PULL, S_CLOUD_KAIZ, S_CLOUD_HEIJ, S_CLOUD_AND, S_CLOUD_JID, S_CLOUD_KAN, S_CLOUD_TPM, S_IOT_VSM, S_IOT_JIT, S_IOT_PULL, S_IOT_KAIZ, S_IOT_HEIJ, S_IOT_AND, S_IOT_JID, S_IOT_KAN, S_IOT_TPM, S_3DP_VSM, S_3DP_JIT, S_3DP_PULL, S_3DP_KAIZ, S_3DP_HEIJ, S_3DP_AND, S_3DP_JID, S_3DP_KAN, S_3DP_TPM, S_AI_JIT, S_AI_PULL, S_AI_HEIJ, S_AI_AND, S_AI_JID, S_AI_KAN, S_AI_VSM, S_AI_KAIZ, S_AI_TPM, S_SIMUL_VSM, S_SIMUL_JIT, S_SIMUL_PULL, S_SIMUL_KAIZ, S_SIMUL_HEIJ, S_SIMUL_KAN, S_SIMUL_JID, S_SIMUL_AND, S_SIMUL_TPM, S_AR_JIT, S_AR_PULL, S_AR_HEIJ, S_AR_AND, S_AR_JID, S_AR_KAN, S_AR_VSM, S_AR_KAIZ, S_AR_TPM, S_CPS_JIT, S_CPS_PULL, S_CPS_HEIJ, S_CPS_AND, S_CPS_JID, S_CPS_KAN, S_CPS_VSM, S_CPS_KAIZ, S_CPS_TPM, S_BD_LS, S_BD_SC, S_BD_WR, S_BD_TQM, S_BD_EE, S_BD_CC, S_CLOUD_LS, S_CLOUD_SC, S_CLOUD_WR, S_CLOUD_TQM, S_CLOUD_EE, S_CLOUD_CC, S_IOT_LS, S_IOT_SC, S_IOT_WR, S_IOT_TQM, S_IOT_EE,

S_IOT_CC, S_3DP_LS, S_3DP_SC, S_3DP_WR, S_3DP_TQM, S_3DP_EE, S_3DP_CC, S_AI_LS, S_AI_SC, S_AI_WR, S_AI_TQM, S_AI_EE, S_AI_CC, S_SIMUL_LS, S_SIMUL_SC, S_SIMUL_WR, S_SIMUL_TQM, S_SIMUL_EE, S_SIMUL_CC, S_AR_LS, S_AR_SC, S_AR_WR, S_AR_TQM, S_AR_EE, S_AR_CC, S_CPS_LS, S_CPS_SC, S_CPS_WR, S_CPS_TQM, S_CPS_EE, S_CPS_CC)

Necessary conditions analysis

The analysis of the necessary conditions of the global performance takes place testing the models presented in the previous paragraph. The results obtained for the outcome is illustrated in Table 4.4.

Table 4.4 Necessary conditions outcome global performance

Variable	Consistency	Coverage
S_BD_VSM	0.500000	0.670000
S_BD_JIT	0.500000	0.670000
S_BD_PULL	0.250000	0.670000
S_BD_KAIZ	0.750000	0.752809
S_BD_HEIJ	0.250000	0.670000
S_BD_AND	0.500000	0.670000
S_BD_JID	0.250000	0.670000
S_BD_KAN	0.250000	0.670000
S_BD_TPM	0.250000	1
S_CLOUD_VSM	0.500000	0.670000
S_CLOUD_JIT	0.750000	0.670000
S_CLOUD_PULL	0.250000	0.670000
S_CLOUD_KAIZ	0.500000	0.802395
S_CLOUD_HEIJ	0.250000	0.670000
S_CLOUD_AND	0.500000	0.670000
S_CLOUD_JID	0.250000	0.670000
S_CLOUD_KAN	0.250000	0.670000
S_CLOUD_TPM	0.250000	1
S_IOT_VSM	0.500000	0.802395
S_IOT_JIT	0.750000	0.752809
S_IOT_PULL	0.373134	0.751880
S_IOT_KAIZ	0.500000	0.802395
S_IOT_HEIJ	0.373134	0.751880
S_IOT_AND	0.750000	0.858974
S_IOT_JID	0.750000	0.858974
S_IOT_KAN	0.500000	0.802395
S_IOT_TPM	0	-1
S_3DP_VSM	0	-1
S_3DP_JIT	0.250000	1
S_3DP_PULL	0	-1
S_3DP_KAIZ	0.250000	0.670000
S_3DP_HEIJ	0	-1
S_3DP_AND	0.250000	1
S_3DP_JID	0.250000	1
S_3DP_KAN	0.250000	1

S_3DP_TPM	0.250000	1
S_3DP_VSM	0	-1
S_AR_JIT	0.250000	1
S_AR_PULL	0.500000	-1
S_AR_KAIZ	0.250000	0.670000
S_AR_HEIJ	0.500000	-1
S_AR_AND	0.250000	1
S_AR_JID	0.250000	1
S_3DP_KAN	0.250000	1
S_3DP_TPM	0.250000	1
S_AI_JIT	0.250000	0.670000
S_AI_PULL	0.250000	0.670000
S_AI_HEIJ	0.250000	0.670000
S_AI_AND	0.250000	0.670000
S_AI_JID	0.250000	0.670000
S_AI_KAN	0	-1
S_AI_VSM	0.25	0.670000
S_AI_KAIZ	0.500000	0.802395
S_AI_TPM	0	-1
S_SIMUL_VSM	0.373134	0.751880
S_SIMUL_JIT	0.750000	0.752809
S_SIMUL_PULL	0.373134	0.751880
S_SIMUL_KAIZ	0.500000	0.802395
S_SIMUL_HEIJ	0.123134	1.000000
S_SIMUL_KAN	0.500000	0.802395
S_SIMUL_JID	0.500000	1
S_SIMUL_AND	0.500000	1
S_SIMUL_TPM	0.250000	0.670000
S_CPS_VSM	0.500000	0.802395
S_CPS_JIT	0.500000	0.752809
S_CPS_PULL	0.373134	0.751880
S_CPS_KAIZ	0.500000	0.802395
S_CPS_HEIJ	0.373134	0.751880
S_CPS_AND	0.250000	0.858974
S_CPS_JID	0.250000	0.858974
S_CPS_KAN	0.250000	0.802395
S_CPS_TPM	0	-1
S_BD_LS	0.500000	0.802395
S_BD_SC	0.500000	0.802395
S_BD_WR	0.250000	1
S_BD_TQM	0.250000	0.670000
S_BD_EE	0.250000	1
S_BD_CC	0.250000	1
S_CLOUD_LS	0.500000	0.802395
S_CLOUD_SC	0.250000	1
S_CLOUD_WR	0.250000	1
S_CLOUD_STQM	0.250000	0.670000
S_CLOUD_EE	0.250000	1
S_CLOUD_CC	0.250000	1
S_CPS_LS	0.500000	0.670000

S_CPS_SC	0.250000	0.670000
S_CPS_WR	0.250000	1
S_CPS_STQM	0.250000	0.670000
S_CPS_EE	0.250000	1
S_CPS_CC	0.250000	1
S_IOT_LS	0.750000	0.858974
S_IOT_SC	0.500000	1
S_IOT_WR	0.500000	1
S_IOT_STQM	0.500000	0.802395
S_IOT_EE	0.500000	1
S_IOT_CC	0.500000	1
S_3DP_LS	0.500000	1
S_3DP_SC	0.500000	1
S_3DP_WR	0.500000	1
S_3DP_STQM	0.500000	0.802395
S_3DP_EE	0.250000	1
S_3DP_CC	0.250000	1
S_AI_LS	0.250000	1
S_AI_SC	0.250000	1
S_AI_WR	0.250000	1
S_AI_TQM	0.250000	0.670000
S_AI_EE	0.250000	1
S_AI_CC	0.250000	1
S_AR_LS	0.373134	0.751880
S_AR_SC	0.500000	0.802395
S_AR_WR	0.123134	1.000000
S_AR_TQM	0.500000	0.802395
S_AR_EE	0.500000	1
S_AR_CC	0.500000	1
S_SIMUL_LS	0.250000	1
S_SIMUL_SC	0.250000	1
S_SIMUL_WR	0	-1
S_SIMUL_STQM	0.500000	0.802395
S_SIMUL_EE	0	-1
S_SIMUL_CC	0.250000	1

According to Ragin (2008), variables represent a necessary condition for the occurrence of the given outcome if the consistency index is greater than 0.75. Based on this assumption, for the global performance outcome, the variables were:

- S_BD_KAIZ
- S_CLOUD_JIT
- S_IOT_JIT
- S_IOT_AND
- S_IOT_JID
- S_SIMUL_JIT
- S_IOT_LS

Sufficient condition analysis

To perform the analysis of sufficient conditions was not necessary to consider all the previous variables, but only those that have a consistency index value greater than 0.75 (Rihoux et al., 2009). The truth table was adopted to identify causal combinations of predictors with the outcome (Crilly, 2011). This approach facilitates the analysis of causal complexity and allows for focused comparisons based on the empirical importance of different combinations of conditions. The truth table tool computes three solutions: a complex solution that avoids using any remainders (i.e. logically possible configurations that lack empirical instances) in the minimization process (Beckfield et al., 2013); a parsimonious solution which allows the incorporation of any remainder that will support in define a logically simpler solution regardless of their empirical plausibility and the existing substantive knowledge (Choi et al., 2017); and intermediate solution which permits the incorporation of only remainders that are expected to affect the outcome based on previous empirical research (Cockerham and Williaman, 1997). Therefore, the existing knowledge is incorporated into the production of the intermediate solution (Stevens, 2006). Furthermore, according to Ragin (2008), the fsQCA intermediate solution tends to be the preferred solution due to its high interpretability. Table 4.5 describes the results gathered for model 1 by applying the truth table algorithm to investigate sufficient conditions in term of intermediate solution.

Table 4.5 Intermediate solutions outcome global performance

Intermediate solution					
	Raw coverage	Unique coverage	Consistency	Solution Coverage	Solution Consistency
~ S_BD_KAIZ * ~ S_CLOUD_JIT * S_IOT_JIT * S_IOT_AND * S_IOT_LS * S_IOT_JID * S_SIMUL_JIT	0.25	0.25	1	0.75	1
S_BD_KAIZ * S_CLOUD_JIT * S_IOT_JIT * S_IOT_AND * S_IOT_LS * S_IOT_JID * S_SIMUL_JIT	0.5	0.5	1		

The solutions were evaluated based on consistency and coverage. Although all the two combinations have a consistency level higher than 0.75, only the solution presented in Table 4.6 have been considered, as this has higher coverage than the other. Figure 4.8 summarizes the results obtained.

Table 4.6 Sufficient condition outcome global performance

	Variables	Combination of conditions
Model 1	S_BD_KAIZ, S_CLOUD_JIT, S_IOT_JIT, S_IOT_AND, S_IOT_JID, S_SIMUL_JIT, S_IOT_LS	S_BD_KAIZ * S_CLOUD_JIT * S_IOT_JIT * S_IOT_AND * S_IOT_LS * S_IOT_JID * S_SIMUL_JIT

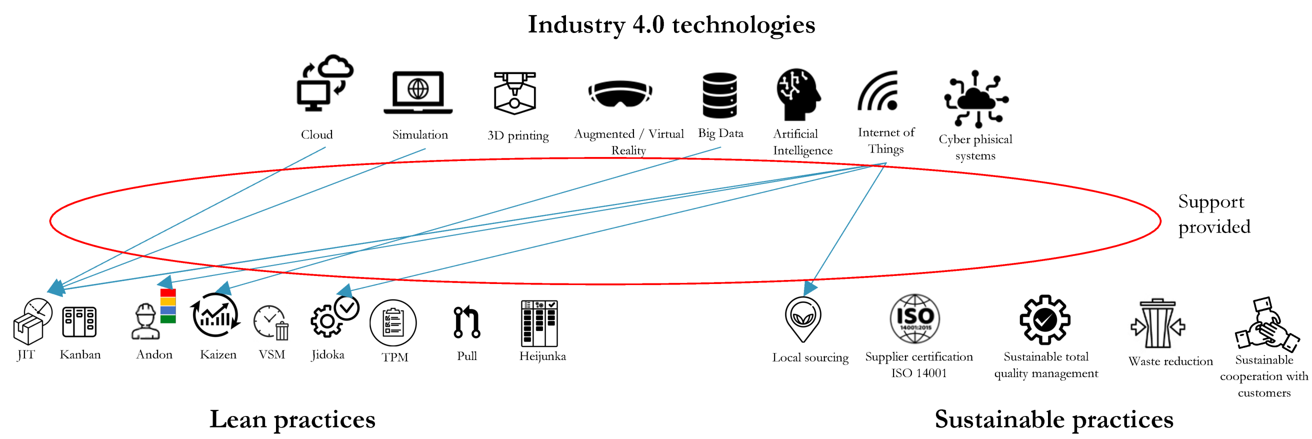

Figure 4.8 Sufficient conditions outcome global performance

4.6 Discussion

The results show that the necessary condition to achieve a better global performance for the automotive firms is the use of BD as a support for Kaizen, IoT as a support for JIT, Jidoka, Andon and local sourcing, and finally simulation within JIT. This result is very interesting as these specific technologies/practices, if used synergistically, become also sufficient condition to reach high level of global performance. More in detail, in the framework, it was assumed that Kaizen could be used in all areas of the automotive SC, with a view to continuous improvement to be pursued starting from product design. This result was partially confirmed, since from the interview with Company 5, it emerged that this practice is suitable for the supply and manufacturing area, furthermore, Company 2 has also highlighted its use, however, not referring to any specific area, while according to Company 4 the Kaizen is used in the supply, manufacturing, and logistics & distribution area. What as more, to improve the operational performance Kaizen might be applied also before the supply area, as explained as follow:

"*When you sort/source parts that they have made the entire blending of car, you have the architecture of the car, question from the prototypes and everything you need, you start to source the material which you need to produce car. So, before sourcing, I would put another bullet point which also includes Kaizen because when you have a target, for example, the engine says the car should not cost more than $1000 but in the actual plan your car engine cost $1100, you have $ 100* *bucks more, Kaizen process will figure how where the $100 get it, so Kaizen starts before sourcing*" (Manager, Company 5).

In that vein, BD can be a support for the Kaizen since in the context of SCM or marketing, if you have more data available, for example from Facebook or social media, it can be used in the process of Kaizen, in optimization, in the search for new methods or verification as they help practitioners to understand if a strategy or operational approach fails or is successful, or in any case, it guides the correct implementation.

As regards JIT, in the framework, it was assumed that its use was linked to the supply, logistics & distribution and customer service area. Company 2, 6, and 7 stressed that JIT is a founding principle of all SC activities, placing its use in all four areas identified. To Company 1, its use is mostly linked to assembly, therefore to the manufacturing area, to Company 2 JIT is applied in the logistics & distribution area, but mostly in the area before production, therefore the sourcing area. Since, before making the car, it is necessary to have a series of supplies, therefore the user will also oscillate between the supply and manufacturing area. The fsQCA showed that the combined adoption of IoT, cloud, and JIT better the performance. In line with that, it was found that through the cloud it is possible to obtain a perfect and faster communication with suppliers, while the simulation involves the whole process of making the cars about the prediction on how to make the car profitable, the right market price, how much you must pay the suppliers, what are the research costs. The following statements will provide evidence of what has been found:

"The intense adoption of JIT procedures can be done thanks to the use of a series of technologies like IoT and cloud, which allow you to have a direct connection, practically in live streaming with the various dealers. We can know with a delay of a few minutes; the number of cars admitted the types of spare parts they require or the number of people who have requested a workshop intervention. I mentioned that of the workshop because it is a world that, in terms of numbers, develops more than the sales of new cars, this is because the number of cars in circulation is higher than those that are sold daily. The same happens in the sale of new vehicles, in fact, Company 3 dealers order the car that the customer requires directly from the factory. In the sense that the customer goes to a dealer if he does not have the car, he orders it directly from the factory, without the intermediation of the local distributor. We are computer-connected directly to the factory" (Manager, Company 2).

"*I'll give a practical example to understand better how JIT would be better through the adoption of the cloud: I'm in Pontedera, the vehicle broke down and the closest dealer is in Pisa, but the dealer does not have the physical part in stock that is useful for repair, the piece is owned by a dealer in Florence. In the future, I will be able to verify this availability thanks to the cloud and I will make sure that the piece moves from Florence to Pisa. In this way, the vehicle can be repaired in the shortest possible time and without having to carry out the entire cycle of sales review, order issuance, distribution of the* *piece, this will have an impact on the handling of materials, impact expenditure and at the same time will allow improving performance. This initiative was studied in 2020 and will impact both the customer service and sales distribution areas*" (Manager, Company 1).

Subsequently, concerning the support provided by IoT to Jidoka, Andon and local sourcing in the framework, it has been assumed that the use of Andon and Jidoka is linked to the manufacturing area, this has been confirmed by Company 1 and 4. For the local sourcing practice, it was supposed that it could be used in the supply area, Company 4 stressed that this has no role in the manufacturing and customer service area but will concern the logistics & distribution. This result is in line with what was hypothesised.

Indeed, in the automotive sector, new operational functions are emerging. These functions will assume key roles in the next years as they combine the use of traditional practices and innovative technologies. Among these, for example, there are the new after-sales assessment management systems. This function aims to generate a virtualization logic in the SC understood as materials management. From a logistical point of view, all the dealers distributed on the commercial network will be integrated with it, creating a virtual warehouse that allows the company to move materials in the most efficient and balanced way possible. This is to minimize the stock available among all the main warehouses of the commercial network and improve performance towards customers. It is, therefore, noted how the use of cloud systems, BD and IoT, necessary for the creation of intelligent virtual warehouses, combined with traditional continuous improvement (Kaizen) and inventory management (JIT) practices, produce an improvement in the involvement of stakeholders (internal/external) to the network. The combination of these tools, therefore, produces a flattening of the SC in which communication between SC and even distant areas is facilitated. Focusing specifically on external involvement, to Company 2 the customer represents the main focus and guides the entire production process, and it is for this reason that JIT is an essential element of the business model. When the customer buys, the car arrives, when the customer requests the spare part to carry out the service, the spare arrives. The customer, thanks to the use of I4.0 IoT, has become much more informed, as explained as follow:

"*When a customer buys a car, even before he owns it, he can download apps through which he can see where his car is, that is, if it is in the factory, if it is on the ship that transports it or on a train, he can check if it has arrived at the hub if it has already been cleared through customs if it is in the dealership or if it is being prepared for delivery. All this in real-time without anyone standing between him and this type of information. This transparency is due to the technologies of I4.0. Furthermore, once he has taken possession of his car, through the application, thanks to the fact that all the cars are connected, he will be able to view how much he is travelling in electric mode, how good his hybrid performance was, that is* *how good he was to enhance the capabilities of the electrified engine. This is a power that is delivered into the hands of the customer thanks to technologies. how good was its hybrid performance, that is how good it was at enhancing the capabilities of the electrified engine*" (Manager, Company 2).

On the contrary, companies that are in the first phases of the digitalization process shown that the bond with the customer is reduced to a simple instruction booklet for the use of the vehicle:

"The use of these technologies has not streamlined relationships with customers, making them more involved in the development process, in the sense that currently, the only relationship we have with the customer is the use and maintenance booklet of the car. It is the only means that allows us to communicate with the final customer" (Manager, Company 3).

As for the disadvantages that emerged, the strong use of technologies has favoured the phenomenon of the digital divide, placing itself as a further watershed between those who have a greater readiness to adapt to the use of technologies and those who do not. This may have been due to cultural reasons or to the fact that, sometimes, the availability of technologies does not require an update of the process at the same time. On the other hand, the introduction of technologies has led to the emergence of new positions, to a reduction in human effort and therefore also to better quality. The use of I4.0 technologies has also highlighted other advantages it made it possible to highlight relationships between the commercial (of the forecasting cycles which are then translated into executive orders), logistics and production function. Triggering everything more strongly than before. This is because we must tend to react to the customer more quickly. The commercial business model has changed, but even internally it is no longer possible to manage the various departments as separate segments. Optimizing production independently from the logistic and commercial functions is no longer feasible. There are also organizational variations as distinct departments tend to come together, creating new entities. The business model requires it but also the customer. Therefore, it is expected that in the future we will move towards a continuous SC. To date, the interaction between the areas takes place only through the exchange of information and this could be because managers are not ready to have this type of transparency. The use of technologies has also opened up a series of scenarios that were not previously analyzed, for example in the functional safety area of Company 3, using cameras, it was observed that the driver assistance systems work very well if all the roads have perfectly drawn stripes, in the case of works in progress or not perfectly drawn stripes, the system does not work. The evaluation of these cases was possible thanks to the use of BD, which allowed the company to test the route many times, seeing how many times the error occurred.

The scarcity of combination between I4.0 technologies and sustainable practices that better the global performance may depend on the fact that companies tend not to measure this result, since, although they

make efforts to implement sustainable practices, they do not have an economic return. From the integrated analysis of the interviews, it has been found that while the effect of technologies on operational performance is direct, it is not the same for sustainable performance. Indeed, this effect appears to be indirect. Businesses have a hard time quantifying the results concerning the commitment to sustainability. Furthermore, it appears that the concept of sustainability is commonly associated with the concept of environmental sustainability and not with the TBL. The initiatives implemented to improve sustainable performance seem to be carried out on an occasional basis without an objective of continuity.
In line with this view, the following statements have been reported:

"In the interrelations between digitalization sustainability figure out something that should be explored way more because I think there's a lot of interlinkages and digital solutions that can definitely facilitate through achieve sustainability. That just a thing that comes to my mind if it's not about production etc. but for example, if you want to sell electric vehicles right also there's maybe arranging to incite or customers to having a lot of apps kind of stored within the car which also gives items to customers and tell them the location of charging station, now you should charge or maybe also teach them how to drive electric vehicles, how to drive more efficiently" (Expert, Company 7).

"We have undertaken several Lean and Green initiatives to minimize energy waste. They are all operations linked by a common thread, intending to optimize operations and make them more compliant with the concept of green, but there is no basic strategy. We go from initiative to initiative to develop affinities" (Manager, Company 1).

The last part of the interviews was aimed at understanding if the level of resilience of companies to the pandemic was affected by technologies. It was found that the intense use of I4.0 technologies has also reflected how companies have responded to the pandemic. The companies that mostly use I4.0 technologies have immediately adopted a full smart working approach, without encountering any difficulty. Instead, Company 1, which is in the initial phase of digitalization, was forced by the current need to adopt the smart working approach with many slowdowns. In this sense, the pandemic has speeded up the adaptation to the use of technologies, more than what the managers themselves had foreseen. The following statements provide evidence of this results:

"Covid19 was stronger to bring about a change in the company's digital sensitivity than the CIO. Covid19 has raised awareness of digitization, starting with the fact that the daily communication asset consists of digital communication tools. Before, the use of tools such as Microsoft Teams, Google Meet was abhorred, now they have become of daily use. This change has made it possible to significantly increase sensitivity on Software Security issues. In the world of 4 wheels, the issue of safety, on the circulation and connectivity of vehicles, is a huge problem since there have been hacks that have also had important repercussions from an economic point of view.

Covid19 has meant that we talk about topics that were previously seen as "Martians", for example Cyber-Security and how to protect yourself from Cyber-attacks. It gave sensitivity on the importance of digitalization of processes demonstrating that some topics, given the circumstances and constraints, could be addressed in a virtual and non-physical way, creating a certain sensitivity towards digital proposals" (CIO, Company 1).

"Our factories have necessarily had to shut down, even the production sites have had a backlash. It is clear that we organized ourselves very quickly in order to be compliant with the new rules and in a few months all our production was back at full capacity. In this sense, our level of resilience is very high, this is also an advantage of the lean organization and the use of I4.0 solution, so the thinner you are, the more agile you are" (Manager, Company 3).

GENERAL CONCLUSIONS

The thesis investigated the role of I4.0 technologies on sustainable and lean SCs. This study starts by analysing the existing literature. With this objective, a tertiary review was performed (Centobelli et al., 2021) aimed to propose a systematic and interdisciplinary approach to systematize the previous literature reviews based on the contributions provided by Hochrein and Glock (2012), Kitchenham et al. (2010), and Seuring and Gold (2012). The need for this tertiary study is justified by the high number of primary and secondary studies published on sustainability issues in SCs in recent years. Unlike previous tertiary studies conducted on the SCM and SSCM topics (Carter & Washispack, 2018; Martins & Pato, 2019; Hochrein et al., 2015), this study goes beyond a descriptive analysis of the secondary studies and their categorisation under sustainable perspectives. A novel tertiary-systematic methodology is proposed by introducing a further step to conduct a dynamic analysis of literature lacks. This approach represents an innovative and reproducible solution to evaluate and prioritise gaps that emerged from the literature. The material was collected and selected following an accurate protocol involving a group of experts in the field of sustainability in the SCM domain. The descriptive analysis highlighted that most reviews adopted a systematic review approach. This implies the use of a review protocol, even if very often the information disclosed concerning the review protocol is limited to the search strategy and selection criteria set to identify significant articles. It was also found that the main aim of the reviews analysed was to perform a state of the art or provide a research agenda. This suggests the call for more reviews focused on the identification of a research framework or taxonomy. Articles were grouped according to eight main topic areas. Most of the reviews concern SSCM and GSCM topic-areas, indeed around half of the SSCM literature reviews surveyed adopt a triple bottom line perspective, and more than 30% of reviews the environmental perspectives. It is evident that dyadic perspectives are still underrepresented in the literature and continue to offer significant research opportunities. However, in recent years, additional main topic areas have been identified: SC operations, corporate social responsibility, production management paradigms, information technologies and innovation, energy efficiency, and circular economy. These topic areas represent a fertile ground for new research.

Starting from these premises, this study highlights those previous reviews consider as a starting point the perspective that the authors aim to analyse (e.g., configurations, definitions, modelling approaches). The perspective adopted by authors thus becomes the lens through which literature is analysed. This lens makes it possible to define future research streams. Besides, the perspectives of analysis are often generic and not focused on the content. The innovative contribution of this tertiary review is related to the importance of starting from research gaps, distinguishing them into three main categories (i.e., context-based, methodology-based, and content-based gaps) and prioritize them. The first two categories are related to gaps that are not linked to the content and that can be extended to different research areas. These two groups belong to research directions like carrying out more empirical studies on specific industrial sectors (e.g., service sector) or in emerging economies, developing new methodologies, identifying new conceptual frameworks, adopting qualitative and quantitative approaches. Two different typologies of gaps belong to the third category, the *primary* and the *contemporary gaps*. The first refers to research directions connected to aspects that change over time (e.g., practices, drivers, performance measurements) and there will always be the need to identify new practices, barriers, drivers. As for *context-based* and *methodology-based gaps*, *primary gaps* are strongly linked to the perspective of analysis adopted by the authors. More interesting insights emerge from the second type of *content-based gap*, namely the *contemporary gaps*. These research directions depend heavily on the context and are independent of the perspective adopted by the author. Primary and *contemporary* research gaps have been submitted to a systematic prioritisation process. As a result of this process, the research proposals were identified and discussed.

Among the different lack highlighted, 2 primary gaps have been identified related to factors affecting SSCM and identification of performance metrics to assess sustainability which led to the formulation of the first two research questions:

- What are the main metrics adopted to evaluate the impact of I4.0 in the context of SSCM?
- What are the practices that affects sustainability along the whole SC?

On the other hand, among the contemporary gaps several issues that could be integrated and analyzed from an overall perspective have been identified. In particular, I focused on the lean aspects, TBL, and on the technological integration contextualized within the SC. This assumption led to the following questions:

- How can I4.0 technologies support lean and sustainable practices?
- What is the impact of the integration of I4.0 technologies, lean and sustainable practices on the performance of the whole SC?

The second chapter allows to answer the first question. Indeed, started analysing the relationship between I4.0 technologies and sustainability, a taxonomy of 21 unique metric was identified. This taxonomy categorises sustainable performance according to different I4.0 technologies and represent a first attempt to classify and generalise the contribution provided by such technologies in the sustainable domain.

As for question 2, the third chapter provides a detailed analysis of the main practices adopted to enhance the sustainable performance of SCs. Furthermore, a classification of practices differentiated according to the type of activities (primary/support) based on the Porter's value chain model is presented. These three chapters represent the ground based on which the integrated framework was developed.

Thus, a novel framework was defined exploiting the results of chapter 2 and 3. The latter is obtained as the integration of the lean and sustainable SC paradigms and I4.0 technologies. This framework has been detailed in the automotive sector, characterized by strong use of all the founding elements each of both sustainable and lean SC and I4.0. In the literature, numerous studies focus on the dyadic links between paradigms, but, to date, there are no studies that analyze and test the link between the three models.
The fsQCA methodology was used to answer the research questions identified. This methodology considers as input the matrix of data collected from semi-structured interviews, which involved seven leading companies in the automotive sector. In answering questions 3 and 4, it is possible to conclude that the use of I4.0 technologies is opening up new scenarios in the automotive sector. Indeed, not only the concept of mobility is changing, but also the way of designing, assembling, selling, and maintaining. It has been seen that the use of digital technologies (e.g., BD, simulation, IoT) facilitates the implementation of lean programs, improving productivity, reducing waste and consequently costs, making modular workstations and flexible production lines. On the other hand, favours the development of environmental sustainability with a view to reducing waste, reducing CO2 emissions, energy consumption and environmental impacts. From the point of view of social sustainability, I4.0 technologies create an environment in which all actors have the same rights. Furthermore, it was found that to achieve better performance, the combined use of BD alongside the Kaizen, of the cloud to the JIT, of the IoT to the JIT practices, Andon, Jidoka and local sourcing and the simulation to the JIT practice is necessary. Therefore, the implementation of sustainable practices is not as evident and intense as that of operational performance. As it turns out, companies tend not to measure results achieved by implementation of sustainable practices, as although they make numerous efforts to implement these practices, they do not have a financial return. For these reasons, only one sustainable practice-technology combo has been identified that would bring appreciable improvements to the performance. In conclusion, the use of I4.0 technologies acts as a driver in the choice of suppliers, it allows to connect the actors and the different areas of the SC and simplifies the processes, reducing redundancies.

Limitations

Before discussing the implications of the findings for researchers and practitioners, the limitations of the thesis are presented. Proceeding by order, first, I'm aware that the limitations of this study are related to the review methodology adopted to perform the tertiary study. Specifically, some relevant studies may be excluded from the sample due to the exclusion criteria or filters adopted. This limitation may be related to the database used, keywords chosen, subject area and inclusion/exclusion criteria identified. In addition, another weakness is related to the perspective of analysis chosen to conduct the content analysis and derive the findings.

Second, concerning the multiple case study methodology, as most empirical studies, the results suffer limitations that concern the nature of data and the proposed models of analysis. Indeed, multiple case studies are characterised by difficulties of reliability, validity, and generalizability. Besides, the case study has mostly been criticized for its lack of representativeness and its lack of rigour in the collection, development, and analysis of the empirical data that give rise to the study. This lack of rigour is linked to the issue of bias introduced by the researcher's and those involved in the case's subjectivity. What as more, several limitations of this research include the relatively small sample size confined to seven leading companies of the automotive sector. Another limitation of this work is the reliance on managers' interviews, which offer subjective perspectives. Future research has the potential to mitigate these limitations and produce stronger results. First, a larger fsQCA study that includes more automotive company cases, could improve the validity of the results. Second, while this study focuses on lean practices specifically, additional research could expand upon the analysis and results by comparing the use of different agile practices. The methodology could use a sample in which multiple perspectives of external partners of the companies are included (e.g., suppliers, customers, distributors).

Implication of the research findings

Despite the limitations presented, results have relevant implications for both academics and practitioners. The study findings aligned well with sector literature and revealed several distinct pathways towards the digital management of processes along with the entire SCs of the automotive industry.

Concerning implications for academia, the contribution of this work is twofold. On the one hand, a systematic and reproducible methodology has been provided, which can be exploited by other authors in other research fields. This tertiary study does not just give a global view of the current literature on the topic of sustainability but goes further, drawing up a ranking of research gaps and formulating an updated and prioritized agenda. On the other hand, the conceptual contribution is flanked by the methodological contribution. The work builds a new way of looking at review papers, representing a tool that looks to the past and, if analysed globally and systematically, allows researchers to understand and trace the guidelines for future research. As a result, researchers can make use of the tertiary study methodology developed in this study to delimit the research areas now outdated by those in which it is necessary to invest. Furthermore, this study paves the way for studies that expand the concept of SC not only to the sustainable and lean field but also to the digital one.

What as more, the taxonomies identified in chapter 2 and 3 can serve as a guide for researchers interested in development studies related to sustainability but with a wider perspective of analysis. This study, also, represents a first attempt to empirically test the link between I4.0 lean and sustainable SC. Based on the results obtained, the research could continue the analysis focusing on a different industrial sector or considering a different set of technologies and practices.

Regarding the implications for practitioners, the results of the empirical analysis have identified a set of I4.0 technologies and practices that can improve the performance along with the automotive SCs. Among the various technologies of I4.0, those on which to invest the most to obtain positive results for the improvement of the performance are IoT, simulation, cloud and BD. Specifically, the ideal combination to have an improvement in performance is given by the combined use of BDs in the Kaizen and by simulation and cloud in the context of JIT processes and by IoT within JIT, Andon, Jidoka and local sourcing. This is because the collection and analysis of data in the vehicle manufacturing phases facilitate continuous improvement as the systems tracks everything that happens on the shop floor in real-time. The data captured are analyzed and may prompt process changes, for example, when a movement is deemed to add little value, or a sequence of movements wastes time or reflects a difficulty in execution. Furthermore, the use of IoT, simulation and cloud in the JIT makes it possible to optimize of the procurement, distribution, and sales phases. These tools allow in the initial part of the SC a monitoring and an improvement in the choice of suppliers in the final part a direct contact with the customer who becomes a central actor of the vehicle production process. Furthermore, as seen previously, the use of systems such as BD for data analysis and cloud for their collection facilitate the exchange of information between the members of the SC by streamlining and reducing delays to constitute an improvement for lean practices. The most innovative result emerged is the combined use of local sourcing and IoT. This technology supports the implementation of local sourcing, as it helps minimizing the vulnerabilities and logistics costs associated with long SCs, increasing efficiency by providing valuable information about machinery conditions, including predictive maintenance requirements, within a logistics centre or warehouse.

Directions for future research

The thesis opens the ranks for numerous studies and future applications. First, the research agenda defined at the end of the first chapter defines interesting insights that researchers can take in the context of the sustainability of SCs. Secondly, the study has highlighted a research gap in the automotive industry sector: there is a need for studies that define and detail indicators for assessing the sustainable performance contextualized in the automotive industry. However, these indicators must not only consider the environmental impact and therefore the levels of emissions and energy consumption commonly assessed, but also consider the human and economic impact of the use of sustainable practices. In fact, from the interviews and subsequent analyzes, it was possible to identify only one combination of sustainable practices and I4.0 technologies that would improve the performance. Starting from this lack, the aim is therefore to give more details about the direct and not only indirect effect that sustainable practices, combined with I4.0 technologies and lean practices, have in improving sustainability levels and the involvement of the actors of the automotive companies. In addition, another important area of research that should be further explored concerns the correct management and analysis of data collected through I4.0 technologies. As, although some of the data is used and leads to the improvements we have seen previously, the automotive sector is still at the beginning of its complete transition to digitalization, it is, therefore, essential to continue to follow companies to evaluate subsequent improvements.

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APPENDIX

APPENDIX A

Journal per subject area

	Decision Sciences	Business, Management and Accounting	Environmental Science	Social Sciences	Computer Science	Engineering	Arts and Humanities	Psychology	Agricultural and Biological Sciences	Energy	Mathematics	Economics Econometrics and Finance	Number of Papers	Number of Citations	Citation/Papers
Annals of Operations Research	X												2	190	95
Benchmarking-An International Journal		X											2	137	68.5
Brazilian Journal of Operations and Production Management*													1	7	7
Business Strategy and The Environment		X	X	X									1	17	17
Competitiveness Review		X											3	87	29
Computers & Industrial Engineering					X	X							2	20	10
Corporate Governance-The International Journal of Business in Society		X											1	3	3
Corporate Social Responsibility and Environmental Management		X	X	X									1	955	955
Decision Support Systems	X	X			X		X	X					1	234	234
Ekoloji			X						X				1	1	1
Energies						X				X	X		2	60	30
Entre Ciencia e Ingenieria*													1	21	21
European Business Review		X											1	6	6
European Journal of Operational Research	X										X		2	72	36
Flexible Services and Manufacturing Journal	X					X							1	52	52
Industrial Marketing Management		X											1	23	23
International Journal of Environment and Sustainable Development			X	X						X			1	5	5
International Journal of Information Management				X	X								1	10	10
International Journal of Logistics Management		X		X									3	6	2
International Journal of Management Reviews	X	X											1	1573	1573
International Journal of Operations & Production Management	X	X											1	9	9
International Journal of Physical Distribution & Logistics Management		X		X									7	636	90.9
International Journal of Production Economics	X	X				X						X	6	1069	178
International Journal of Production Research	X	X				X							3	6	2
International Journal of Productivity and Performance Management		X											2	110	55
Journal of Cleaner Production		X	X			X				X			18	748	41.6

Journal of Global Responsibility													1	19	19
Journal of Purchasing and Supply Management		X											1	7	7
Journal of Scientometric Research*													1	135	135
Journal of Supply Chain Management		X			X							X	1	47	47
Logistics Research	X	X			X	X							1	111	111
Management & Marketing-Challenges for The Knowledge Society		X											1	1	1
Management Research Review		X											1	20	20
Omega	X	X											1	171	171
Production Planning & Control	X	X			X	X							1	2	2
Resources Conservation and Recycling			X									X	2	3	1,5
Supply Chain Management-An International Journal		X											9	2494	297
Sustainability			X	X						X			8	132	15.7
Sustainable Production and Consumption			X			X				X			2	20	10
Vestnik Sankt Peterburgskogo Universiteta – Ekonomika – St-Petersburg University Journal of Economic Studies*													1	0	0
Total	11	24	8	7	6	9	1	1	1	5	2	3	**94**	**9219**	98

* Subject area not retrieved. Journal not indexed in SJR

APPENDIX B

Findings of the protocol analysis

#	Authors (year)	Search String	Time range	Database(s)	Inclusion-Exclusion criteria	Papers Pre-Screening	Papers Post-Screening
1.	Abbassi et. al (2017)	x	x	x	x	x	x
2.	Ahi and Searcy (2013)	x	NA	x	x	NA	x
3.	Ahi et. al (2016)	x	x	x	x	x	x
4.	Alexander et. al (2014)	x	x	x	x	x	x
5.	Ansari and Kant (2017a)	x	x	x	x	x	x
6.	Ansari and Kant (2017b)	x	x	x	x	x	x
7.	Arnette et. al (2014)	x	x	x	x	x	x
8.	Ashby et. al (2012)	x	x	x	x	x	x
9.	Barbosa-Povoa et. al (2018)	x	x	x	x	x	x
10.	Bastas and Liyanage (2018)	x	x	x	x	NA	x
11.	Batista et. al (2018)	x	x	x	x	x	x
12.	Beske et. al (2014)	x	NA	x	x	NA	x
13.	Beske-Janssen et. al (2015)	x	x	x	x	x	x
14.	Brandenburg et. al (2014)	NA	x	x	x	x	x
15.	Brandenburg and Rebs (2015)	x	x	x	x	NA	x
16.	Camilleri (2017)	NA	NA	NA	NA	NA	NA
17.	Carter et. al (2008)	NA	NA	x	NA	NA	NA
18.	Carter et. al (2011)	x	x	x	x	x	x
19.	Cazeri et. al (2017)	x	x	x	x	x	x
20.	Centobelli et. al (2018)	x	x	x	x	x	x
21.	Chen et. al (2017)	x	x	x	x	x	x
22.	Ciccullo et. al (2018)	x	x	x	x	x	x
23.	Coenen et. al (2018)	x	x	x	x	x	x
24.	Correia et. al (2017)	x	x	x	x	x	x
25.	De Oliveira et. al (2018)	x	x	x	x	x	x
26.	De Sousa Jabbour et. al (2013)	x	x	x	NA	NA	x
27.	Denham et. al (2015)	x	x	x	x	NA	x
28.	Dubey et. al (2017a)	x	x	x	x	NA	NA
29.	Dubey et. al (2017b)	NA	x	x	x	x	x
30.	Eskandarpour et. al (2015)	NA	x	x	x	NA	x
31.	Fahimnia et. al (2015)	x	x	x	x	x	x
32.	Feng et. al (2017)	x	x	x	x	x	x
33.	Fiorini and Jabbour (2018)	x	x	x	x	x	x
34.	Fritz and Silva (2018)	x	x	x	x	x	x
35.	Gao et. al (2017)	x	x	x	x	NA	x
36.	Garza-Reyes (2015b)	x	x	x	x	NA	x

37.	Ghadimi et. al (2019)	NA	x	NA	NA	NA	x
38.	Gold et. al (2010)	NA	x	x	x	NA	NA
39.	Gosling et. al (2017)	x	NA	x	x	x	x
40.	Govindan and Hasanagic (2018)	x	x	x	x	x	x
41.	Govindan et. al (2016)	x	x	x	x	x	x
42.	Guo et. al (2017)	x	x	x	x	x	x
43.	Gurtu et. al (2015)	x	x	x	x	x	x
44.	Hazen et. al (2016)	NA	NA	NA	NA	NA	NA
45.	Islam et. al (2017)	x	x	x	x	x	x
46.	Jabbour et. al (2017)	x	x	x	x	x	x
47.	Jesus Munoz-Torres et. al (2018)	x	NA	x	x	x	x
48.	Jia et. al (2018)	x	x	x	x	x	x
49.	Jing et. al (2019)	NA	x	NA	NA	NA	x
50.	Johnsen et. al (2017)	x	x	x	x	x	x
51.	José et al (2014)	x	x	x	x	x	x
52.	Kache and Seuring (2014)	x	x	x	x	x	x
53.	Khalid et. al (2015)	x	x	x	x	x	x
54.	Koberg and Longoni (2019)	x	x	x	x	x	x
55.	Koeksal et. al (2017)	x	x	x	x	x	x
56.	Liu et. al (2017)	x	x	x	x	x	x
57.	Liu et. al (2018)	x	NA	x	x	x	x
58.	Maditati et. al (2018)	x	x	x	x	x	x
59.	Malviya et. al (2015)	x	x	x	x	NA	x
60.	Manavalan and Jayakrishna (2019)	NA	x	NA	NA	NA	NA
61.	Marchi and Zanoni (2017)	x	x	x	x	x	x
62.	Masi et. al (2017)	x	x	x	x	x	x
63.	Meixell et. al (2015)	NA	NA	x	x	x	x
64.	Min and Kim (2012)	x	x	x	x	NA	x
65.	Mishra et. al (2017)	x	x	x	x	x	x
66.	Monteiro et. al (2018)	x	x	x	x	x	x
67.	Nakamba et. al (2017)	x	x	x	x	x	x
68.	Quarshie et. al (2016)	x	x	x	x	x	x
69.	Rajeev et. al (2017)	x	x	x	x	x	x
70.	Rebs et. al (2019)	x	x	x	x	NA	x
71.	Roy et. al (2018)	x	x	x	x	x	x
72.	Sarkis et. al (2011)	NA	NA	NA	NA	NA	NA
73.	Sarkis et. al (2012)	x	NA	x	NA	NA	NA
74.	Seuring (2013)	x	x	x	x	x	x
75.	Seuring and Mueller (2008)	x	x	x	x	NA	x
76.	Sharma and Gandhi (2016)	x	x	x	x	NA	x
77.	Silva (2017)	NA	NA	x	x	NA	x
78.	Singh and Trivedi (2016)	x	x	x	x	NA	x
79.	Sirilertsuwan et. al (2018)	x	x	x	x	x	x

80.	Srivastava (2007)	x	x	NA	x	x	x
81.	Stindt et. al (2014)	x	x	x	x	x	x
82.	Strozzi and Colicchia (2015)	x	x	x	x	NA	x
83.	Tachizawa and Wong (2014)	x	x	x	x	x	x
84.	Tachizawa et. al (2015)	NA	NA	NA	NA	NA	NA
85.	Tajbakhsh et. al (2015)	x	x	x	x	x	x
86.	Taticchi et. al (2013)	x	x	x	x	NA	x
87.	Taticchi et. al (2015)	x	x	x	x	x	x
88.	Tebaldi et. al (2018)	x	x	x	x	NA	x
89.	Thoni et. al (2017)	x	x	x	x	NA	x
90.	Touboulic et. al (2015)	x	x	x	x	NA	x
91.	Waltho et. al (2015)	NA	x	NA	NA	NA	x
92.	Winter et. al (2013)	NA	x	x	x	NA	x
93.	Yun et. al (2019)	x	x	NA	x	x	x
94.	Zhu et. al (2018)	x	x	x	x	NA	x

*NA=not available