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INDUSTRY 4.0, LEAN MANUFACTURING AND CIRCULAR ECONOMY: A NOVEL PATHWAY FOR CIRCULAR SUPPLY CHAIN MANAGEMENT AND SUSTAINABLE PRODUCTION

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Abstract

The integrated approach constituted by Industry 4.0, Lean Manufacturing and Circular Economy is a novel pathway – where technological, economic, social and environmental perspectives are simultaneously taken into consideration – to pursue the circularity through the support of Reverse Logistics and achieve circular and sustainable production processes.

In an interconnected world, emerging technologies such as cloud manufacturing, cyber-physical systems, cloud computing, wearable and human-machine interface, internet of things, industrial integration, big data, blockchain, robotics, advanced automation, additive manufacturing (a.k.a., 3D printing), artificial intelligence, digital twins guide the transition to a digitalised era and are recognised as enabling factors for improving the quality and efficiency of production processes.

Thus, these digital tools connected to Lean methodologies, Reverse Logistics, Circular Economy and Supply Chain Management make this management approach a strategic business model for policymakers, entrepreneurs, managers in order to collect and analyse data concerning process performance of productive flows and achieve the aim of sustainable and resilient production.

The following Thesis investigated the contribution of Industry 4.0 technologies, Lean Manufacturing, Reverse Logistics and Circular Economy in the Supply Chain Management in the manufacturing sector to improve the decision-making processes and gain sustainability and circularity within the economic, environmental, social and technological perspectives.

The research objectives of the Thesis concern (1) the investigation of the relationships among Industry 4.0, Lean Manufacturing, Reverse Logistics, Sustainability and Sustainable Production; (2) the potential synergies between technological and organizational innovations in the industrial sector, also in the light of the new challenges of the Circular Economy paradigm to holistically propose a production process model in a circular economy-oriented perspective at micro level, also compliant with the goals of the UN Agenda 2030 (United Nations, 2015).

In order to achieve these research objectives, the study was based on an extensive literature review upon Industry 4.0, Lean Manufacturing and Sustainability and their interrelations and, on a detailed cross-sectional analysis on Industry 4.0, Lean

Manufacturing and Circular Economy to better clarify these relationships in order to represent Sustainable and Circular Supply Chain as a product of the simultaneous engagement of lean strategies and emerging technologies through reverse logistics.

One of the most interesting insights that emerge from this novel management approach is that this innovative perspective overcomes some of the limitations identified in the traditional view based on Lean Manufacturing methodologies, integrating it with the principles of Supply Chain Management and environmental issues.

The results confirm that adopting Lean Manufacturing and Industry 4.0 technologies to achieve sustainable production requires a throughout economic, environmental and social assessment, applied to the whole supply chain.

Therefore, taking these aspects into consideration in the planning, monitoring and evaluation phases of industrial processes, they can lead to the implementation of a novel strategic business model for the development of Circular Supply Chain Management.

Keywords

Industry 4.0, Lean Manufacturing, Sustainability, Circular Economy, Reverse Logistics, Sustainable Production, Circular Supply Chain

Table of Contents

List of Figures

List of Tables

Introduction

The research elaborated in this Thesis examines some topics of fundamental importance and recent interest in economic, management and environmental fields. A new industrial revolution is taking place and encountering a modern approach to business that replaces traditional technologies, processes, business models and mindsets and seems to be indispensable in order to hope for success in the future market.

On one hand, Industry 4.0 technologies are developing by leaps and bounds. The digital revolution is deeply redesigning how people live and work, and the public remains optimistic about the possibilities Industry 4.0 offers for circularity.

On the other hand, the crucial importance of the customer and customer satisfaction as sources for the achievement of competitive advantages lead companies, immersed in a context in which every day we witness the unprecedented expansion of the possibilities of choice between alternative goods, to commit themselves to the management and "strengthening" of relations with their customers by making the principle of customer orientation the *fulcrum* of their strategies.

As a contribution to what has just been said, the scholars Valdani and Busacca (1999) proposed the theoretical perspective of the customer-based view whose principles are represented by the consideration of the customer as the primary source of the generation of economic value and by the recognition of the centrality of customer satisfaction as the organisational language indispensable to defend and manage this source of value. The real reason for the existence of businesses is therefore to serve and satisfy customers in order to defeat the competition and above all to prevent them from becoming powerful defamers.

Unfortunately, the business literature in some cases fails to recognise the close link between value for the enterprise and the value it provides to the customer with its offerings. For example, Porter with his strategic competitive approach privileges the attractiveness of the sector in which the company operates and its ability to pursue differentiation, leadership, cost and focus strategies as tools for achieving a sustainable competitive advantage, thus neglecting the centrality of the customer as a source of business success.

In addition, the need to comply with the Sustainable Development Goals (SDGs) of the UN 2030 Agenda is a categorical imperative for Governments and companies all over the world.

Thus, in this context, an unprecedented approach which derives from the integration of Industry 4.0 technologies, that can create a suitable environment for growth, Lean Manufacturing, able to satisfy customer needs and, Circular Economy, which is a precondition for Sustainability and sustainable production, is proposed.

In this perspective, my co-authors and I explored how this could be done through the support of Lean methodologies. Progressively, adopting a mixed methodological approach made up of literature review, cross-sectional analysis, the elaboration of a Multi-criteria decision making model and case study analysis, the theoretical and managerial aspects of the novel approach began to take form and substance.

The result is the integration of the five studies described below that constitute the framework that led to the development of the Circular Supply Chain as a concept that incorporates the Lean methodologies and circularity enabled by the emerging technologies to achieve sustainable production.

Study I

Ciliberto, C., Taddeo, R., Liao, Szopik-Depczynska K., W., Yigitcanlar, T., Ioppolo, G. Industry 4.0, Lean Production and Sustainability: A Bibliometric and Literature Review. *The Routledge Companion to Creativity, Routledge, Taylor & Francis Group*, September 2023. (Accepted for publication).

This study is focused on the examination of the relationships among Industry 4.0, Lean Production and Sustainability in order to identify potential synergies between technological and organizational innovations in manufacturing and solutions for a more eco-efficient production. At the same time, this research provides theoretical insights into Industry 4.0 technologies.

In this perspective, a conceptual integrated framework is elaborated which results in a digitalised lean and sustainable system offering better understanding on its potential theoretical and practical implications.

Stakeholders (institutions, small and medium-sized enterprises (SMEs), companies at business, operational, process and individual (BOPI) level) can foster the transition from traditional business strategies to lean, digitalised and sustainable business strategies by exploiting this integration. The research is at the intersection of different research streams. It contributes to stressing the relevance of the digital transition in a Triple Bottom line perspective and the need for innovative integrated business models to achieve sustainable goals and a competitive edge in the market.

Study II

Ciliberto, C., Szopik-Depczynska K., Tarczynska-Łuniewska, M., Ruggieri, A., Ioppolo, G. Enabling the Circular Economy transition: a sustainable lean manufacturing recipe for Industry 4.0.
Business Strategy and the Environment, 2021. https://doi.org/10.1002/bse.2801.

This paper tries to design a relationship between Sustainable Production and Lean Manufacturing, highlighting the opportunity to invest in Reverse Logistics and how Industry 4.0 system represents a breeding ground for Circular Economy targets application.

The aim of the study is to examine the relationships among Sustainable Production, Lean Manufacturing and Industry 4.0 in order to evidence the need for adopting a lean methodology and Industry 4.0 technologies in a sustainable development perspective for companies. Following a holistic vision, the production principles and formulas, which, although in parallel, lead to similar results, and, therefore, represent the pillars of a competitive and sustainable business model, are summarised.

Study III

Caristi, G., Boffardi, R., Ciliberto, C., Arbolino, R., Ioppolo, G. Multicriteria Approach for Supplier Selection: Evidence from a Case Study in the Fashion Industry. *Sustainability*, 2022. 8038. https://doi.org/10.3390/su14138038

This study, through the analysis of a case study, testes and validates the effective need for manufacturing companies to adopt lean methodologies and achieve sustainable goals to maintain a competitive advantage and gain market share. In this perspective, the paper proposes a multicriteria decision-making model (MCDM) to ease supplier evaluation and selection. Supply chain operation reference metrics (SCOR metrics) and fuzzy technique for order of preference by similarity to ideal solution (FTOPSIS) are combined to build a model for supplier selection. The former allows us to conduct a very thorough fact-based analysis of all features in the supply chain, while the combination of fuzzy theory and SCOR model allows us to deal with uncertainty. The main novelty of this method is that it incorporates consolidated supply chain management criteria within the framework of fuzzy set theory and multicriteria decision-making model (MCDM) facilitating their application into practice. The criteria adopted for the supplier selection process resulted to be in line with the JIT principles drawn from Lean Manufacturing theory.

The proposed approach is, then, tested by considering the company case of a manufacturing firm operating in the fashion industry, willing to designate the most appropriate supplier within a set of three potential ones.

Study IV

Ciliberto, C., Majorana, F., Szopik-Depczynska, K., Ioppolo, G. Supply Chain 4.0: Lean Six Sigma, Industry 4.0 technologies and Circular Supply Chain applied to an Italian hospital case study, in Lagioia G., Paiano A., Amicarelli V., Gallucci T., Ingrao C. (Editors), Innovation, Quality and Sustainability for a Resilient Circular Economy. The Role of Commodity Science, Series: Circular Economy and Sustainability, *Springer Nature*, 2023, ISBN: 978-3-031-28291-1.

The aim of this paper is presenting a practical application of the integration among Industry 4.0 technologies, Lean methodologies and the principles of Circular Economy. In this direction, a Circular Supply Chain 4.0 of an Italian hospital is introduced. It is derived from the implementation of Lean and Six Sigma techniques to reduce waiting times and improve processes in the surgical unit and Industry 4.0 technologies. Lean Six Sigma methodology, which is a Lean Manufacturing technique, is preliminary to a good implementation of Industry 4.0. Before digitalising and robotising it is necessary to improve efficiency both in terms of Lean waste and in terms of variance and efficiency for Six Sigma in order to be able to "feed" Industry 4.0 with a product that is already optimised and ready for digitalisation.

Results show a dramatic increase in the average of the number of surgery interventions and that the jointly adoption of Industry 4.0 technologies, Circular Economy and Lean Six Sigma methodologies enables Circular Supply Chain.

Study V

Shafi, M., Szopik-Depczyńska, K., Cheba, K., Ciliberto, C., Depczyński, R., Ioppolo, G. Innovation in traditional handcraft companies towards sustainable development. A systematic literature review. *Technological and Economic Development of Economy*, 2022. https://doi.org/10.3846/tede.2022.17085.

This study addresses potential future research directions. At the same time the article improves the understanding of innovation, given by the integration of Industry 4.0 technologies and innovative managerial approach, in traditional handicrafts, for a sustainable development. The paper emphasises the importance and potential advantages of innovation and highlights its synergistic effect with cultural traditions leading to sustainable production.

Hence, from this research it emerges that handicraft producers must carefully adopt incremental innovation to survive, grow, and achieve better market results as well as maintain cultural values, identity, and history of local communities. In this perspective, innovation will enable handicraft enterprises to differentiate between their products and those of competitors (mass-produced) and offer intangible advantages leading to improving their value and increase the likelihood of acceptance in the marketplace.

Therefore, the *fil rouge* of the Thesis, in an increasingly interconnected world and in the face of the growing consumer demand for maximising sustainable products and services and of good quality, is the identification of the right changes required to companies to meet the challenges and seize the opportunities of the New Millennium. In response to this need for increased flexibility and resilience in the industrial context, the so-called “Industry 4.0” seems to be emerging, which, thanks to the use of modern technologies, allows a fusion of the physical and digital worlds.

This is a change that does not only affect the production process or physical assets, but also management, business models and the workforce itself; it can even be said that this “Revolution”, as it has often been called, does not take place within the confines of the individual company, but involves the entire supply chain and even the customer itself.

Despite the considerable advantages of Industry 4.0, the implementation path that leads companies to become true smart factories is not always smooth. Several obstacles can be encountered, including the risk of tackling this major challenge without actually being mature and having truly considered the possible consequences. Companies with limited financial resources and of a smaller size, such as small and medium-sized enterprises, seem to find it more difficult to face a change of this magnitude. Thus, in response to these critical issues, the literature proposes a possible solution: an incremental innovation through the conjunction of Industry 4.0 and the Lean Manufacturing system.

Indeed, these two approaches seem to share the same objectives of reducing complexity and increasing productivity and flexibility through the elimination of waste, continuous improvement, the creation of an uninterrupted production flow and maximising customer value (Tortorella et. al, 2019).

From the combination of the lean methodology on the one hand and advanced digital technologies on the other, it is possible to derive great benefits and overcome the obstacles that the introduction of only one of the two production paradigms would entail.

This production system, as conceptualised, needs to be contextualized in the sustainable perspective as requested by the Sustainable Development Goals of UN Agenda 2030 and requires the support, at the same time, of the Circular Economy principles.

Furthermore, when implementing Lean Manufacturing, it is not enough to focus on production but must also be extended to product design, aspects of product distribution, and Supply Chain Management (Holweg, 2007; Fuentes et al., 2012).

Lean methodology has become a very important aspect of the effective implementation of Supply Chain Management with regard to time and cost containment and responsiveness to customer needs (Mason-Jones and Towill, 1999; Handfield and Nichols, 1999; Li et al., 2005; Fuentes et al., 2012).

The focus of Lean Supply Management is on eliminating all waste, including waste of time, to enable planning of various activities (Naylor et al., 1999). The Lean

Manufacturing model on the contrary focuses on the elimination/reduction of waste within the production plant (Ohno, 1988); whereby despite the presence of lean principles within the various organizations and the significant reduction in time, customers continued to endure delays in the delivery of their orders (Fisher, 1997) demonstrating its ineffectiveness and inapplicability.

Indeed, the pursuit of Sustainability at the organizational level remains one of the most topical issues of our time: the social, environmental and economic problems related to the loss of biodiversity, increased pollution and the high impact of waste on the ecosystem are calling businesses to contribute through their activities to a reduction of these negative effects, as well as to foster new employment opportunities and better working conditions (Geissdoerfer et al., 2018).

The Circular Economy represents a practical and tangible transposition of Sustainability, with a focus on reducing waste, either through its reuse within new production processes or through the use of renewable and biodegradable materials during production (Ellen Macarthur Foundation, 2015).

Circular Economy presents great opportunities from the perspective of Sustainable Supply Chain Management, offering organizational solutions with concrete environmental, social, and economic effects.

The overlap of the concept of Circular Economy with that of Supply Chain Management is an emerging area of research (Hussain and Malik, 2020).

Supply chain Management is defined, in the meaning proposed by Christofer (2011), as a network of interconnected organisations for the control, management and improvement of materials and information from the supplier to the end customer. The supply chain can be developed and managed from a Circular Economy perspective, then called in literature a Circular Supply Chain (Canning, 2006; Du et al., 2010; Genovese et al., 2017; Nasir et al., 2017), when specifically aimed at "*closing, intensifying, or shortening*" production processes (Geissdoerfer et al., 2018).

With these processes, we aim for higher supply chain efficiency through the sharing of resources, process design, and investment costs, as well as the minimisation of associated waste. The supply chain-level extension of circularity-oriented activities, therefore, contribute to the greater sustainable effect of the companies involved, as well as their resilience (Farooque et al., 2019).

Consequently, from the perspective of waste reduction, the combination of Circular Economy with Lean principles and Supply Chain Management, ideally, will produce zero waste because it is planned to systematically restore and regenerate resources in the industrial and natural ecosystem in which it is embedded.

Therefore, the traditional approach of considering Industry 4.0, Lean Production, and Sustainability three concepts separately or matching them in pairs (Varela et al., 2019; Amjad et al., 2020; Awan et al. 2021) represents an obsolete and simplistic perspective in order to consider the complexities and needs of the companies' production system in continuous, rapid technological and strategic change.

Hence, based both on the insights of Ghobakhloo (2020), Ghobakhloo and Fathi (2020), Kamble, Gunasekaran, and Gawankar (2018), Bressanelli, Adrodegari, Perona, and Saccani (2018), Stock and Seliger (2016), Wang et al. (2016), Fosso Wamba, Akter, Edwards, Chopin, and Gnanzou (2015) about the contribution of Industry 4.0 technologies in optimising sustainable production in a circular perspective and on those of Tortorella and Fettermann (2018), Qian, Zhong, and Du (2017) and Brettel, Friederichsen, Keller, and Rosenberg (2014), about the impacts of Lean Manufacturing on sustainable production, Study I (Ciliberto et al., *Forthcoming publication*) offers theoretical insights into the innovative managerial approach given by the integration of Industry 4.0, Lean Production and Sustainability and Study II (Ciliberto et al., 2021) introduces the need to adopt Circular Economy as a management strategy to achieve sustainable production, holistically summarising this vision in the concept of Circular Supply Chain through the adoption of Reverse Logistics.

In this regard, Study I proposes a conceptual framework in the effort of providing a deeper understanding of this phenomenon and, in the attempt to bridge the aforementioned gap, outlines the need for an integrated approach, more sustainable in a Triple Bottom line perspective. On the other side, Study II highlights the crucial role of Industry 4.0 as a productive formula which introduces innovation and represents the new bridge between human and machine interactions, Lean Manufacturing as a productive managerial methodology and, Circular Economy as a productive business strategy.

Thus, the first aim of this Thesis is focusing on the implications deriving from the implementation of Industry 4.0 technologies, Lean Manufacturing and Circular Economy and on the need to implement a different managerial approach to ease the shift towards the environmental and digital transition and increase the resilience of Small and Medium enterprises (SMEs) coping with change management and innovation.

From the other side, the second objective of the Thesis concerns the empirical evaluation of the novel holistic approach concerning the simultaneous integration of the emerging technologies, Lean Manufacturing in a circular perspective to achieve sustainable production processes.

Therefore, this is the context from which the following Doctoral Thesis emerged. Following this phase of Introduction and Conceptualization of the novel approach deriving from the interaction among Industry 4.0, Lean Manufacturing and Circularity to achieve sustainable production, contained in the "Introduction" section, the "Methodology" section outlines the methodological framework adopted, describing the approach used in each procedural phase. Chapter 1 develops, from one side, a literature review on (a) the emerging technologies that represent the ideal environment able to develop circularity and achieve sustainable production in a Triple Bottom Line perspective and (b) examines the interrelations among Industry 4.0, Lean Manufacturing and Sustainability.

From the other side, Chapter 1 also introduces a cross-sectional analysis on the topic concerning the interrelations among Industry 4.0, Lean Manufacturing and Circular Economy and examines the need to adopt Reverse Logistics to reach sustainable process flows in the manufacturing sector.

Chapter 2 provides the testing and description of the results phase through the proposal and analysis of an MCDM model and the examination of a case study. As part of the ever-increasing integration between Lean Manufacturing, Industry 4.0 technologies and Circular Economy, Chapter 3 introduces the practical applications of a Lean methodology on circularity in a technology-driven supply chain. Chapter 4 proposes future perspectives of this research path by introducing the notion of Incremental Innovation in the handicraft production into the theoretical and managerial debate.

Finally, the "Discussion" Section provides several considerations on the advantages and drawbacks of adopting an integrated approach based on Industry 4.0 technologies, Lean Manufacturing and Circular Economy throughout the supply chain to achieve the aim of sustainable production and the "Conclusion" Section includes final remarks.

Methodology

This Thesis, as aforementioned exposed, aims to advance the theoretical and managerial debate on the role of Industry 4.0 and Lean Manufacturing in sustainable production and Circular Supply Chain.

Indeed, a mixed methodological approach was adopted to provide the thesis with both a theoretical foundation related to the prior literature and the identification of the research gap but also with a managerial perspective to better address the effectiveness of the need on building Circular Supply Chain with "zero waste".

The adopted methodologies of literature review with a bibliometric analysis related to the descriptive statistics of the sample of selected studies and the cross-sectional analysis complement each other in an integrated manner.

Furthermore, the proposal of a Multi Criteria Decision Making model (MCDM) through the combination of SCOR metrics and FTOPSIS tested and validated in a textile and apparel company contributes to the comprehension of the crucial role of Lean Manufacturing in a supplier selection process from the stakeholders' perspective.

In addition, the analysis of a case study focused on the implementation of a Lean methodology, the Lean Six Sigma methodology, in the healthcare sector, provides significant insights on the need of integrating Industry 4.0, Lean Manufacturing in a Circular Economy perspective to achieve consistent process improvements.

Consequently, thanks to the adoption of these methodologies, the comprehension and awareness of this issue appear to be improved for policymakers, economists, scientists, students, top managers, managers, organisations, companies and entrepreneurs.

Hence, the methodological foundations on which the Thesis is built on are composed of five procedural phases: Introduction and Conceptualisation; Bibliometric and Literature Review and a Cross-Sectional Analysis; Testing and Description of the Results; Practical Applications to Circular Supply Chain 4.0: Lean Six Sigma in the Italian Healthcare, and Future Perspectives for Sustainable Production. These procedural phases correspond, respectively, to each of the following parts of the Thesis.

Each phase is developed on the basis of a reference study published in scientific journals and/or book series and/or conference proceedings concerning the theorisation and development of a novel business model and an innovative strategy to achieve Circular Supply Chain in sustainable production, all enabled by the implementation of the emerging technologies. Thus, within each phase a series of results are obtained, analysed and interpreted.

To sum up, the methodological approach followed is presented in Table 1.

Procedural phases	Title	Year	Journal/Book	Authors
Introduction and Conceptualisation (“Introduction” Section of the Thesis)	**Study I.** Industry 4.0, Lean Production and Sustainability: A Bibliometric and Literature Review	September 2023	**The Routledge Companion to Creativity, Routledge, Taylor & Francis Group** (Accepted for publication)	Ciliberto, C., Taddeo, R., Liao, W., Szopik-Depczynska K., Yigitcanlar, T., Ioppolo, G.
	Study II. Enabling the Circular Economy transition: a sustainable lean manufacturing recipe for Industry 4.0	2021	**Business Strategy and the Environment**,1–18. https://doi.org/10.1002/bse.2801	Ciliberto, C., Szopik-Depczynska K., Tarczynska-Łuniewska, M., Ruggieri, A., Ioppolo, G.
Bibliometric and Literature Review and a Cross-Sectional Analysis (Chapter 1 of the Thesis)	**Study I.** Industry 4.0, Lean Production and Sustainability: A Bibliometric and Literature Review	September 2023	**The Routledge Companion to Creativity, Routledge, Taylor & Francis Group** (Accepted for publication)	Ciliberto, C., Taddeo, R., Liao, W., Szopik-Depczynska K., Yigitcanlar, T., Ioppolo, G.
	Study II. Enabling the Circular Economy transition: a sustainable lean manufacturing recipe for Industry 4.0	2021	**Business Strategy and the Environment**,1–18. https://doi.org/10.1002/bse.2801	Ciliberto, C., Szopik-Depczynska K., Tarczynska-Łuniewska, M., Ruggieri, A., Ioppolo, G.
Testing and Description of Results (Chapter 2 of the Thesis)	**Study III.** Multicriteria Approach for Supplier Selection: Evidence from a Case Study in the Fashion Industry	2022	**Sustainability**, 2022, 14, 8038. https://doi.org/10.3390/su14138038	Caristi, G., Boffardi, R., Ciliberto, C., Arbolino, R., A., Ioppolo, G.

Practical Applications to Circular Supply Chain 4.0: Lean Six Sigma in the Italian Healthcare (Chapter 3 of the Thesis)	**Study IV.** Supply Chain 4.0: Lean Six Sigma, Industry 4.0 technologies and Circular Supply Chain applied to an Italian hospital case study	2023	in Lagioia G., Paiano A., Amicarelli V., Gallucci T., Ingrao C. (Editors), Innovation, Quality and Sustainability for a Resilient Circular Economy. The Role of Commodity Science, Series: Circular Economy and Sustainability, **Springer Nature**, 2023, ISBN: 978-3-031-28291-1.	Ciliberto, C., Majorana, F., Szopik-Depczynska, K., Ioppolo, G.
Future Perspectives for Sustainable Production (Chapter 4 of the Thesis)	**Study V.** Innovation in traditional handcraft companies towards sustainable development. A systematic literature review	2022	**Technological and Economic Development of Economy Journal**, https://doi.org/10.3846/tede.2022.17085	Shafi, M., Szopik-Depczyńska, K., Cheba, K., Ciliberto, C., Depczyński, R., Ioppolo, G.

Table 1. Methodological approach adopted in this Thesis

Introduction and Conceptualisation

This part of the Thesis introduces the "Conceptualisation" phase and corresponds to the "Introduction" Section. It is referred to Study I entitled "*Industry 4.0, Lean Production and Sustainability: A Bibliometric and Literature Review*", accepted for publication in the book The Routledge Companion to Creativity, Routledge, Taylor & Francis Group, edited by Professor T. Yigitcanlar and Study II, "*Enabling the Circular Economy transition: a sustainable lean manufacturing recipe for Industry 4.0*", published in Business Strategy and the Environment, Wiley.

The first study was thought to overcome the limitations of the traditional perspective strongly oriented to consider the three topics, Industry 4.0, Lean Production and Sustainability separately or matched in pairs (Kolberg and Zühlke, 2015; Tortorella and Fettermann, 2018; Luthra and Mangla, 2018; Sharma, R. et al., 2021).

Thus, the study aims at outlining the greater importance of Sustainability in recent years within its three declinations, economic, environmental and social to achieve sustainable production and circular production processes through the combination of

Industry 4.0 technologies and lean techniques to optimise the entire production process and maximise product utilisation. The research also investigates the role of Industry 4.0 technologies which, according to the literature review, is not well identified and is dispersed by different technological definitions.

In summary, this novel approach emphasises the need that all these pillars should be connected in an integrated and holistic manner. To address the gap concerning the need for a further investigation on the interrelations among these three topics, the research proposes a conceptual framework to analyse the effects of Lean Manufacturing and Industry 4.0 under a sustainable perspective.

The second Study conducts an in-depth analysis through a magnifying glass on the relationship among Industry 4.0, Sustainable Production and Lean Production, highlighting the opportunity to invest in Reverse Logistics and how Industry 4.0 system represent a breeding ground for Circular Economy targets application. In this sense, the research goes further and constitutes the core of the "Conceptualisation" phase giving an attempt in expanding and theorising the Lean Manufacturing theory including environmental aspects and in contributing to highlighting the positive role of Industry 4.0 as an essential environment where redesign flows, processes, and targets.

Therefore, the goal of the overall Section is to represent the implementation of a Circular Supply Chain 4.0 as a product of lean strategies and emerging technologies, adopting Reverse Logistics to reach circularity and sustainability.

Bibliometric and Literature Review and a Cross-Sectional Analysis

Research methodology (Study I)

This chapter concerns the "Bibliometric and Literature Review and a Cross-Sectional Analysis" phase and refers to Study I "*Industry 4.0, Lean Production and Sustainability: A Bibliometric and Literature Review*", accepted for publication in the book The Routledge Companion to Creativity, Routledge, Taylor & Francis Group, edited by Professor T. Yigitcanlar and Study II "Enabling the Circular Economy transition: a sustainable lean manufacturing recipe for Industry 4.0", published in Business Strategy and the Environment, Wiley.

The review was developed following a literature review based on the methodology proposed by Briner and Denyer (2012), which is presented in Figure 1. It consists of a five-step analysis, as follows.

- Phase 1: Identification. The objective of the research, keywords, research databases and cover period are defined. The keyword string used is: ("Industry 4.0" OR "Smart manufacturing") AND ("Lean Production" OR "Lean manufacturing" OR "Lean management") AND ("Sustainability"). Google Scholar, Science Direct, Scopus, Emerald Insight and Web of Science are utilised to carry out the analysis. Industry 4.0 is a topic which officially came on stage in 2011 at the Hannover Fair (Kagermann et al., 2011; Chiarini et al., 2020). For this reason, it could be assumed that the year 2011 would be a natural cut-off point of the current literature review.

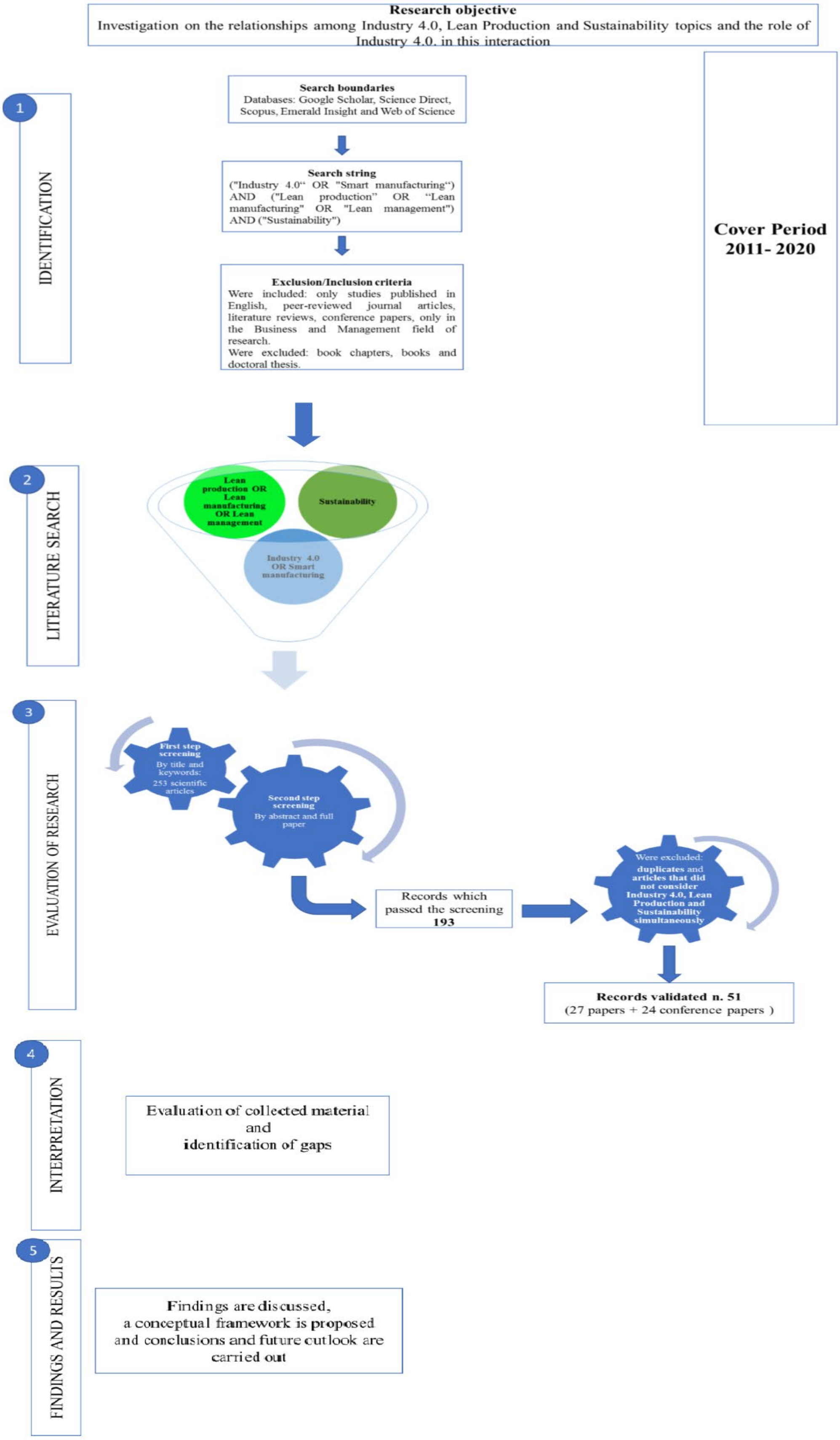

Figure 1. Literature Review's Research Methodology based on Briner and Denyer (2012)

- Phase 2: Literature search. In this phase, resources are collected.

- Phase 3 Evaluation of the research. The review performed aims to select a set of resources that consider simultaneously the relationships among Industry 4.0, Lean Production and Sustainability.

Inclusion and exclusion criteria were applied to the above illustrated five-step process (Figure 1) in order to achieve the goal of the research. First, only documents written in English were considered, peer-reviewed journal articles, literature reviews and conference papers aligned with the aim of the analysis and pertaining only to the Business and Management field of research.

Furthermore, book chapters, books and doctoral theses were excluded to guarantee high scientific and academic quality and standard (Ramos et al., 2004; Lamba and Singh, 2017).

The total number of papers found was 276. All these resources were screened following a two-step screening process: (a) by titles and keywords; (b) by abstract and full paper. In the first phase, articles were filtered by screening the titles and the keywords. The number of papers from this first step was of 253. The second step consisted in screening and choosing those publications, according to the abstract and the full paper. Therefore, the number of selected papers dropped to 193 articles.

From these, only those papers more adherent to the specific purpose of the research and focused on the simultaneous investigation of relationships among Industry 4.0, Lean Production and Sustainability and on the role of Industry 4.0 in this integration were considered. Duplicates were excluded. As a result, the final number of records that passed the screening process dropped to 51 (27 scientific articles and 24 conference papers).

- Phase 4: Interpretation. The collected studies were critically appraised to achieve research objective and, research gaps highlighted.

Lastly, in Phase 5, results were presented and discussed. A conceptual framework that interrelates Industry 4.0, Lean Production and Sustainability in its triple dimension (environmental, social, and economic), was proposed. Conclusions and future outlooks were, then, elaborated.

Bibliometric Analysis through Descriptive Statistics of the Sample

Trend of Publications

The descriptive statistics of the examined sample of papers is carried out. In this sense, it is noteworthy to outline that the first publication in Lean Production dates back to the early 90s (Womack et al., 1990), whereas the environmental aspects were considered from the early years of their manifestation (1994) (Taddeo et al., 2019) and, Industry 4.0 was investigated from its occurrence in 2011 (Kagermann et al., 2011; Chiarini et al., 2020). In literature the topic of the relationships among Industry 4.0, Lean Production and Sustainability is quite new and debated and, as emerged by the research, studies are mainly concentrated between 2017 and 2020. Furthermore, it is true that 2011 is assumed as the cut-off point of the current literature review, but as findings reveal, only since 2013 first studies investigated upon the proposed research topic.

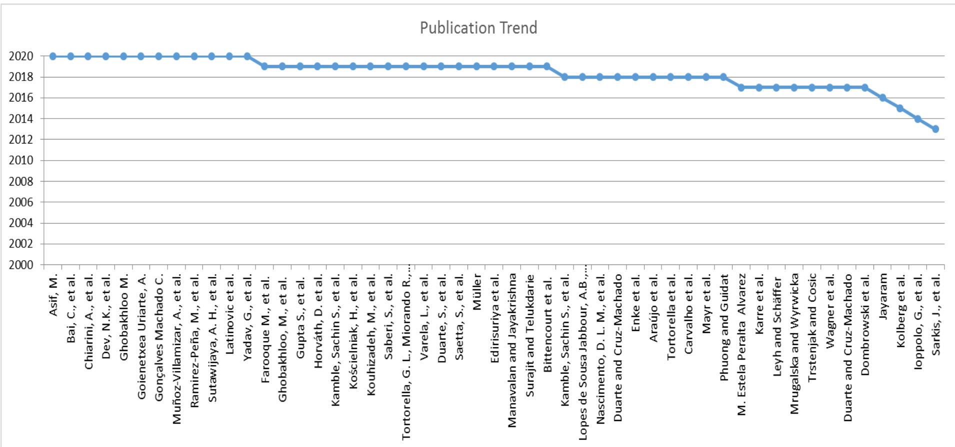

Figure 2. Trend of publications

Contributions from Journals, by Country and by Type of Papers

Excel tool was used to classify journals. Journal of Cleaner Production has the highest number of publications in the selected period (2011-2020), with six papers, followed respectively by International Journal of Production Research with five publications and Sustainability with three ones. This means that Industry 4.0 issues related to Lean Production and Sustainability are discussed in different Journals with a broad dissemination (Figure 3).

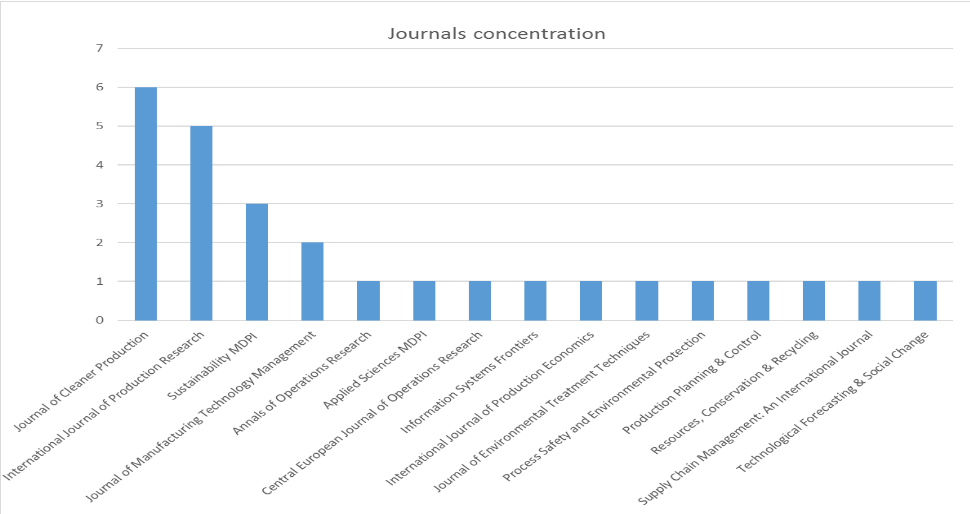

Figure 3. Journals' concentration

As shown in Figure 4, distribution of publications is quite widespread in the world considering the relevance and the novelty of the topic.

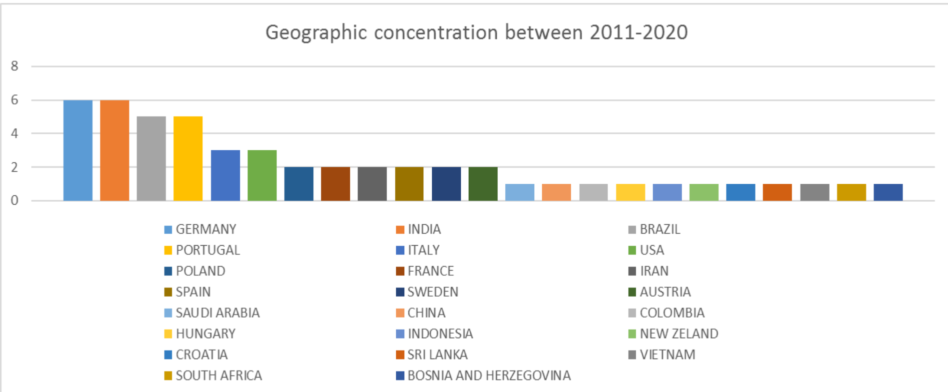

Figure 4. Geographic concentration (countries of first authors are considered)

In Figure 5, the 51 selected papers were divided according to the type of study, of which 24 studies are classified as conference papers. They are followed by 11 literature reviews, 14 research papers, 1 case study and 1 special issue. This shows that the interest for this topic is growing up and, the large number of conference papers confirms this trend.

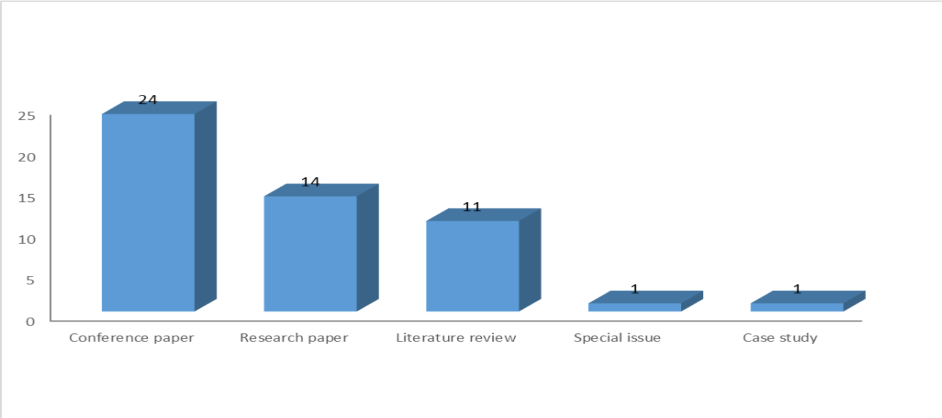

Figure 5. Types of studies reviewed

Keywords Statistics

Figure 6 shows the most prevalent keywords in the 51 scientific articles. “Industry 4.0/Smart Manufacturing” was the most frequently used keyword (46%), followed by “Lean Production/Lean manufacturing/Lean management” (35%) and “Sustainability” (19%).

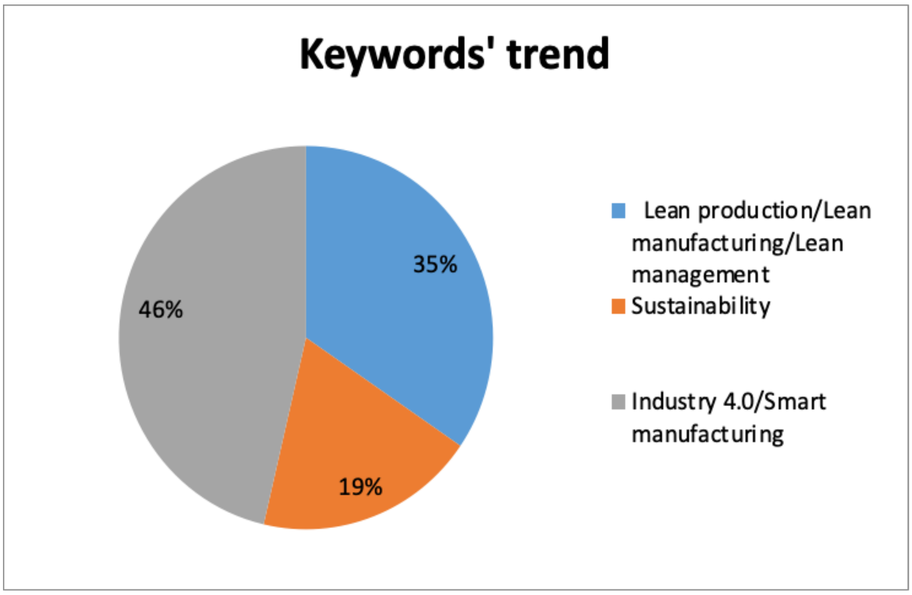

Figure 6. Keywords’ trend

Furthermore, in Figure 7, it is meaningful to observe that in the reviewed literature the keyword “Industry 4.0” is always present. On the other hand, keywords are matched together in order to understand both their relationships and whether Industry 4.0 is a dominant topic compared to the others. What emerged is that leading integrations are between Industry 4.0 and Lean Production (50%) as well as between Industry 4.0 and Sustainability (33%), whereas combination among keywords Industry 4.0 and Lean Production and Sustainability, do not reach high value (17%) and it confirms the existing gap on this topic.

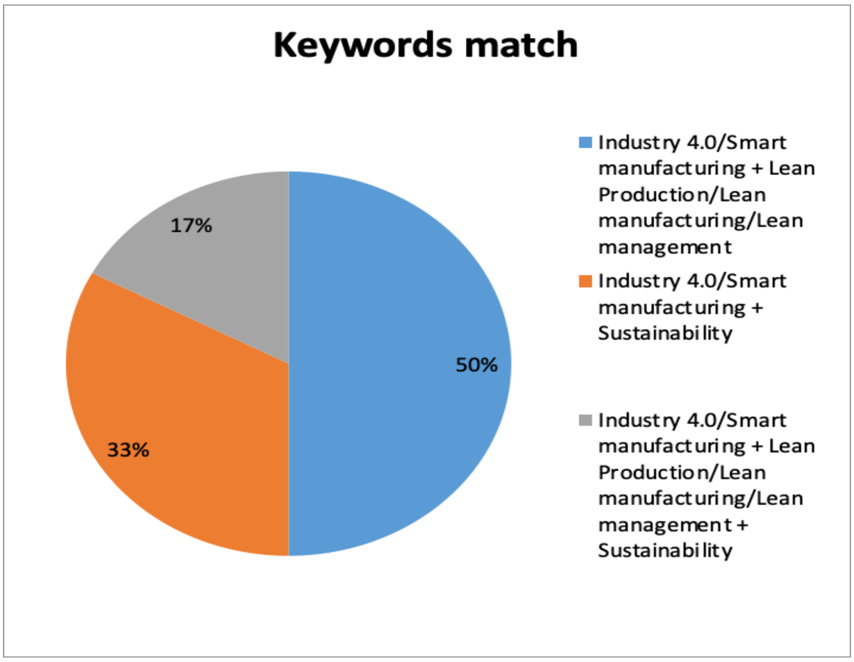

Figure 7. Keywords' match

The persistent presence of Industry 4.0 in these combinations mean new technologies play a significant role in this trilateral relationship, as it is confirmed by relevant literature (Peralta-Álvarez et al., 2017; Kamble et al., 2018; Trstenjak and Cosic, 2017; Araújo et al., 2018; Tortorella et al., 2018; Duarte et al., 2019; Saetta and Caldarelli, 2020; Ghobakhloo and Fathi, 2020; Chiarini et al., 2020). Moreover, a novel trend in literature that considers these three topics in an integrated way is represented.

Research methodology (Study II)

This study examines in depth the integration of Industry 4.0 technologies, Lean Manufacturing and Circular Economy and their impacts on sustainable production through a cross-sectional analysis which matches these three topics in pairs. For each of them the main features, investigated in literature, are shown and this technique allows a deeper analysis as methodological support on the interrelations among these three pillars.

The paper explores Circular Economy principles in order to point out a practical business-oriented strategy that helps implement sustainable production paths. Moreover, the focus has been set upon the Lean Production theory and tools, as one valid methodological support for a new strategy of competitive eco-business, highlighting ways for Reverse Logistics to answer the urgent need to translate the Circular Economy principles into actions.

In the paper it is outlined that the selection of a management model, especially in the manufacturing sector, becomes a strategic factor in the transition towards a circular economy-oriented business model. Indeed, the difficulty is due to the complexity of the manufacturing sector, which also needs to acquire the guidelines deriving from the sustainable development goals and consistently the circular economy principles.

Womack and Jones (1996) introduced a method - the Lean Manufacturing, which proved to be particularly efficient and effective in the interpretation and management of processes and operations.

Lean Manufacturing contains, in short, five basic elements, namely: value, value flow, flow, pull and perfection. In this sense, the principles of production management e.g. elimination of waste, satisfying customer needs, focusing on activities that generate value and value flows, striving for perfection, guaranteeing reliability at all phases of production and guaranteeing continuous improvement (Kaizen) in all processes are taken into account (Salem et al., 2006).

Recalling that circular economy aims at: a) reducing waste, prices volatility and the number of steps in the processes; b) improving flow, transparency, flexibility and control in processes; c) satisfying customer needs through benchmarking and continuous improvement (Koskela, 1992), there is a clear awareness that Lean Manufacturing principles have great potential to contribute to environmental well-being, it is necessary to explore in detail the fundamental principle of Lean Management, which focuses on identifying and minimizing waste (Taddeo et al., 2019).

Lean management was introduced by Toyota's lean philosophy, which has evolved over time by adopting different application methods (Shingo, 1989; Babalola et al., 2019; Koskela et al., 2002).

On the other hand, Lean Supply Chains have their origin in the just-in-time philosophy which was first adopted by many American and European companies in the late 1980s and, then, performed at Toyota's Takaoka facility.

One of these approaches is an attempt to apply lean tools directly in the production environment (i.e. 5S, Value Stream Mapping , Just-in-Time) (Tan et al., 2013).

Specifically, 5S, which stands for "order, straighten, standardise, polish, sustain" is a lean tool that is usually adopted as a first step towards lean manufacturing by most companies (Chiarini, 2014; Salem et al., 2014). Furthermore, 5S focuses primarily on labelling and organising material storage and inventory management, it is able to quickly identify spills, dangerous leaks and reduce air pollution (Bae and Kim, 2008; Francis and Thomas, 2020). Dieste et al. (2019) developed a framework for integrating lean and environmental Sustainability.

Chugani et al. (2017) specified tools such as lean and six sigma, claiming that Sustainability can be easily achieved in corporate business saving energy and resources.

Value Stream Mapping lean tool is used to understand waste and value in the production process. At the same time, it is possible to implement environmental assessment tools in order to understand the environmental impact.

In addition, the Six-Sigma approach has been adopted using Cause and Effect Diagrams and Pareto diagrams, thus helping to take steps to mitigate and control costly activities in processes.

Hence, it is assumed that it is necessary to incorporate lean, environmental tools and Six-Sigma to evaluate and improve processes and to achieve better efficiency with less environmental impact.

Erdil et al. (2018) developed a framework to integrate Sustainability into Lean and Six-Sigma projects. In detail, it introduces Sustainability aspects into the Six Sigma, Lean and DMAIC (Define, Measure, Analyse, Improve and Control) cycle to promote design improvements in projects in all dimensions of sustainability.

Traditionally, the lean approach does not directly identify opportunities for resources such as energy efficiency, but is instead strategic for activities focused on eliminating waste and improving process flow time. This is the reason why a large number of Small and Medium Enterprises are providing themselves with lean-digitised strategies (Ghobakhloo and Fathi, 2019).

Arroyo and Gonzalez (2016) suggest that the definition of waste within the lean boundary should be rethought to also incorporate social and environmental impacts. Therefore, it is worth exploring the potential of lean practices in the context of combating both resource and energy waste in all processes.

A rethinking of the Lean Manufacturing paradigm could be the start of a Circular Economy adoption strategy.

In this sense, Lean Manufacturing can therefore support a Sustainable and Circular Supply Chain in Muda (Defect) Management, by being able to clearly and schematically represent bidirectional flows and highlight waste and wasteful activities. Evidence from the production environment shows that resources and energy are considered to be a significant and expensive input for the flow of value, and therefore unnecessary energy and material consumption must be considered as waste (Sciortino et al., 2009).

From this perspective, "energy waste", that incorporates under-utilisation, loss, dissipation as well as uneconomical energy use and transformation processes, could be identified by the lean philosophy as the ninth waste, considering its potential for saving money and reducing polluting emissions (Baysan et al., 2019).

Therefore, the lean philosophy already allows to support eco-design already at the design stage, thus promoting a circular production model that improves, through Reverse Logistics, the recyclability of a product that is increasingly sustainable, less energy-consuming and based on secondary raw materials.

Nonetheless, the lean-sustainable and circular production concept is still a new business strategy, without tangible feedback on its practical implementation (Abualfaraa et al., 2020; Zhang et al., 2020).

In Figure 8, there is a built-up matrix in which Lean Production (also known as Lean Manufacturing) strategies and Industry 4.0 attributes are combined. Also here, it is shown a strong correlation between them. As a large number of authors argued (Rosin et al., 2019), Industry 4.0 technologies are able to strengthen the efficiency of lean approaches, despite the lack of their empirical validation, e.g. through real increase in profits for the organization.

This means that adopting lean strategy under the umbrella of Circular Economy principles, achieving the aims underlying new technologies, which can be summarised in improving efficiency, productivity, flexibility, transparency and reducing complexity, is strongly enhanced.

Lean production features	I. 4.0 features: Improving efficiency	Increasing productivity	Improving flexibility	Improving transparency	Reducong complexity
Elimination of wastes	⊕	⊕	⊕	⊕	⊕
Satisfaction of customers' needs	⊕	⊕	⊕	⊕	⊕
Generation of value	⊕	⊕	+	+	⊕
Pursuing perfection	⊕	⊕	⊕	⊕	⊕
Guaranteeing reliability	+	+	+	+	+
Providing continuous improvement	⊕	⊕	⊕	⊕	⊕
Reducing lead times	⊕	⊕	⊕	⊕	⊕

⊕ Strong positive correlation
\+ Mild positive correlation
⊖ Strong negative correlation
− Mild negative correlation

Figure 8. Matrix combining Lean Production strategies and features of the environment Industry 4.0

Furthermore, in Figure 9, there is also a constructed matrix which summarises the Circular Economy principles and Lean Manufacturing strategies. This matrix emphasises the existence of a strong, positive correlation between them. By interpreting these results, it can be said that both Circular Economy principles and Lean Production strategies can be integrated into the same Industry 4.0 environment to improve the competitiveness of organizations. In the Figure, the only mild negative correlation concerns innovating and elimination of wastes. The reason lays in the fact that innovation should be considered not only sic et simpliciter as adopting emerging technologies and lean strategies, but as eco-innovation and eco-design of both technologies involved in the process flow, products and packages (Sumrin et al., 2021).

Innovation determines the elimination of wastes only if it is considered as eco-innovation and eco-design. Thus, this would imply recovering not only production wastes but also technological scraps. Therefore, achieving the elimination of wastes should involve the adoption of all forms of innovations (technologies, products, services) which are able to reuse production waste as eco-designed smart new products (Gavrilescu et al., 2018).

		Lean production features						
		Reducing lead times	Providing continuous improvement	Guaranteeing reliability	Pursuing perfection	Generation of value	Satisfaction of customers' needs	Elimination of wastes
CE features	Optimizing	⊕	⊕	⊕	⊕	⊕	⊕	⊕
	Regenerating	⊕	⊕	+	⊕	⊕	+	⊕
	Sharing	⊕	⊕	⊕	⊕	⊕	+	⊕
	Dematerializing	⊕	⊕	+	+	⊕	+	⊕
	Innovating	+	⊕	+	⊕	⊕	+	–
	Closing the loop	⊕	⊕	+	⊕	⊕	+	⊕
	Increasing economic efficiency (reducing price volatility)	⊕	⊕	+	⊕	⊕	⊕	⊕

⊕ Strong positive correlation
\+ Mild positive correlation
⊖ Strong negative correlation
– Mild negative correlation

Figure 9. Matrix combining Circular Economy principles and Lean Production strategies. In the Figure, the only mild negative correlation concerns innovating and elimination of wastes. The reason why the aforementioned correlation is mild negative is that innovation determines a complete elimination of wastes provided that it is considered not only *sic et simpliciter* as adopting emerging technologies and lean strategies, but as eco-innovation and eco-design of both technologies involved in the process flow, products and packages

Finally, Figure 10 shows a matrix that indicates strong correlation and complementarity between the bases and main characteristics of Circular Economy principles and Industry 4.0. Each of the considered Circular Economy models positively influences the improvement of those that are objectives of Industry 4.0.

		I. 4.0 features				
		Improving efficiency	Increasing productivity	Improving flexibility	Improving transparency	Reducong complexity
CE features	Optimizing	⊕	⊕	⊕	+	⊕
	Regenerating	⊕	⊕	⊕	+	⊕
	Sharing	⊕	⊕	⊕	+	⊕
	Dematerializing	⊕	⊕	⊕	+	⊕
	Innovating	⊕	⊕	⊕	+	+
	Closing the loop	⊕	⊕	⊕	+	⊕
	Increasing economic efficiency (reducing price volatility)	⊕	⊕	⊕	+	⊖

⊕ Strong positive correlation
\+ Mild positive correlation
⊖ Strong negative correlation
– Mild negative correlation

Figure 10. Matrix combining Circular Economy principles, taken from the "Circular Economy Action Plan", elaborated by European Commission, 2010, Europe 2020: A strategy for smart, sustainable and inclusive growth. and features of the environment I.4.0, with features of the environment I.4.0, gathered from the literature considered in the study. The only strong negative correlation is placed between an increase of economic efficiency and the reduction of complexity in technological process flows because complexity is still viewed as a "measure of uncertainty" due to the fact that it has to manage a high number of data and variables in companies and, its reduction represents a challenge for them (Mourtzis et al., 2019)

By matching Circular Economy models with the attributes of Industry 4.0 in this matrix, the results reveal the previous ones make a significant contribution to the achievement and improvement of all technological goals that could be achieved through the implementation of new technologies and vice versa. This implies Industry 4.0 technologies can better improve economic and quality performance of an organization, whether or not they are implemented in a Circular Economy perspective.

It is noteworthy to notice that the only strong negative correlation is placed between an increase of economic efficiency and the reduction of complexity in technological process flows. This because, differently from the other combinations taken into consideration, which combine a kind of Circular Economy model and a potential benefit deriving from the implementation of Industry 4.0 technologies, in the last case an economic benefit (the increase of economic efficiency) is linked to the reduction of complexity in process flows within a company. It is true that digitalising and automated processes would mean meeting customers' demand and the reduction of complexity. But, this kind of correlation should be represented through a strong negative correlation because complexity is still viewed as a "*measure of uncertainty*" due to the fact that it has to manage a high number of data and variables in companies and, its reduction represents a challenge for them (Mourtzis et al., 2019).

It must be said that Industry 4.0 and Circular Economy, although sharing the same objectives to improve efficiency, productivity and flexibility, present completely different operative approaches (Garcia-Muiña et al., 2019). Circular Economy models operate through the implementation of best practices aimed at resource productivity and process efficiency, through waste stream valorisation, with a sustainability perspective. Meanwhile, Industry 4.0 improves process performance through the integrated use of smart technologies.

Testing and Description of Results

After establishing the theoretical and conceptual bases in Chapter 1 "Bibliometric and Literature Review and a Cross Sectional Analysis", it is crucial evaluating our findings through empirical methods.

The phase of "Testing and Description of the Results" aims at identifying and analysing the stakeholders' consideration upon Lean Production principles and Sustainable Production in the supplier selection process and the adoption of Lean methodologies as a potential strategic factor in sustainable production processes.

This phase is included in Paper III (Caristi, G., Boffardi, R., Ciliberto, C., Arbolino, R., A., Ioppolo, G., 2022) entitled "*Multicriteria Approach for Supplier Selection: Evidence from a Case Study in the Fashion Industry*", published in Sustainability, MDPI. In this phase, we aim to establish whether or not the re-modelling of the Lean Manufacturing paradigm, in the perspective of circular and sustainable production, as claimed in Chapter 1, is taken into account by industries in a crucial phase of the supply chain, the suppliers' selection.

To do so, an MCDM model based on the combination of SCOR metrics and Fuzzy TOPSIS is provided. This part of the thesis if focused on the evaluation by stakeholders of the adoption of Lean strategies in the supplier selection process of a textile and fashion company. However, the choice to analyse a single industry located in Vietnam is due to the fact that there is still limited evidence of selection criteria and selection models in the Vietnamese textile sector. Furthermore, the decision of not making a comparison between this model and other MCDM models applied to the same sector for selecting suppliers may undoubtedly entails limitations to research. Indeed, the research was a preliminary study on this topic given that further empirical studies on this issue are needed to validate the model and generalize the obtained results to all Vietnamese textile manufacturing sectors.

In this sense, the study does not represent the totality of textile manufacturing industries globally engaged in the lean and sustainable transition towards more resilient business models.

The present research relies on an innovative combination of two techniques—i.e., MCDM model with SCOR metrics—implemented to support textile industries in the process of supplier evaluation and selection. The proposed approach is constructed following three main phases (Figure 11):

- Establishing goals and criteria: SCOR metrics and literature reviews were used to develop robust criteria for assessing and selecting suppliers.

- Including all potentially efficient suppliers, through a model which determines the weight of all criteria and sub-criteria.
- By applying a fuzzy TOPSIS model, the set of probable suppliers is ranked and, based on PIS and NIS, the optimum supplier is proposed.

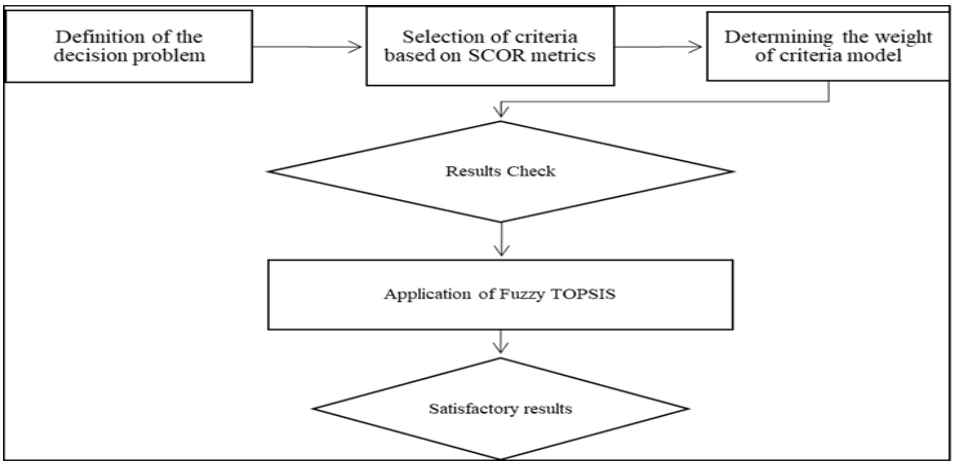

Figure 11. Flow chart of the proposed Method for Supplier Selection Process

The final assessments are provided by three managers of a Vietnamese company in the textile industry. They were interviewed on the basis of identified criteria to validate the model and understand what requirements a potential supplier should meet.

Practical Applications to Circular Supply Chain 4.0: Lean Six Sigma for Sustainable Production

The "Practical Applications to Supply Chain 4.0: Lean Six Sigma for Sustainable Production" phase is introduced by Chapter 3 of the Thesis and, referred to Paper IV entitled "Supply Chain 4.0: Lean Six Sigma, Industry 4.0 technologies and Circular Supply Chain applied to a case study of an Italian hospital", published by Springer Nature, shows through the practical application of Lean methodologies, in this case Lean Six Sigma, that Lean Manufacturing paradigm improved with Circular Supply Chain Management principles is a management approach that can bring added value to the business strategy in a circular economy perspective. At the same time, the chapter offers valuable insights on the importance of the creation in companies of an Industry 4.0 environment supported by the emerging technologies.

Methodology adopted in the study is based on a mixed approach, characterised by a detailed literature review and a case study of an Italian hospital.

Firstly, objectives, research questions, keywords and search databases were determined.

Regarding the objective and the research question, the article aims at understanding the scope of the main topics: Lean Six Sigma, Industry 4.0 and Circular Supply Chain and their peculiarities. Lean Six Sigma and Circular Supply Chain are reviewed in healthcare sector to understand their scope of application.

In terms of databases, Google scholar, Scopus and Elsevier were chosen to implement the research. Peer-reviewed journal articles, books and non-academic research such as international reports available online were considered. Subsequently, the following keywords were used: 'Lean Six Sigma', 'Supply Chain 4.0', 'Digitalized Supply Chain', 'Circular Supply Chain', 'Industry 4.0' and 'Healthcare'.

Finally, the study draws on process information and primary data from a real anonymized project carried out in an Italian hospital. In this regard, the Lean Six Sigma methodology adopted in the case study is shown step by step (Figure 12).

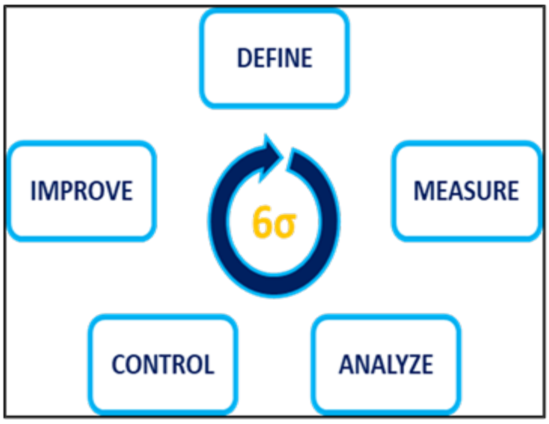

Figure. 12 Lean Six Sigma Methodology

Future Perspectives for Sustainable Production

The phase of elaboration of "Future Perspectives for Sustainable Production" of the novel approach based on the integration of Lean Production, Industry 4.0 and Circular Economy is based on the insights included in Paper V "Innovation in traditional handcraft companies towards sustainable development. A systematic literature review", published in the Technological and Economic Development in Economy Journal.

The paper – through a qualitative approach - addresses the understanding of innovation in traditional handicrafts for sustainable development.

Despite being rich in cultural heritage, traditional handicrafts require innovation to achieve competitiveness. The study emphasises the importance and potential advantages of innovation and its synergistic effect with cultural traditions leading to sustainable development. Apart of the explanation of most important issues regarding this topic, publications containing the following keywords selected for the study were identified in the Web of Science database. A total of 500 different publications from 1975 to 2021 were identified. The database was used for text-mining analyses. The clustering method (data mining) was used. The systematic literature review was carried out with the use of VOS Viewer software. This tool was used to identify and analyse clusters and dominant research areas and to identify potential new research directions.

In this paper it is shown that future studies should focus on the issue of measuring incremental innovation in cultural creative industries, especially handicraft since this topic is not enough analysed in the literature. The findings can help academics and practitioners to improve the knowledge about the topic and concentrate on identified priority areas to fulfil the assumptions of sustainable development.

The procedure used in the paper to answer the research questions covers several stages (Bartolacci et al., 2020; Ferasso et al., 2020). The procedure was also discussed by Shashi et al. (2021) and Suchek et al. (2021). The flowchart of the procedure developed for the literature review has been presented in Figure 13.

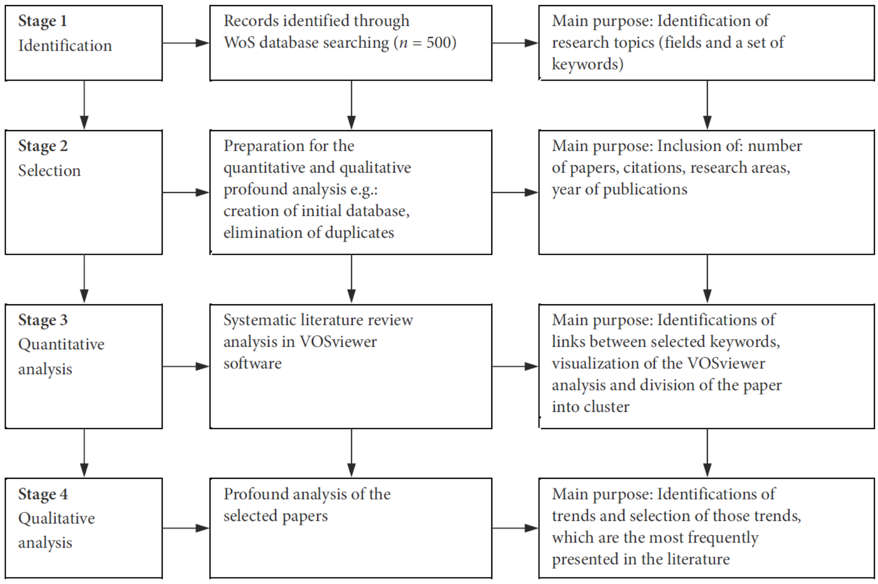

Figure 13. Systematic Literature Review flowchart

In the first stage of the study, publications containing the following keywords selected for the study were identified in the Web of Science database: innovation, handicraft, sustainability, traditional handicraft, and incremental innovation.

Logical operator combinations AND, OR, and a symbol to replace the string (*) were used when searching the database. Different formulas have been tested for consistency between the logical and substantive quality of the results obtained. A total of 500 different publications from 1975 to 2021 were identified in the Web of Scince database. The database (stage 2 of the adopted procedure) was used for text-mining analyses to identify publications that best fit the purpose of the study, i.e., those that allow searching for links between innovation, sustainability, and handicraft (stage 3). The recognition of research trends based on analysis of the occurrence and co-occurrence of keywords is a well-established bibliometric approach. Like any form of scientific inquiry, however, it has its limitations due to the risk of subjectivity in the choice of keywords and the inherent instability of language systems, as well as the lack of guarantee that the fields in which most papers are, or have been until recently, published will be the priority fields in the future.

The clustering method, which belongs to data mining methods, was used in the conducted analyses. It is an exploratory method, the purpose of which is to identify non-obvious relationships and patterns in data and internal similarities between data vectors and, based on these values, to determine the division of data into disjoint groups. As a result, elements within each group have strong mutual similarity, while any objects from different groups show negligible similarity. This method is often used in the processing and semantic analysis of text documents. The conducted research also identified clusters containing selected keywords and their reference networks (van Eck & Waltman, 2010; Waltman et al., 2010; Perianes-Rodriguez et al., 2016).

The bibliographic research was carried out with the use of VOS Viewer software. This tool was used to identify and analyse dominant research areas and to identify potential new research directions. Table 2 shows the number of passes identified in the Web of Science database, taking into account different combinations of the selected keyword.

Analysing the results of this search, it is worth noting that among 2373 publications in which the term handicraft was used in the title, keywords, or abstract, only 304 also raise issues related to innovation and 249 to sustainable development. The combination of these three keywords, i.e., handicraft, innovation, and sustainability, was identified in only 53 publications. A relatively small number of publications in this area may indicate a possible existence of a research gap in the literature on the subject. The growing interest in research in this area may be evidenced by the increase in the number of publications referring to this kind of issue in the literature on the subject in recent years. The evolution of the number of publications in the last ten years (2011–2021) and its citations in the analysed period was presented in Figure 14.

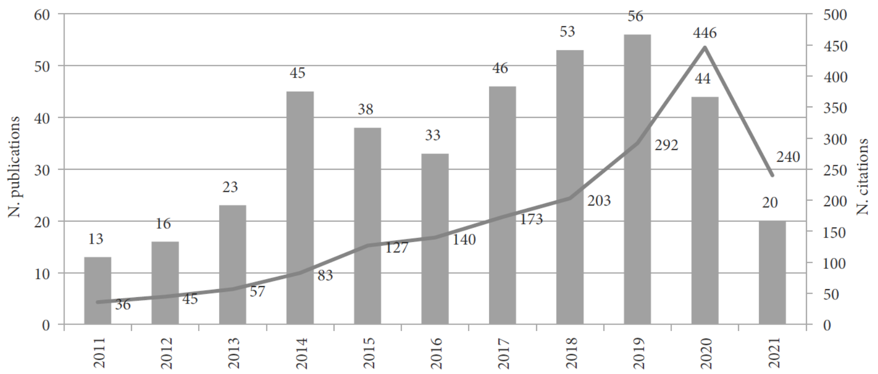

Figure 14. Total publications and citations by year – final database from 2011 to 2021

The first article in the established database entitled Handicrafts and technical innovation in Ethiopia by A. Cassiers was from 1975 and published in the journal Cultures. Until 2010, only a few articles (maximum 10 in 2010) were indexed in the database. The number of publications reached its highest point in 2019 with 56 publications. Since 206, a systematic increase in citations of publications has also been observed, the largest in the last few years, reaching the highest level in 2020 (446 citations). These are mainly publications in the fields of agriculture (75 publications), business economics (60), science technology (54), environmental sciences ecology (51), engineering (50), social science (47), computer science (43), education and educational research (41), planet sciences (30) and material science (33). The authors of the identified studies come mainly from China (77 publications), Italy (52), Brazil (38), France, Indonesia, and the USA (30 papers each).

The combinations of topics	Number of papers
handicraft*	2373
handicraft* AND innovat*	304
handicraft* AND sustainab*	249
handicraft* AND innovat* AND sustainab*	53
"traditional handicraft*" AND innovate*	39
"traditional handicraft*" AND innovate* AND sustainab*	10
handicraft* AND "incremental innovation*"	1
innovat* AND handicraft* OR sustainab* AND handicraft* OR innovat* AND handicraft* AND sustainab* OR innovat* AND "traditional handicraft*" OR innovat* AND "traditional handicraft*" AND sustainab* OR "incremental innovation*" AND handicraft*	500

Table 2. Number of papers identified in the Web of Science according to the selected keywords

Table 3 presents information on the most frequently cited publications in this field. The information presented in this table shows that among the most frequently cited papers, there are mainly publications in the field of Bio-Economy. These are predominantly studies on rural development, bio-food, ethnobotany, ecology and agriculture. They also discuss issues related to environmental protection.

Vox et al. (2010) describe the advantages of sustainable greenhouse systems in the context of traditional handicraft. Pieroni (2008) also discusses the advantages of traditional handicraft in agriculture. At the same time, Al-Dajani et al. (2015) explore the links between entrepreneurship, emancipation, and gender within the international development arena. It is also worth noting the work of Sánchez-Medina et al. (2011), in which the relationship between environmental innovation and sustainability in 168 handicraft businesses in the Mexican states of Oaxaca, Puebla, and Tlaxcala is analysed. A positive relationship between environmental innovation and sustainability in three dimensions: economic, social, and environmental were confirmed. The main purpose of the paper of Sánchez-Medina et al. (2015) was to develop models to explain better the economic and environmental performance as a result of environmental compliance, thus moving towards an explanation of the sustainable behaviour of these businesses.

The presented list shows that among the most frequently cited papers, there are mainly publications in the field of Bio-Economy. These are predominantly studies on rural development, bio-food, ethnobotany, ecology and agriculture.

Paper	**Author/year**	**Journal**	**Total citations**
Geotourism and Geoparks as Novel Strategies for Socio-economic Development in Rural Areas	Farsani, NT; Coelho, C; Costa, C (2011)	*International Journal of Tourism Research*, *13*(1), 68–81	125
Pig Domestication and Human-Mediated Dispersal in Western Eurasia Revealed through Ancient DNA and Geometric Morphometrics	Ottoni, C; Flink, LG; Evin, A; Georg, C et al. (2013)	*Molecular Biology and Evolution*,*30*(4),824–832	117
Insects: A sustainable source of food?	Ramos, EJ (1997)	*Ecology of Food and Nutrition*,*36*(2–4),247–276	106
Sustainable greenhouse systems	Vox, G; Teitel, M; Pardossi, A; Minuto, A; Tinivella, F; Schettini, E (2010)	*Sustainable Agriculture: Technology, Planning and Management*, 1–79	70
Local plant resources in the ethnobotany of Theth, a village in the Northern Albanian Alps	Pieroni, A (2008)	*Genetic Resources and Crop Evolution*, *55*(8), 1197–1214	59
Ethnobotany and effects of harvesting on the population ecology of Syngonanthus nitens (Bong.) Ruhland (Eriocaulaceae), a NTFP from Jalapao Region, Central Brazil	Schmidt, IB; Figueiredo, IB; Scariot, A (2007)	*Economic Botany*, *61*(1), 73–85	56
Entrepreneurship among the Displaced and Dispossessed: Exploring the Limits of Emancipatory Entrepreneuring	Al-Dajani, H; Carter, S; Shaw, E; Marlow, S (2015)	*British Journal of Management*,*26*(4), 713–730	41
Ancient goat genomes reveal mosaic domestication in the Fertile Crescent	Daly, KG; Delser, PM; Mullin, VE; Scheu, A et al. (2018)	*Science*, *361*(6397), 85–87	41
A cross-cultural comparison of folk plant uses among Albanians, Bosniaks, Gorani and Turks living in south Kosovo	Mustafa, B; Hajdari, A; Pieroni, A; Pulaj, B; Koro, X; Quave, CL (2015)	*Journal of Ethnobiology and Ethnomedicine*, *11*	34
When lessons from population models and local ecological knowledge coincide - effects of flower stalk harvesting in the Brazilian savanna	Schmidt, IB; Ticktin, T (2012)	*Biological Conservation*, *152*, 187–195	26

Ancient pigs reveal a near-complete genomic turnover following their introduction to Europe	Frantz, LAF; Haile, J; Lin, AT; Scheu, A; Georg, C et al. (2019)	*Proceedings of the National Academy of Sciences of the United States of America*, *116*(35), 17231–17238	26
Sisal Fiber Based Polymer Composites and Their Applications	Saxena, M; Pappu, A; Haque, R; Sharma, A (2011)	*Cellulose fibers: bio- and nano-polymer composites: green chemistry and technology*, 589–659	25
Historical change of soil Pb content and Pb isotope signatures of the cultural layers in urban Nanjing	Zhang, GL; Yang, FG; Zhao, WJ; Zhao, YG; Yang, JL; Gong, ZT (2007)	*Catena*, *69*(1), 51–56	25
Environmental Innovation and Sustainability in Small Handicraft Businesses in Mexico	Sánchez-Medina, PS; Corbett, J; Toledo-Lopez, A (2011)	*Sustainability*, *3*(7), 984–1002	22
Environmental Compliance and Economic and Environmental Performance: Evidence from Handicrafts Small Businesses in Mexico	Sánchez-Medina, PS; Diaz-Pichardo, R; Bautista-Cruz, A; Toledo-Lopez, A (2015)	*Journal of Business Ethics*, *126*(3), 381–393	21

Table 3. The most frequently cited publications in Web of Science database

In the next stage to identify the tendencies in the literature, especially to answer the question of how research on this topic is divided into clusters, an analysis of co-citations of references was carried out based on articles with at least five co-citations (Figure 15). The keywords that formed relationships with each other with at least 5 times the frequency, were combined into clusters. This stage of the analysis resulted in four following clusters:

– cluster 1: handicraft, innovation, sustainable development, crafts, community, tourism, creativity, culture, entrepreneurship;

– cluster 2: traditional handicrafts, sustainability, protected areas, managements, determinants;

– cluster 3: handicrafts, cultural heritage, intangible cultural heritage, economy, protection, rural development,

– cluster 4: traditional knowledge, communities, ethnobotany, forest, growth, plants.

In a map made using VOS Viewer software, the same color indicates clusters with related terms, characterized by strong relationships and co-existence. In terms of the number of labels with each keyword, it reflects the frequency of the word. The most common keywords are located in the center of the map. Their co-existence determines the distance between words.

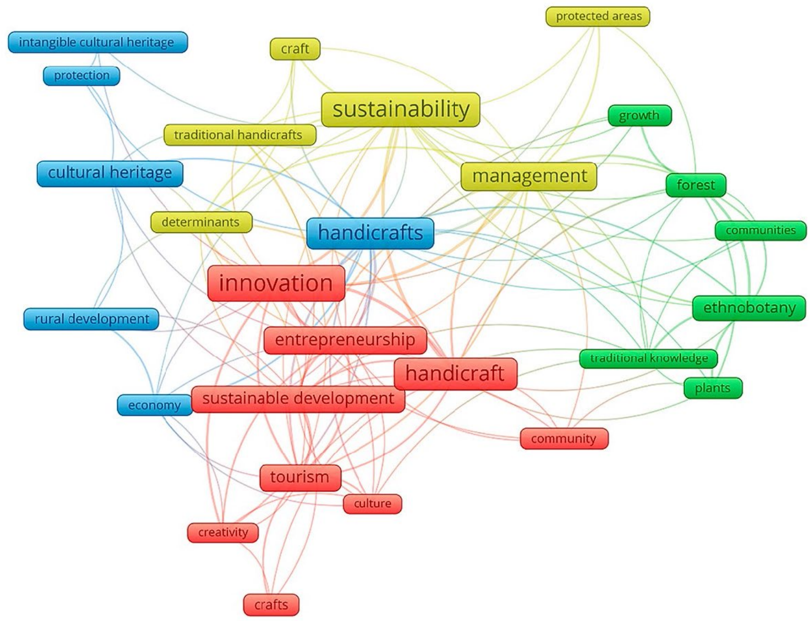

Figure 15. Clusters network

When analysing the map, it is worth paying attention to the first three clusters, in which strong links between keywords selected for the study are visible. In cluster one, all the keywords selected for the study are identified, which were additionally associated with, for example, entrepreneurship.

In cluster two, the relationships between the terms: traditional handicrafts and sustainability are important. There are references to cultural aspects in cluster three, including (environmental) protection and rural development. Cluster four focuses on keywords most related to bioeconomy, agricultural production, etc.

Chapter 1

Literature Review and Cross Sectional Analysis

1. Literature Review

Agenda 2030 is an outstanding program which consists of 17 Sustainable Development Goals (SDGs), adopted by the United Nations in 2015. It lays the groundwork for the achievement of sustainable development (Stock et al., 2018). Currently, industrial organizations are called to strive for changing the way they create value in a sustainable perspective. The SDG 9 and SDG 17, respectively, are focused on improving the use of technology and innovation and, in particular, promoting "*clean and environmentally sound technologies*". In accordance with these new rules, digital innovation and the implementation of Industry 4.0 technologies are becoming vital for an actual sustainable development (Frederico et al., 2020).

Over the past two decades, a great effort was made in integrating issues such as Lean Manufacturing, Reverse Logistics and Sustainability, because of the spread of environmental issues (Kleindorfer et al., 2005). A new scenario is connoted by emerging technologies among which cloud manufacturing, cyber-physical systems, cloud computing, wearable and human-machine interface, internet of things, industrial integration, big data, blockchain, robotics, advanced automation, additive manufacturing (a.k.a., 3D printing), artificial intelligence, digital twins can be counted, that allow the transition to a digitalised era (Xu, et al., 2018; Olsen and Tomlin, 2019; Verboven et al., 2020). These new technologies are *"gathering force [and will] be far reaching, affecting every corner of the factory and the supply chain*" (McKinsey, 2015), by enhancing quality and economic performance, improving lead time, and reducing environmental impacts (Olsen and Tomlin, 2019). Thus, a sustainable top-quality system that responds to the consumers' demand is developing (Womack et al., 1990; Fullerton et al., 2003; Simpson and Power, 2005; Shah and Ward, 2007).

With the onset of Industry 4.0, Lean Production and Sustainability industrial processes could benefit from the implementation of these new technologies able to reduce waste production. Smart environments with machines, devices and products interconnected, able to be flexible and to rapidly respond to the market changes, have been adopted by companies. Scholars have often aimed at analysing Industry 4.0, Lean Production, and Sustainability concepts separately or matching them in pairs (Amjad et al., 2020; Awan et al. 2021). It is only since 2011 that scientific research on these topics began to face how Industry 4.0, Lean Production and Sustainability can interrelate. Findings reveal that, despite the increase of works in this direction, there are still not many papers which consider all these three fields simultaneously. Furthermore, in literature does not clearly emerge whether one of them is a propulsive force against the others.

Thus, in the effort to fulfil this gap, this chapter aims at investigating the relationships among Industry 4.0, Lean Production and Sustainability and highlighting the potential synergies between technological and organizational innovations in manufacturing, also in the light of the new challenges of Circular Economy paradigm. As a result of this, a better understanding of the role of Industry 4.0 in a lean and sustainable context is carried out.

The literature analysis introduced in this section helps to understand what is already known and what is not yet known about the relationships among Industry 4.0, Lean Production and Sustainability and the role played by Industry 4.0. In order to proceed with a such analysis, the three main topics faced in the current research, Industry 4.0, Lean Production and Sustainability, are connoted and reviewed studies are shown in Table 4.

N°	Authors	Year	Field of study	Object of study
1	Sarkis *et al.*	2013	Green information system, Green technology, Supply chain	Green information systems & technologies
2	Ioppolo *et al.*	2014	Lean management, Industrial Ecology, Technology Environmental Innovations (TEIs) and Computer Integrated Manufacturing (CIM)	The integration of Lean management and Industrial Ecology
3	Alvarez *et al.*	2017	Sustainability of the machining processes	Implementation of Sustainability in machine processes to achieve a leaner and cleaner production in digitalised operations
4	Kamble *et al.*	2018	Industry 4.0, Sustainability and Lean manufacturing	Industry 4.0 technologies and their interactions with Sustainability and Lean Production
5	de Sousa Jabbour *et al.*	2018	Industry 4.0 and Sustainable operations	The relationship between Industry 4.0 and Sustainability
6	Nascimento *et al.*	2018	Sustainable Supply Chain management, Industry 4.0 technologies, Reverse logistics and Sustainability	The integration of Industry 4.0 technologies (3D printing) with Sustainability

7	Farooque *et al.*	2019	Circular supply chain management, Reverse logistics and Industry 4.0	Identification of a unified definition of Circular Supply Chain Management (CSCM)
8	Ghobakhloo and Fathi	2020	Digitisation, Lean manufacturing and Industry 4.0	The relationships between Information Technology, manufacturing digitisation, and Lean manufacturing
9	Gupta *et al.*	2019	Lean management and Big data	The application of big data analytics in the use of Lean Six Sigma
10	Horváth and Szabó	2019	Implementation of Industry 4.0	Driving forces and barriers to the implementation of Industry 4.0
11	Kamble *et al.*	2019	Industry 4.0 technologies, Lean manufacturing practices and Sustainable organizational performance	The indirect effects of Industry 4.0 technologies on Lean manufacturing practices and sustainable organizational performance
12	Kościelniak *et al.*	2019	Sustainable development, Augmented reality and Lean management	The integration of Augmented Reality and Lean culture in the light of a sustainable development management of organizations
13	Kouhizadeh *et al.*	2019	Blockchain technology, Sustainability and Supply chain	The relationship among Blockchain Technology, product deletion and Sustainability
14	Saberi *et al.*	2019	Blockchain technology and Sustainable supply chain	The relationship among Blockchain Technology and sustainable supply chains
15	Tortorella *et al.*	2019	Lean Production, Industry 4.0 and Lean supply chain management	The moderating effect deriving from the introduction of Industry 4.0 technologies on the relationships between Lean supply chain management (LSCM) and supply chain performance improvement in the Brazilian industry
16	Varela *et al.*	2019	Lean Manufacturing, Industry 4.0 and Sustainability	The integration of Lean Manufacturing, Industry 4.0, and Sustainability
17	Asif	2020	Quality management models, Industry 4.0 and Artificial intelligence	The alignment of quality management models with Industry 4.0 technologies
18	Bai and Sarkis	2020	Blockchain technology, Sustainability and Supply Chain Transparency	The role of transparency in the evaluation process of Blockchain Technology
19	Chiarini *et al.*	2020	Industry 4.0, Manufacturing industry and Lean Production	Identification of Industry 4.0 technologies adopted in Italy and investigation on their aim to achieve specific manufacturing strategies

20	Dev *et al.*	2020	Sustainable Reverse Supply Chain, Industry 4.0 and Sustainability	The operational excellence obtained through the integration of Industry 4.0, Reverse logistics and a Lean approach
21	Ghobakhloo	2020	Industry 4.0, Smart manufacturing and Sustainability	Sustainability of Industry 4.0
22	Goienetxea Uriarte *et al.*	2020	Lean Production, Industry 4.0 and Simulation	The integration of Lean management and Simulation as one of the main technologies of Industry 4.0
23	Gonçalves Machado *et al.*	2020	Sustainable manufacturing and Industry 4.0	Impacts of sustainable manufacturing research on Industry 4.0 and the links between the Industry 4.0 and Sustainable Manufacturing
24	Muñoz-Villamizar *et al.*	2020	Lean management, Lean techniques, Industry 4.0 and Efficiency	The integration of existing approaches in Lean Thinking, Industry 4.0 and mathematical optimisation
25	Ramirez-Peña *et al.*	2020	Industry 4.0, Supply chain, Green and Lean approaches	Integration of Industry 4.0 technologies with the most significant supply chain paradigms (Lean, Agile, Resilience and Green) in the shipbuilding sector
26	Sutawijaya and Nawangsari	2020	Industry 4.0, Green paradigm, Supply chain and Sustainability	Impacts of Industry 4.0 on Green supply chain in the event management sector
27	Yadav *et al.*	2020	Sustainable supply chain and Industry 4.0	The development of a framework able to integrate Sustainability and Industry 4.0
28	*Kolberg et al.*	*2015*	Lean automation and Industry 4.0	The integration of Lean Production and its methods with Industry 4.0 technologies
29	*Jayaram*	*2016*	Lean Six Sigma, Industry 4.0 and IoT	The integration of Lean Six Sigma and IoT in Green supply chain management
30	*Karre et al.*	*2017*	Learning Factory, Industry 4.0, Lean Manufacturing and Hands-On Education	The presentation of the LeanLab at Graz University of Technology
31	*Leyh and Schäffer*	*2017*	Industry 4.0 and Lean Production	The integration of Industry 4.0 with Lean Production
32	*Mrugalska and Wyrwicka*	*2017*	Industry 4.0, Lean automation and Lean Production	Identification of how Lean Production and Industry 4.0 coexist
33	*Trstenjak and Cosic*	*2017*	Industry 4.0, process planning and Lean manufacturing	The presentation of the"product planning software"

34	*Wagner et al.*	*2017*	Cyber physical production system, connected industry, Industry 4.0, Lean Production	The integration of Lean Production Systems and Industry 4.0
35	*Duarte and Cruz-Machado*	*2017*	Industry 4.0, Supply Chain Management and Lean/Green paradigms	Investigation whether Industry 4.0 can support the implementation of the lean and green supply chain
36	*Dombrowski et al.*	*2017*	Industry 4.0 and Lean Production Systems	Investigation on interdipendencies between Industry 4.0 and Lean Production Systems
37	*Duarte and Cruz-Machado*	*2018*	Industry 4.0, Supply Chain Management and Lean/Green paradigm	The integration of lean and green supply chain characteristics in Industry 4.0 environment
38	*Enke et al.*	*2018*	Industry 4.0, Lean management and Learning factory	Identification of the required competencies to integrate Industry 4.0 and Lean management
39	*Araújo et al.*	*2018*	Automation, Industry 4.0, Production efficiency and Lean Production	Identification of technological improvements in Lean company processes
40	*Tortorella et al.*	*2018*	Industry 4.0, Lean and Operational performance improvement	The moderating effect of Industry 4.0 on the relationship between Lean Production and operational performance improvement within a developing economy of Brazil
41	*Carvalho et al.*	*2018*	Industry 4.0, CPS and Sustainable manufacturing	Identification of the principal forms of collaboration between Industry 4.0 and Sustainability
42	*Mayr et al.*	*2018*	Lean management, Industry 4.0, CPS and IoT	The integration between Industry 4.0 and Lean management
43	*Phuong and Guidat*	*2018*	Sustainability, Sustainable value stream mapping, Lean manufacturing, Big data, Radiofrequency identification	Sustainability of VSM applied to processes of an apparel company
44	*Duarte, S., et al.*	*2019*	Industry 4.0, Business model, Canvas and Lean/Green management	Integration of lean/green management with Industry 4.0
45	*Saetta, S., et al.*	*2019*	Supply chain management and Industry 4.0	Investigation on how technological innovations introduced achieve economic, social and environmental Sustainability and influence production process in the foundry sector
46	*Müller*	*2019*	Industry 4.0, Industrial Internet of Things, Lean Management and Quality Management	Identification of the potentials on quality management which can be improved with the use of Industry 4.0 technologies

47	*Edirisuriya et al.*	*2019*	Green Concepts, Industry 4.0, Lean Management, Logistics and Operational Performance	Examination of lean techniques and green concepts to enhance the operational performance of logistics functions
48	*Manavalan and Jayakrishna*	*2019*	Sustainable supply chain, Industry 4.0 and IOT	Integration of Industry 4.0 and Sustainability
49	*Surajit and Telukdarie*	*2019*	Business process management, Green manufacturing, Industry 4.0, optimisation, remanufacturing and Reverse Logistics	The impact of Industry 4.0 on green operations and the Institutional pressures
50	*Latinovic et al.*	*2020*	Intelligence system and Industry 4.0	The creation of an intelligent system in the cigarette industry to reduce the machine's failure time
51	*Bittencourt et al.*	*2019*	Lean Production, Lean Thinking, Industry 4.0, Smart Factory and 4th Industrial Revolution	The role of Lean Production in the ongoing 4th Industrial Revolution

Table 4. Reviewed literature. Conference papers are listed in italics from n. 28 to n. 51; "Field of study" concerns the general topic of the paper, identified through keywords; "Object of study" deals with the results and insights after reading the full paper. In addition, it is important to outline that, despite the cut-off point of the current review is intended to be 2011, year of birth of Industry 4.0, only since 2013 works that consider simultaneously Industry 4.0, Lean Production and Sustainability are emerged

1.1 Industry 4.0 and the emerging technologies

The term Industry 4.0 was coined at the Hannover Fair, in 2011. It is used to indicate the Fourth Industrial Revolution (Kagermann et al., 2011). From a historical point of view, three Industrial Revolutions eras can be recognised: the first one, at the end of the 18th century, was characterised by the use of water and steam in the functioning of mechanical production facilities; at the beginning of the 20th century, the second one was featured for the first time by assembly lines, mass production and the use of electricity; in the 1970s, the third one, including the use of electronics and information technology, showed a broad application of digital automation (Nascimento et al., 2018; Horváth and Szabó, 2019).

The Fourth Industrial Revolution, a.k.a. Industry 4.0, is featured by an increasing digitalisation of the entire supply chain and, at a first sight, it seems to be a rebirth of the old idea of computer integrated manufacturing (Kolberg and Zühlke, 2015). Currently, cloud manufacturing, cyber-physical systems, cloud computing, wearable and human-machine interface, internet of things, industrial integration, big data, blockchain, robotics, advanced automation, additive manufacturing, artificial intelligence, digital twins are considered key enabling technologies of Industry 4.0. In Table 5 an overview of the principal technologies of Industry 4.0, found in the sample of analysed papers, and their purpose in the integration of the three selected topics, is presented. In this regard, it is crucial to understand both how new technologies work and how they interact together (Ortt, R. et al., 2020; Zheng et al., 2021).

Industry 4.0 Technologies	**Examples**	**Purpose of Industry 4.0 Technologies in the integration of the three topics (Industry 4.0, Lean Production and Sustainability)**	**References**
Cyber-physical systems (CPS)	Automated systems, control systems of processes and products in real time, Pick-to-light systems, intelligent logistics, intelligent warehousing, Automated Guided Vehicles (AGV), Digital supply chain, Artificial Intelligence (AI)	The main goal is to monitor physical systems while creating a virtual copy. These technologies aim at detecting and eliminating potential 'physical waste' in production processes.	4, 5, 7, 8,10, 11, 16, 17, 19, 21, 32, 33, 34, 36, 41, 42, 47
Cloud computing (CC)	Internet, Smart Factory	These technologies provide online storage services for all applications, programs and data in a virtual server to sustainably achieve the shortest lead time, best quality and value, and highest customer delight at the lowest cost.	1, 4, 5, 7, 11, 16, 17, 19, 21, 23, 25, 32, 33, 34, 36, 42, 47, 49
Internet of Service (IoS)	Internet	Internet of Services derives from the convergence of two concepts: Web 2.0 and SOA - Service-oriented architecture. Its aim is to use software applications which need internet to work. It also improves interactivity, social networks, tagging and web services, improve product customisation and reduce waste.	8, 21
Internet of things (IoT)	RFID, sensors, barcodes, smartphones, intelligent and autonomous machines, wearable computing systems, advanced predictive analytics, machine-human collaboration, machine to machine communication, wireless technologies, IO-Link, Artificial Intelligence (AI)	Information network of physical objects (sensors, machines, cars, buildings, and other items) enables the collection and exchange of data, allowing interaction and cooperation of these objects. This kind of technology helps to increase quality and safety in organizations and can substantially improve energy efficiency, thereby reducing energy costs.	4, 5, 7, 10, 11, 16, 17, 19, 21, 23, 25, 26, 32, 33, 34, 36, 41, 43, 47, 48, 49, 50

Additive manufacturing (AM)	3D printer; Augmented reality (AR), Virtual reality (VR)	This technology consists of a process which joins materials to make objects from 3D model data. The purpose is achieving great potential for mass-customisation. It can improve resource efficiency, enable closed-loop material flows and leverage on product and process design.	4, 5, 6, 7, 8, 10, 11, 16, 17, 19, 20, 21, 23, 25, 42
Big data analytics (BDA)	Predictive analytics	Through the collection and analysis of large amount of available data, these technologies capture and report crucial insights about data processed in high volume and great variety. They can achieve higher environmental performances through waste minimisation, reduction of energy consumption and resource depletion.	4, 7, 8, 9, 10, 11, 17, 19, 21, 23, 25, 34, 36, 42, 43, 47, 48, 49
Simulation and prototype	IP communication protocol, Augmented reality (AR), Virtual reality (VR), Digital twins (DT)	These technologies mirror the physical world data such as machines, products and humans in a virtual world, aiming for simplification and affordability of the design, creation, testing and live operation of the systems. One of the main purposes of these technologies, recognised in literature, concerns elimination of waste and reduction of production losses.	4, 7, 11, 12, 17, 19, 21, 22, 23, 25, 32, 34, 36, 42, 47
Robotic systems (RS)	Robots, Collaborative robots, Smart robots	Machinery and equipment that automate operational processes, containing also Collaborative Robotics, which allows humans and machines to operate in a shared learning environment play a crucial positive economic and environmental effect. Robotic systems reduce lead time, enhance productivity, improve recycling, reduce carbon footprint and make manufacturing more sustainable.	4, 10, 11, 16, 17, 19, 23, 25, 47
Cyber security systems (CSS)	Internet	These technologies are security risk assessment tools with the aim of defending computers, servers, mobile devices, electronic systems, networks, and data from malicious attacks. Such tools can improve energy profitability performance and secure and speed up processes.	4, 7, 11, 23, 25

Blockchain (BC)	Internet	It consists of a database that creates a distributed digital ledger of transactions, including timestamps of blocks maintained by every participating node. It can provide benefits to larger manufacturers looking to improve their Lean operations and reduce waste. It helps risk reduction thanks to a complete tracking of every single activity which is constantly verifiable and controllable.	8, 13, 14, 18
Artificial intelligence (AI) and Machine learning (ML)	Internet	These technologies are able to analyse specific data and accurately predict the expected output, thus eliminating exorbitant material use or waste. Through its deep predictive capabilities and intelligent grid systems AI and ML can manage the demand and supply of renewable energy, optimise efficiency, cut costs and contribute to the reduction of carbon pollution.	17, 42

Table 5. Overview of Industry 4.0 emerging technologies. Overview of Industry 4.0 emerging technologies (numbers in the column "References" identify Authors listed in Table 4). In this Table is also highlighted the purpose of technologies in the integration of the three topics, Industry 4.0, Lean Production and Sustainability

It is still controversial what technologies belong to Industry 4.0 (Dombrowski and Krenkel, 2017; Wagner et al., 2017; de Sousa Jabbour et al., 2018; Horváth and Szabó, 2019). Indeed, it is argued that there is not a universal definition of Industry 4.0 (Leyh and Schäffer, 2017). This could be probably because the term 'industry' incorporates several engineering and business disciplines, not only manufacturing (Ortt, R. et al., 2020). On the other hand, Nosalska et al., 2019 elaborated a punctual overview of the various definitions of Industry 4.0 and, stated that Industry 4.0 is a "*multidimensional system of value creation*". The paradigm of Industry 4.0 relies on advanced technological innovations in order to link their physical and virtual sides. This continuous interaction takes place in different ways and is defined as horizontal, end-to-end or vertical depending on the interplay among machines, humans or among humans and machines (Kamble et al., 2018; Nascimento et al. 2018).

Industry 4.0 technologies help manufacturing industries to improve work environment, employee morale and product quality. New technologies can increase safety in work environments through the implementation of cutting-edge product planning softwares to minimise human errors and contribute to the creation of new professions such as the process planner (Trstenjak and Cosic, 2017). Besides, through the individualisation of customers' needs, creation of customised products, improvement on productivity and reduction of lead time are fostered (Jayaram, 2016; Duarte and Cruz-Machado, 2017; Kamble et al., 2018; Muller, 2019; Latinovic et al., 2020). Mrugalska and Wyrwicka (2017) add emerging technology, as a competitive strategy, optimise value chains. Some authors have also underlined the importance of implementing specific technologies in companies, such as artificial intelligence, big data, and robotics, to reach the goal of smart manufacturing, improve quality standards and increase productivity (Gupta et al., 2019; Asif, 2020).

1.1.1 Industry 4.0 and Lean Production

Lean Production is a management model and a strategic factor in the development of production processes (Fullerton et al., 2003; Simpson and Power, 2005; Shah and Ward, 2007). It is based on the principles presented by the Toyota Production System and implies "*doing more with less*" (Holweg, 2007). Lean Production model adopts practices such as *Kanban*, a type of scheduling system, and Just-In-Time, to minimise waste and improve a company's performance (Womack *et al*., 1990; Duarte and Cruz-Machado, 2018). Chiarini et al., 2020 add that Lean Production acts as an enabler of Industry 4.0 technologies, only if, previous defects in process flows are eliminated.

Industry 4.0 is a complementary environment to Lean Production so that, they can support and enhance each other (Kamble et al., 2018; Chiarini et al., 2020). In this regard, Leyh and Schäffer (2017) assume that both the emerging technologies and Lean Production have as common goals the reduction of the cost per unit produced and the improvement of communication in three relationships: man-man, machine-man and, above all, machine-machine for the further development and appropriate implementation of Industry 4.0. Practical examples of the beneficial implementation of system automatisation, through advanced technologies and Lean Production are shown in some of the collected studies.

These studies provide lean digital tools such as a product planning software (Trstenjak and Cosic, 2017), an intelligent and automated system (Araújo et al., 2018) and, a technological tool in the foundry sector (Saetta and Caldarelli, 2020) that through the simultaneous adoption of Lean Production techniques and technological devices help companies to improve their production processes in terms of cost containment, lead time and quality. Other authors offer empirical evidence on the beneficial effects of this integration through a detailed survey among Brazilian manufacturing companies. They assess the operational performance improvement through ordinary least squares regression method (Tortorella et al., 2018) and provide a framework in which Lean Production techniques are combined in a Canvas business model (Duarte et al., 2019).

Literature review reveals that the integrated application of Lean Production and Industry 4.0 has been an effective business strategy to reach higher levels of operational excellence. In this regard, Tortorella et al. (2019) empirically confirm the adoption of emerging technologies, in Brazil, can be assumed as a moderating variable with direct effects on lean supply chain performances.

1.1.2 Industry 4.0 and Sustainability

Sustainability has become paramount in smart manufacturing (Kusiak, 2017). According to the definition provided in the Brundtland report (1987), '*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' in its three dimensions, environmental, economic and social*'. Elkington (1998) first introduced the concept of Triple Bottom Line, that implies creating value added activities in economic, environmental, and social perspectives. On the other hand, the European Union (EU) encourages the transition towards Sustainability with measures to reduce the consumption of raw materials, reduce waste and increase the reuse of resources. This would make our economy more sustainable, increase innovation and sustainable development through sustainability of operations. Van Buren et al., (2016), Potting et al., (2017) and Kirchherr et al., (2017) argued this would be the right path to follow in order to decrease depletion of resources, energy consumption, create value added, closed-loop supply chain and reduce waste.

According to Cherrafi et al. (2017), achieving Sustainability has become crucial for companies as they are increasingly facing pressures from customers, policymakers and other stakeholders in this direction. Thus, such a more sustainable transition in operations can help companies to develop products and processes aligned with stakeholders' expectations (Zhan et al., 2016). For this reason, Sustainability has emerged as a conceptual paradigm and an operational approach for organisations to optimise sustainability of their operations through a reduction of waste and a minimisation of the negative impacts on the environment of their products and services.

Several studies confirm the implementation of new technologies in a sustainable perspective can lead firms towards greener operations, better operational performances and significant economic, social and environmentally-friendly advantages (Surajit and Telukdarie, 2018; de Sousa Jabbour et al., 2018; Nascimento et al., 2018; Farooque et al., 2019; Manavalan and Jayakrishna, 2019; Dev et al., 2020; Yadav et al., 2020). In this regard, Nascimento *et al.* (2018) propose a model in which electronic waste is recycled through 3D printing, one of the most flexible technologies, and Reverse Logistics of materials. Therefore, in this way this sustainable supply chain would result in the enhancement of the Overall Equipment Effectiveness, a reduction of negative environmental impacts, resource consumption and creation of specialised local jobs.

In support of this, Ghobakhloo (2020) remarks that the most direct outcomes deriving from the interaction of Industry 4.0 and Sustainability are related to production efficiency and, in particular, lay the groundwork for business model innovation.

It is also highlighted that implementation of new technologies in industrial processes is different between small or medium-sized companies and bigger ones. The former consider one of the most powerful drivers for integration cost saving (Ioppolo et al., 2014; Horváth et al., 2019), whereas, according to the latter, customers' targets, consisting in environmental safeguards and in a responsible environmental protection, are crucial. In this sense, Horváth et al. (2019), conducted a study in the Hungarian ecosystem and realised that small and medium-sized companies are generally less ready to implement new technologies in contrast to multinational enterprises which invest in new technologies much easier.

However, some studies also measure sustainable impacts and improvements through empirical methods. For example, Kamble et al. (2019) empirically demonstrate that the implementation of the emerging technologies in Indian manufacturing organisations is strongly related to sustainable organisational performances. Similarly, Varela et al. (2019) adopt a Structural Equation Model to prove the beneficial connection between emerging technologies and Sustainability in a sample of companies in the Iberian Peninsula.

1.1.3 Industry 4.0, Lean Production and Sustainability

Matching these three concepts, it can be affirmed they holistically accomplish their common goal of improving production processes, quality, design, flexibility, product customisation, transparency, interoperability, reduction of complexity, waste, lead time, costs and increase in efficiency and productivity (Garay-Rondero et al., 2019; Kamble et al., 2019; Ramirez-Pena et al., 2020; Sutawijaya and Nawangsari, 2020).

Through this interaction, it is possible monitoring in real-time the operation phase and obtaining a reduction of resource depletion, economic costs, and human errors (Peralta-Álvarez et al., 2017). Over the past years, it has often been recognised that information technology and lean methodologies may influence companies both at individual level, motivating employees towards more sustainable goals and, at business level, through more sustainable decision-making solutions (Sarkis et al., 2013). Furthermore, the evolution of the Enterprise Resource Planning system led to its integration with green information systems and information technology. According to Sarkis et al. (2013), Cloud Computing is one of the greener technologies to be adopted to reduce dispersion of data, maximise production and reduce waste.

Duarte and Cruz-Machado (2017) add that lean and sustainable approaches jointly aspire to improve Industry 4.0 features such as flexibility, transparency, and optimisation of company's functions. In other words, the implementation of lean-digitised manufacturing systems is the most suitable corporate strategy to keep up with competitiveness in a sustainable perspective. It is shown that the integration of emerging technologies and lean techniques, despite costly, can strongly support internal processes such as Just-in-Time, supplier relationship management, customer relationship management and enhance environmental sustainability (Ghobakhloo and Fathi, 2020).

Similarly, Ioppolo et al. (2014) assume that Lean Production is not a mere set of tools but, a "*modus operandi and a mindset*" that has to be implemented into production systems in order to achieve Sustainability. The jointly implementation of Lean Production techniques and emerging technologies results in the creation of a system which works as a "*catalyst*" to facilitate environmental sustainability (Edirisuriya et al., 2018).

Industry 4.0, Lean Production and Sustainability were found to share the same goals because they are focused on the improvement of quality and the satisfaction of consumer's needs even though they present different operative approaches (Farooque et al*.,* 2019; Ghobakhloo, 2020).

Lean Production aims at the elimination of waste, satisfaction of customer needs, generation of value and value flows, striving for perfection, ensuring reliability, in all phases of the production process, and continuous improvement (Kaizen) (Ghobakhloo and Fathi, 2019; Gonçalves Machado et al., 2020).

Industry 4.0 reaches these goals by improving process performances through the integrated use of smart technologies (Asif, 2020).

Similarly, Sustainability is focused on the same goals through the reduction of resource depletion, energy consumption and waste stream valorisation (Nascimento et al., 2018).

According to Porter's seminal article in 1996 "What Is Strategy?", strategy "*is about being different*" and "*the essence of strategy is choosing a unique and valuable position rooted in systems of activities that are much more difficult to match.*" In this perspective, Sustainability has to be intended as a strategy which adopts Circular Economy as a precondition for sustainable manufacturing. This can be achieved through the implementation of the 10 R's, ten key circular economy principles (Rashid et al., 2013; Geissdoerfer et al., 2017).

Thus, Industry 4.0 becomes an integrated environment of smart technologies able to act as a facilitator towards the achievement of sustainable goals tracking products post-consumption in order to recover components (Dombrowski et al., 2017; Wagner et al., 2017; Lopes de Sousa Jabbour et al., 2018; Carvalho et al., 2018; Gonçalves Machado et al., 2020).

In addition, at the intersection with Lean methodologies and Sustainability, Industry 4.0 technologies are also a propulsive force of this new paradigm and a key element to shift companies towards a cutting edge and sustainable business model (Nascimento et al., 2018; Surajit and Telukdarie, 2018; Farooque et al., 2019; Dev et al., 2020; Ghobakhloo, 2020).

1.1.4 Analysis

Literature review highlights that out of 51 examined scientific articles, only 11 effectively tackle the topic on the relationships among Industry 4.0, Lean Production and

Sustainability (Sarkis et al., 2013; Peralta Álvarez et al., 2017; Kamble et al., 2018; Lopes de Sousa Jabbour et al., 2018; Ghobakhloo et al., 2019; Kamble et al., 2019; Varela et al., 2019; Chiarini et al., 2020; Ghobakhloo, 2020; Gonçalves Machado et al., 2020; Phuong and Guidat, 2018).

Pagliosa et al., (2019) conducted a systematic literature review. They identified and categorised only 9 studies concerning Industry 4.0 technologies and 14 on the combination between Lean Production methodologies and the emerging technologies. These authors declared the necessity for further investigation on the relationship among these topics and Sustainability. Likewise, Buer et al., (2018), despite recognizing that both Industry 4.0 and Lean manufacturing are focused on the increase of productivity and flexibility, affirmed that there are few studies investigating the link between these two domains.

Furthermore, Ghobakhloo et. al., (2021) confirmed the need for a better understanding on the relationships among Industry 4.0, Lean Production and Sustainability. In this regard, a potential reason for this lack of investigation was identified in the fact that a unified concept of Industry 4.0 is still missing (Zheng et al., 2020).

These three topics, if applied simultaneously, as suggested by the trend identified in this research, can lead to the actual and effective achievement of sustainable goals, economic, environmental and social. Sarkis et al., (2013) affirmed that Lean manufacturing and Industry 4.0 technologies, such as Cloud Computing, could lead to a potential reduction in worldwide data centre of energy dissipation, better operational performances, safety in industrial processes and reduced costs. This integration may also contribute to the maximisation of power usage efficiency, improvement of recycling efforts, reduction of carbon and gas emissions, minimisation of water usage, reduction of wastes, lead time and enhancement of customisation. In this sense, Industry 4.0 represents a smart integrated environment where the adoption of Lean Production methodologies can give rise to a sustainable transition, as claimed in 2030 Agenda by United Nations (UN) in 2015. Awan et al., (2021) argued such an implementation of a digitalised, lean, closed-loop production system can lead companies towards the development of a more sustainable business model.

According to Amjad et al. (2019), cyber-physical systems with monitorisation in real-time during the operation phase can provide feedbacks about processes and help the reduction of material consumption, minimisation of human errors and the increase of worker's safety and autonomy.

In addition, they can improve scheduling, reducing economic costs, environmental damage, and worker negative impact. Lean tools and new technologies, implemented together, in a sustainable perspective, enhance performance, increase productivity, quality and gain a competitive edge (Abualfaraa et al., 2020).

In this regard, Kang et al., (2016) affirm the future is Smart Manufacturing, which is considered the 'fourth revolution' in the manufacturing industry and, is seen as a new paradigm, consisting of in real time technologies that contribute to effective decision-making. Smart Manufacturing is addressed as the future growth engine for companies that will be focused on a sustainable growth through improvement of productivity, quality, delivery, and flexibility based on technology. Furthermore, considering the interaction of emerging technologies with Lean Production techniques and Sustainability, holistically, this integration could create value chain and competitiveness and could be a challenge for future supply chain in terms of economic, environmental, and social improvements (Kusiak, 2017; Luthra et al., 2019).

On the other hand, some drawbacks are also highlighted. The debate on the emerging technologies connected to Lean Production and Sustainability could also lead to unfavourable results. It is noteworthy an ongoing discussion on the potential negative effects of lean models in sustainable logistics (Garza-Reyes et al., 2016) and, the impact of cloud computing models on energy consumption (Chen et al., 2012; Hassini et al., 2012; Kong et al., 2018; Ouammou et al., 2018) which cannot be glossed over.

Although Industry 4.0 technologies adoption has taken on greater importance and visibility (Luthra and Mangla, 2018; de Sousa Jabbour et al., 2018; Kiel et al., 2017), these technologies implications on sustainability objectives need to be cautiously evaluated (Bai and Sarkis, 2020).

Traditional production systems are known for their poor ecological disproportions (Bai et al., 2020). Higher resources consumption, global warming, general environmental degradation, and higher environmental pollution are observable in traditional manufacturing systems and technologies (Tseng et al., 2018; Griggs et al., 2013).

Thus, the elimination of wastes implies the adoption of eco-design and eco-innovation (Awan et al., 2021).

Based on the results of the literature review, a conceptual integrated framework is elaborated (Figure 16).

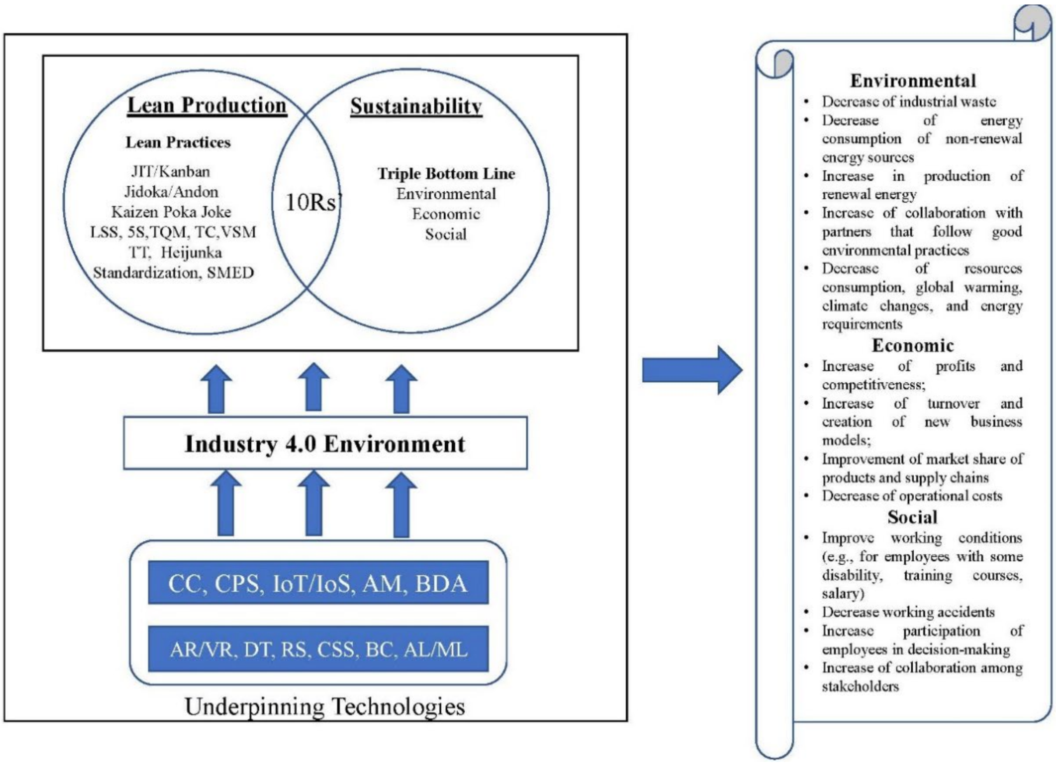

Figure 16. The conceptual framework of the integration among Industry 4.0, Lean Production and Sustainability. The 10 Rs' principles consist of ten stages, namely Refuse; Rethink; Reduce; Reuse; Repair; Refurbish; Remanufacture; Repurpose; Recycle; Recover and it is applied to Lean methods in an Industry 4.0 environment. Acronyms of underpinning technologies are explained in Table 5. Examples of Lean techniques mentioned are: Just In Time, Kanban, Jidoka, Andon, Kaizen, Poka Joke, Lean Six Sigma, 5 S methodology, Total Quality Management, Target costing, Value Stream Mapping, Takt Time, Hejiunka, Standardisation, Single Minute Exchange of Dies.

The proposed framework outlines that Industry 4.0 facilitates production processes through cyber-physical integration of connected elements. Moreover, it highlights that adopting lean methodologies makes the manufacturing system more agile, cost-effective, and environmentally-friendly (Kamble et al., 2018; Ghobakhloo et al., 2021). The framework also acknowledges the effective role of Industry 4.0 technologies in the accomplishment of the whole process integration.

Emerging technologies boost lean methodologies capability to achieve sustainable goals through the 10R's framework, (Refuse; Rethink; Reduce; Reuse; Repair; Refurbish; Remanufacture; Repurpose; Recycle; Recover), considered as a robust sustainability paradigm (Maldonado-Guzmán et al., 2020). In the proposed framework, all the three pillars of Sustainability are addressed and economic, environmental, social and operational impacts deriving from the interaction among Industry 4.0, Lean Production and Sustainability are highlighted (Pagliosa et al., 2019; Awan et al., 2021; Kamble et al., 2018; Kusiak, 2017).

From an economic point of view, this interaction may lead to an increase of profits, efficiency, flexibility, and competitiveness; increase of turnover, and creation of new business models; improvement of market share of the products, supply chains and security and a decrease of operational costs and massive savings for companies (Müller et al., 2018; de Sousa Jabbour et al., 2017). Furthemore, the adoption of such an integrated system would also imply environmental effects such as a decrease of industrial waste, energy consumption of non-renewal energy sources; increase of production of renewal energy; increase of circular economy practices comprising collaborations with partners that follow good environmental ones; decrease of resources consumption, global warming, climate changes, and energy requirements; increase of renewable resources (Lund and Mathiesen, 2009; Shrouf et al., 2014).

In addition, some social impacts could be recognised, such as an improvement of working conditions (e.g., for employees with some disability, training courses, salary); a decrease of working accidents and an increase of participation of employees in decision-making (Jabbour, et al., 2012).

Finally, operational effects, such as improvement of process performances and management performances; improvement of the Overall Equipment Effectiveness; reduction of lead time and delivery time; improvement of quality; pursuit of perfection, value generation, satisfaction of customer's needs, continuous improvement and guarantee of reliability are identified (Duarte and Cruz-Machado, 2017).

Following these recommendations, managers may be helped to simplify production processes, decision-makers may elaborate more straightforward rules for sustainable growth and scholars may develop further research rethinking the role of new technologies in connection with Lean production and Sustainability (Ghobakhloo et al., 2021; Kamble et al., 2020).

In this regard, Luthra *et al.,* (2019) underlined that Industry 4.0 has the potential to contribute to an environmental-economic-social sustainability.

The concept of functional economy elaborated by Stahel (1997) based on the optimisation of goods and services would be accomplished with the implementation of more sustainable process flows. Industry 4.0 has the potential to enhance global manufacturing to meet the rising human needs without hurting the environment. In other words, it can make the world more sustainable, taking into account eco-innovation and eco-design of products and technologies (Sumrin et al., 2021).

To sum up, managers, end-users and policy-makers are called to adopt Industry 4.0 technologies, Lean Production methodologies in a sustainable dimension to reduce costs, lead times and minimise wastes.

It can be affirmed that Industry 4.0 has launched a lean and sustainable system, where Industry 4.0 technologies become a leading force and a vector with the application of Lean Production methodologies in a sustainable perspective. Industry 4.0 can be viewed as a productive formula which introduces innovation and represents the new bridge between human and machine interactions; Lean production becomes a productive management model that is enhanced by emerging technologies and, at the same time, improve production processes; and, Sustainability is found to be a productive competitive strategy to pursue.

Therefore, theoretical contributions on the interrelations among Industry 4.0, Lean Production and Sustainability concern the deeper analysis of their main characteristics and applications, the identification of similarities and differences among them and their theorisation in a potential integrated development. Indeed, the proposed framework can be considered a preliminary step to contribute to a better understanding of the topic.

This smart structure provides the basis for a lean and sustainable system that gives rise to favourable outcomes. The framework will guide practitioners towards a sustainable technological environmental transition and policy-makers to develop appropriate guidelines. The study may also be the starting point for further research to evaluate impacts of Industry 4.0 technologies, Lean Production methodologies and Sustainability.

For what concerns practical implications, the study suggests how a simultaneous implementation of Industry 4.0 technologies, Lean Production methodologies and Sustainability results in many economic, social, environmental, and operational effects. This implies that practitioners will be pushed to adopt such frameworks to have a better industrial control on production processes, increase agility of their organisations, make in-real-time decisions, save money, offer highly customised products in shorter lead times and reduce waste.

According to Kamble, Gunasekaran, and Gawankar (2018) practitioners should focus on obtaining ever higher levels of process integration by collocating appropriate Industry 4.0 technologies efficiently in the interaction between cyber-physical systems and human-machine interface.

Furthermore, managers should strive to achieve a higher environmental respect with an efficient use of available resources and a reduction of energy consumption. Therefore, they should not get unmotivated in adopting Industry 4.0 technologies. Indeed, they should work hard to reach a smarter and more sustainable system in their companies through the simultaneous implementation of emerging technologies, Lean Production methodologies and Sustainability, to be intended as a competitive business strategy.

1.2 Cross-sectional Analysis

Pollution, and the limited availability of natural resources to satisfy people's needs are causing increasingly alarming pressure upon the global ecosystem and, at the same time, dramatically determine different impacts on the costs of material and energy commodities and on the volatility of their market prices. Here emerges a critical condition to be managed by any companies involved in planning and programming of the materials, energies, and fuels flowing throughout its productive system. In this competitive business scenario, the next question arises as to whether it is possible or even necessary to manage the adverse effects of consumption of unsustainable resources and production models.

The concept of sustainable production is not so new and dates back to quite some time by now.

It was, indeed, Elkington (1994, 1998a, b) - one of the first scientists encouraging companies to reconsider their value creation activities in a multidimensional perspective, that integrates economic aspects, e.g. profit, revenues, and economic returns on capital invested, that are a classic in the economic management of industries, with the environmental and social dimensions in an integrated framework called "Triple Bottom Line" (TBL). Sustainability exists only when those three dimensions are holistically accomplished. In this sense, companies should carry out environmental life-cycle and socio-economic assessments of their production systems, according to the TBL model.

Doing so, this will allow them to improve the quality and Sustainability of products they deliver and, in turn, of the downstream phases in which those products are utilised to produce more complex commodities, in an industrial symbiosis perspective. However, even today, companies have difficulty in having a clear and complete vision of the impact of their sustainable policies and strategies because there is no single and universal standard for calculating TBL performance (Helleno et al., 2017; Henao et al., 2019; Slaper and Hall, 2011).

In the last decade, in March 2010, the European Commission presented its "Europe 2020" strategy, with the main aim of putting an end to the excessive exploitation of natural resources, and to the disparity in the availability of those resources in different geographical areas. "Europe 2020" was a ten-year strategic plan aimed at a structural transformation of the economic system and capable of facing the European economic crisis (European Commission, 2010).

Later, between 25th-27th September 2015, the platform "Transforming our world: the 2030 Agenda for sustainable development", was launched for the creation of a global action to favour sustainable development for people and the entire planet, while assuring the necessary prosperity conditions. This is also known as the "3P Agenda" and represents the document adopted by the Heads of State and Government which establish the commitments for sustainable development to be achieved by 2030, identifying 17 goals (SDGs) and 169 related targets (United Nation, 2015).

In recent years, sustainable production has been strongly linked to Circular Economy (CE) principles which have taken a guiding role for the formulation of sustainable policies. According to Geng et al. (2008), this concept brings together different strategies and approaches aimed at:

• increasing economic efficiency;
• adding value to businesses by maximising energy, materials and other resources;
• reducing the environmental impact of anthropic activities (in terms of exploitation of resources and emission of pollutants).

Circular Economy can be considered as an industrial economy that is oriented to Sustainability (Ghisellini et al., 2016). Several key actions aimed at improving the economic and environmental performance of used resources are related to introducing Circular Economy on an industrial scale through adoption of closed loops for valorisation of wastes and their recovery into material and energy commodities (Kalmykova et al., 2017).

Indeed, Industry 4.0 represents the manufacturing scenario where various sustainable production strategies are being developed.

The manufacturing sector plays multiple key roles, from introducing innovation in production process and in terms of new or improved products, to the change in knowledge, job skills, market/consumer behaviours, as well as in worldwide adoption and promotion of sustainable production strategies and practices (Tan et al., 2011; Shankar et al., 2017). The concept of Sustainability - expressed in the production model - incorporates objectives such as the reduction of consumption of resources and energy, selection of production processes with low environmental impact and the development of eco-friendly products (Schrader and Thøgersen, 2011; Govindan et al., 2015).

In order to summarise the definitions elaborated by the notable scholars, a table has been built, in which definitions of Circular Economy, Lean Production, Industry 4.0, Reverse Logistics and Sustainable Lean Production are gathered.

Topic	Definition	Reference
Circular Economy	CE implies the implementation of closed loops of materials that generates the achievement of an increased economic efficiency, adds value to businesses and reduces the environmental impact.	Geng et al., 2008
	By considering CE as closed-loop supply chains, it has to be viewed as an innovative path to create value over the whole life cycle of the product. Furthermore, reverse logistics processes, through redesigning and dematerializing of products, valorize process flows.	Guide et al., 2009
	CE is focused on the redefinition of growth. It implies the decoupling of economic activity from the consumption of finite resources.	Ellen MacArthur Foundation, Circular Economy Overview, 2013
Circular Economy	CE is a way to optimize the use of resources, add value and regenerate wastes, increase both corporate and consumers responsability. In other words, it accomplishes the goal of sustainability.	Ghisellini et al., 2016

	The CE notion embraces optimization of natural resources, reusing and recycling them in production processes, eco-design of products, waste minimization and the extension of their end of life.	Kalmykova et al., 2017
	CE concept concerns an "*economic system that replaces the concept of "end of life" with the reduction, reuse, recycling and recovery of materials in the production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim of achieving sustainable development, simultaneously creating environmental quality, economic prosperity and social equity, for the benefit of current generations and future. It is empowered by new business models and responsible consumers.*"	Kirchherr et al., 2017
	The incipit of the European «Circular Economy Action Plan» states that «*Building on the single market and the potential of digital technologies, the circular economy can strengthen the EU's industrial base and **foster business creation** and entrepreneurship among SMEs. Innovative models based on a closer relationship with customers, **mass customisation**, the **sharing and collaborative economy**, and powered by **digital technologies**, such as the internet of things, big data, blockchain and artificial intelligence, will not only accelerate circularity but also the **dematerialisation** of our economy and make Europe **less dependent on primary materials***».	European Commission, 2010. Europe 2020: A strategy for smart, sustainable and inclusive growth.
	CE can be considered as an enabler of economic, environmental, societal benefits. This is due to the adoption of recovery, reuse, recycling, sharing and collaboration practices which redefine the corporate business model.	Moktadir et al., 2020
Lean production	The definition of LP evolved through three stages. In the first one, it was considered a set of tools (like Kanban; in the second one, a manufacturing method (like JIT); in the third, it is assumed to be a general management philosophy based on the reduction of wastes and lead times.	Koskela, 1992

	Lean production is a strategy based on 5 key elements, value, value flow, flow, pull and perfection. It aims at the elimination of waste, satisfaction of customer needs, generation of value and value flows, striving for excellence, guarantee of reliability in all production phases and continuous improvement in all processes	Womack and Jones, 1996
	The concept of LP is intended as Lean transformation and means to do more with less. For the first time, beside the eight wastes (defects, excess processing, overproduction, waiting, inventory, transportation, motion and non utilized talent), energy is addressed as the nineth waste.	Sciortino et al., 2009
	LP is based on Toyota Production System principles and is a strategy or philosophy that aims at minimizing waste and improving the company's performance.	Ioppolo et al., 2014
	LP paradigm is a management approach that focuses on the elimination of wastes and the improvement of production and quality.	Taddeo et al. 2019
Industry 4.0	Industry 4.0 contribute to forecast customer requests and manage the entire supply chain. Technological innovation has a key role in developing competitive companies' skills to remain on the market.	Flint et al., 2005
	Industry 4.0 has tremendous potential. It enables dynamic businesses and flexible engineering processes. New technologies gain continuous resource productivity and efficiency, help to manage complexity and provide and guarantee transparency.	Kagermann et al., 2013
	Industry 4.0 represents the fourth industrial revolution and has significant impact on the production and operation management. In fact, it allows real-time planning of production plans and focuses on their optimization and flexibility.	Sanders et al., 2016
	Industry 4.0 provides in depth analysis of autonomous systems and cutting-edge design of human-machine interactions.	Klumpp, 2017
Industry 4.0	Industry 4.0 represents an integrated system of information and knowledge that improves productivity, enables sustainability and optimizes management of process flows.	Garcia-Muiña et al., 2019
	Industry 4.0 entails digital transformation of companies and end user market.	Ghobakhloo, 2020
Sustainable Lean production	“Green” or sustainable supply chain operate in sociotechnical systems. To evaluate their positive impacts and sustainability transition, they need to be empirically assessed.	Papachristos, 2014

	The implementation of sustainability in supply chain management plays a key role in keeping up with corporate competitiveness. Furthermore, the integration of a lean approach could contribute to the competitive advantage of companies.	Brandenburg et al., 2015
	The implementation of sustainability principles in LP leads to an environmental improvement in enterprises process flows. SLP is the result of interaction between lean principles and sustainability paradigm.	Zhang et al., 2020
	A SLP featured as lean-green manufacturing is a new practice that lack a clear research definition. Despite this, there is unanimous consensus on the fact that a lean-green approach improves performances in the Triple Bottom Line perspective simultaneously.	Abualfaraa et al., 2020
Reverse Logistics	RL succeeds in achieving the minimization of waste through eco-effectiveness and "cradle to cradle" design of products.	Braungart et al., 2007
	In RL waste is reintroduced into the same or another production cycle as a second raw material to create regenerative and circular systems.	Howard et al., 2018
	RL implies recovery operations and plays a key role in the sustainability paradigm. It includes measuring environmental impacts in order to minimize waste and reduce the use of energy in distribution strategies. RL should be focused on circular supply chain designed in such a way to restore and regenerate resources in industrial process flows and produce zero waste.	Farooque et al., 2019
	RL is perceived as an environmentally friendly practice. It is due to the outstanding reduction of sourcing costs of used materials in comparison with new ones.	Pushpamali et al., 2020

Table 6. Circular Economy, Lean Production, Industry 4.0, Reverse Logistics (RL) and Sustainable Lean Production (SLP) (definitions, extracted from the reference list)

It is crucial to highlight that Sustainable Production promotes Sustainability throughout the supply chain and, through the launch of sustainable products, the development of a community of sustainability-oriented end users (Smith and Ball, 2012; Gupta 2016; Gupta et al., 2016) that could be representatives of a new socio-technical system, becoming the leading infrastructure to support a green interaction between people and technology (Geels, 2011). Governments around the world promote financial and tax initiatives to accelerate the transition towards sustainable production practices and, subsequently, to favor increase of global growth and competitiveness (Sheldon, 2014; Moktadir et al., 2018).

Indeed, promoting industrial-scale sustainability has become a central goal for national governments worldwide. In this regard, managers are facing the one big challenge to expand the concept of Circular Economy to productive company networks, so contributing to creating efficient interconnection models within a symbiotic industrial ecosystem and optimising the market supply with a sustainable orientation of economies of scale (Simboli et al., 2015).

It is essential to consider that policies supporting the development of industrial sustainability must necessarily combine certain aspects of sustainable production that relate to different European strategies, e.g., Horizon 2020, the 9th Framework Program-FP9 and other sectoral policies (European Parliament and Council of the EU, 2019).

Therefore, the implementation of adequate governmental policies plays a strategic role as a support to eco-innovation, promoting continuous pro-active collaborations between industrial companies (Aquilani et al., 2017).

In the last decade, the new vision of sustainability is represented and developed through the "circular economy" (Ellen MacArthur Foundation 2013a; b; c). Starting from the concept of closed loop, based upon the "cradle-to-cradle" approach, Andersen (2007) proposed the first scientific study to attempt defining the Circular Economy, through an analysis of the main principles and approaches that integrate environmental economics and Sustainability. Specifically, from the policy maker's point of view, the first environmental policies that formally introduced the Circular Economy on a national scale were the Japanese and Chinese ones (Flynn et al., 2019). Then, it was the European Union's turn with countries like Denmark, Germany, the Netherlands and United Kingdom setting relevant initiatives, policies and guidelines to introduce the Circular Economy principles on the productive and societal system (McDowall et al., 2017; Reike et al., 2018).

In December 2019, European Commission launched the "Green New Deal" challenge, through an investment plan, which aims at an ecological transition model that sees the whole of Europe taking leadership roles. The goal is to become the first climate-neutral continent by 2050, supporting the competitiveness and sustainability of European industry towards an ecologically and socially equitable transition. In particular, with the New Circular Economy Action Plan, European Commission proposed a plan to shift towards a transformation of products, using a sustainable way to make it and empowering consumers. The new proposal actually seeks to leverage on sectors considered strategic in the first Action Plan, such as batteries and vehicles, electronics and plastic, extending the priority to new sectors, e.g. textiles, construction and buildings and food. Therefore, attention is focused not only on the final phase of the production system, which concerns waste management, but on the pre-production related to design and in particular eco-design (European Commission 2020).

Industry 4.0 (I. 4.0) represents the new bridge between human and machine interactions; named also the "the fourth industrial revolution", I. 4.0 is a smart manufacturing environment based on cyber-physical systems, that combines technologies, IoT solutions within a powerful horizontal and vertical system integration model. In this regard, the Internet of Things (IoT) embraces organisations in an intelligent environment. The technology backbone involves key elements as additive manufacturing, augmented reality, big data and analytics, cybersecurity and cloud computing.

At the same time, I. 4.0 incorporates and enhances sustainability performances (Ghobakhloo, 2020). The approaches adopted by I. 4.0 allow the linkage between Sustainable Production and Circular Economy, demonstrating a certain complementarity; indeed I. 4.0 could be considered as a synergic environment essential to achieve holistic, integrated sustainability in production systems.

Many studies in literature have indicated Circular Economy and I. 4.0 as the future of the organisations (Zhong et al., 2017; Yadav et al., 2020; Kristoffersen et al., 2020).

Furthermore, their interaction is catching the attention of different topics from strategic management to technological and operations management. The reason lays in the fact that companies need to re-design their business model focused on their sustainable development (Centobelli et al., 2020). In this regard, such a closed-loop production systems can be improved through the implementation of I.4.0 technologies (Awan et al., 2021). Thus, elaborating such a circular economy based business model, would mean to try to fill the existing gap in literature regarding the possibility to adopt circular economy principles for building new business models as a strategic management tool (Lüdeke-Freund et al., 2018).

To better explore the mainframe of the sustainable production, it is first necessary to highlight the circular economy principles, recognizing the complex concept and main aspects covered by the meaning of Circular Economy.

Guide and Van Wassenhove (2009) defined closed-loop supply chain as: “the design, control and operation of a system to maximise the creation of value during the entire life cycle of a product with dynamic recovery of value from different types and volumes of returns over time”. In this regard, some researchers have compared these loops with manufacturing metabolism (McDonough and Braungart, 2002; Ellen McArthur Foundation, 2013 a, b, c). Moreover, thanks to Kirchherr et al. (2017), a clear definition of Circular Economy exists today and that is “economic system that replaces the concept of “end of life” with the reduction, reuse, recycling and recovery of materials in the production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso-level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim of achieving sustainable development, simultaneously creating environmental quality, economic prosperity and social equity, for the benefit of current generations and future. It is empowered by new business models and responsible consumers.”

To sum up, Circular Economy re-evaluates the concept of waste in economic and environmental terms, reconsidering all phases of the production chain. In this way, closed flows of recycled resources can be designed through a circular economy principles-based value chain.

Hence, circular economy can be considered as generating economic, environmental, societal benefits that results from adopting recovery, reuse, recycling, sharing and collaboration practices which redefine the corporate business model (Moktadir et al., 2020). These results are beneficial and strongly related to environmental conditions, as well as cultural, political and technological skills. So far, the main barriers have resulted from: a) low technological density and lack of homogeneous diffusion of digital infrastructures; b) gaps in poorly integrative and unrepresentative governance models and the rigidity and fragmentation often characterizing supply chains; c) difficulty in abandoning the traditional linear model of the economy as it is still too deeply embedded in people’s behavior; d) lack of widespread knowledge and the ability to make conscious choices; e) policy being influenced by priority environmental issues; f) the market and competition being not completely ecofriendly; and, finally, g) traditional, non-proactive and innovative management formulas.

In addition, circular economy model transition needs a legal framework support. In this matter, the mandatory system plays a critical role in promoting circular bio-based models within a more sustainable business (Batista et al., 2018).

Finally, in circular economy assessment there is still lack of standard methods (Kristensen and Mosgaard, 2020; Sassanelli et al., 2019). Only few scholars have examined this topic, for example Vinante et al., 2020, who has identified a large number of circular economy metrics at micro, meso and macro level according to different sectors.

In the light of the above, the transition from traditional, linear systems to circular economy -based sustainable production models (Figure 17) is very difficult. If at the country level (macro) or in a general industrial system such as industrial parks (meso), it would be easier to find applications and relevant outcomes, but at the micro level, data lacks and a fragmented culture of sustainable production reduce the broad and general development that remains only as a best practice or a limited experience. According to Savaskan et al. (2004), the entire manufacturing sector should be reconfigured to focus, as much as possible, on reusing waste and process residues as a zero-burden resource for re-processing to produce secondary raw materials, which then feed into the production of new goods (Svensson, 2007; Angelis-Dimakis et al., 2016; Jia et al., 2020). At the same time, it should have the ability to avoid rebound effects (see for e.g. Hertwich 2005), which can have counterproductive effects for the whole process.

Furthermore, as clarified by Geissdoerfer et al. (2017), the main beneficiaries of circular economy activities are the same economic actors who, as supply chain partners and system implementers, receive benefits and have returns from their investments.

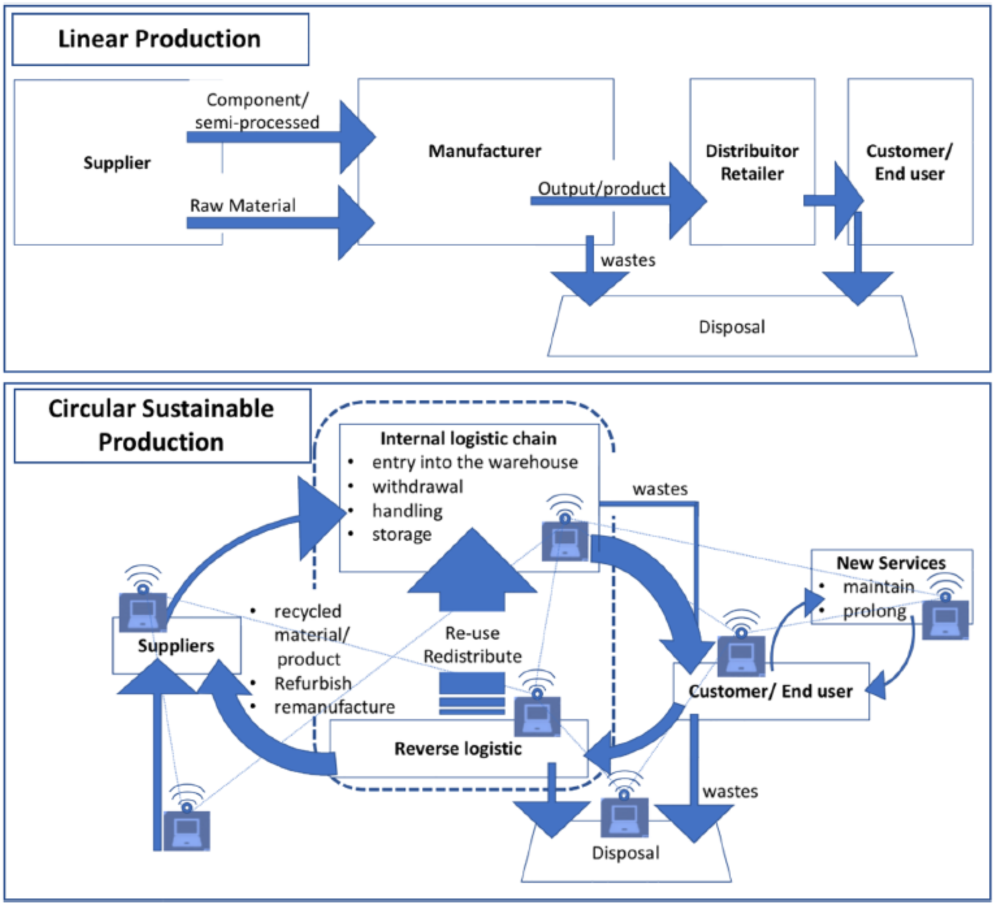

Figure 17. Traditional, linear systems and Circular Economy-based Sustainable Production models

The main contribution that Circular Economy can make to the strategic transition towards a sustainable production model covers the entire life cycle of products, which then become waste after use and are recycled to feed the same or different life cycles. The positive effect of this innovative approach is the increase in material circulation, i.e. the relationship between secondary raw materials derived from waste and used materials. European countries that lead the ranking in terms of this indicator are: the Netherlands (29.9%), France (18.6%), Belgium (17.8%) and United Kingdom (17.8%), followed by Italy (17,7%) (Circular Economy Network and ENEA, 2020).

Despite the strategies implemented, the results obtained so far are still unsatisfactory and require significant efforts to improve performance both as single country and together as the whole European system.

A transition towards a circular economy model in the industrial sector would imply the application of appropriate sustainable production principles that focus on:

• increasing productivity through efficient usage of raw materials, by-products, waste and energy;
• reducing emissions of pollutants from industrial processes.

Hence, it is understood that the holistic application of the environmental, economic, social and technological principles of a circular economy model would represent the essential element to pursue sustainable development in the Industry.

1.2.1 Analysis

The exploration of Lean Production shows that it represents an advanced production strategy that guarantees improved productivity (Ohno, 1988; Resta et al., 2016). Recently, stakeholders involved in the value chain have been expecting greater integration of performance and competitiveness with environmental and social issues (Gupta, 2016; Martínez Leon and Calvo - Amodio, 2017). Lean Production in particular is increasingly used in highly complex socio-technical systems characterised by high levels of uncertainty, diversity and dynamic interactions, making them in fact already oriented towards the complexity of sustainability issues (Cilliers, 1998; Azadegan et al., 2013).

Internal effects are greater operational efficiency achieved through a reduction of costs and waste, while the external effects are related to brand and reputation enhancement that maintain loyalty to new market portions (Geldermann et al., 2007).

Sustainable production can be considered as a complex strategy that achieves the success only through the involvement of the entire supply chain. In this sense, in order to promote Sustainability, there is a need for a strong ability to identify and pursue common and mutual benefits for producers, suppliers and customers in an integrated and holistic perspective.

Furthermore, it is crucial the interaction between policy-makers and companies. In fact, it can support or hinder transition towards the implementation of circular business models.

The activity of regulation of policymakers and international institutions can significantly influence and lead towards a circular economy transition. In addition, they can have the power to get rid of the existing barriers to innovation and implementation of circular economy, through *ad hoc* actions for the market, society and for the adoption of the emerging technologies. Though this kind of collaboration, it could be feasible reduction of waste, reuse of products and the achievement of zero-waste goals.

Therefore, the role played by policy-makers or international institutions has a high degree of importance. In fact, they can tip the balance leading the production model to a radical change. It would shift from a linear one, where natural resources are used for mass products to be disposed after use, to a "circular economy" model, where economic growth is boosted by Reverse Logistics.

Based on this statement, this is configured as a managerial problem. Adopting a lean approach as theoretical, methodological support can be useful for assessing the various contents and the areas covered by the Supply Chain Management (SCM). Therefore, it would be noteworthy to highlight where principles of Circular Economy find a positive and pragmatic connection.

Indeed, thanks to SCM systems, which can be considered as the evolution of integrated company logistics, a strategic model based on the vertical integration of material management activities can be drawn as follows:

• the forecasting phase;
• the intermediate stages of the critical order process;
• the purchase activity;
• planning and programming;
• procurement and follow-up of production;
• storage of materials;
• the shipment, transport and delivery of the finished product to the market;
• the accounting of warehouse materials.

The SCM embeds eight business areas and relative processes:

1. Customer Relationship Management (CRM), including the identification of market objectives and targets and the development of engagement programs in collaboration with customers. The purpose of this process is to identify and acquire new customers in order to establish long-term loyalty relationships.
2. Customer Service management including the exchange of information with customers about the product and the progress of orders. To this end, many companies use information systems that, for example, allow the customer to modify their orders or check their status.

3. Demand Management providing reliable forecasts and reduces the variability of production installments, considering that the flow of materials and products is strongly correlated with the final demand.

4. Order fulfillment ensuring that deliveries to customers are accurate in terms of time, quality and quantity.

5. Manufacturing Flow Management comprising the production of products requested by the customer. To this end, the company must be able to develop reliable predictions on the trend of market demand.

6. Procurement focusing on managing interactions with suppliers in order to create shared production process and new product development.

7. Product development/marketing (New Product Development and Marketing) integrating key customers and suppliers with the aim of developing new products and to reduce the time to market.

8. Reverse logistics (Return Management) concerning the recycling and reuse of products at the end of their useful life cycle.

The analysis of the areas that characterise the SCM shows that only one refers to Reverse Logistics (point 8), represents a strategic action suitable for integrating the principles of the circular economy into the supply chain, where LP can play a successful role. In this regard, the European working group (REVLOG) defines Reverse Logistics as the "*process of planning, implementation and control of flows of raw materials, semi-finished and finished products from production, distribution and the end customer to the recovery point or to the collection and distribution point*".

Through reverse logistics, it is possible to recover important quantities of materials using circular flows. In the reverse cycle, in particular, the residue is reintroduced into the same or another production cycle as a second raw material (Howard et al., 2018).

According to Pushpamali et al. (2020), Reverse Logistics is perceived as an environmentally- friendly practice in construction operations. In this study, in fact, it is highlighted that its implementation leads to a significant reduction of cost for materials in comparison with a purchase of new ones. It is also addressed the need for a quantitative analysis for future research. Therefore, it would be interesting carrying out empirical analysis based on case studies or statistical methods.

In order to access the opportunities deriving from the reverse cycles (closed circuits), it is necessary to strengthen the legislation, also through intersectoral agreements, promoting the key role of logistics also through symbiotic and inclusive production systems (Farooque et al., 2019).

Thierry et al. (1995) divided recovery into repair, renewal, regeneration, cannibalization and recycling. In another study, Fleischmann et al. (2000) classified the recovery process into collection, inspection/separation, reworking, disposal and redistribution, while Camilleri (2018) defined the recovery process as a combination of reuse, service, re-manufacture, recycling and disposal. From this definition it emerges that Reverse Logistics differs from the classic definition of logistics, since it considers the product only at the end of its life or cycle.

Comprehensively, the Council of Logistics Management (CLM) defines Reverse Logistics (RL) as "a term often used to refer to the role of logistics in recycling, waste disposal and management of hazardous materials; a broader perspective includes a report on logistical activities carried out in the reduction of sources, recycling, replacement, reuse of materials and disposal". In summary, Reverse Logistics is considered more than a configuration of the logistics system to collect products from end users for recycling or renewal at recycling plants (Braungart et al., 2007).

According to Brandenburg and Rebs (2015), sustainable production encompasses the concepts of Circular Economy, Reverse Logistics and Sustainable Supply Chain in an integrated manner (Figure 18) (Papachristos, 2014). As main result, the key success factor is the interdependence between technical and economic aspects and, environmental responsibility (Saez-Martínez et al., 2016).

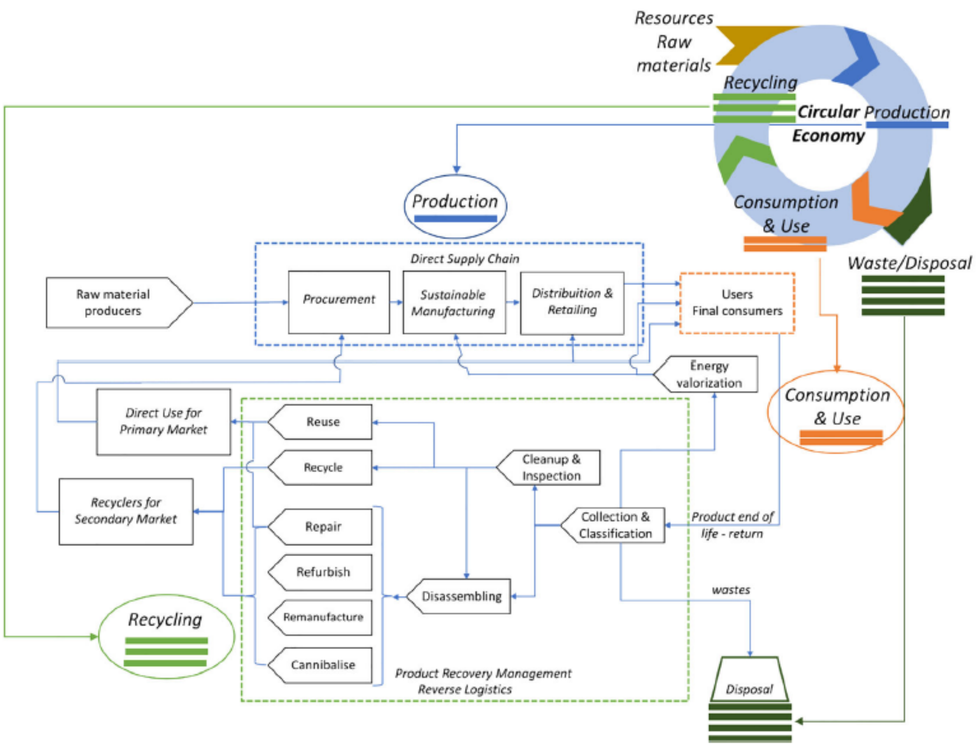

Figure 18. Production and Reverse Logistics within Circular Economy cycle

Based upon the previous statements, sustainable production requires a throughout environmental assessment, applied to whole supply chain. In this sense, sustainable production can maximise resource efficiency in the entire industrial production system by minimising negative environmental impact in each process (Macchi et al., 2020).

According to Ioppolo et al. (2014), Lean Production contributes to the qualitative and quantitative measurement and analysis of consumption, and associated environmental loads of resources and energy, with particular attention to the recovery of secondary raw materials, derived also from reverse logistics processes.

Sustainable production improves the competitive positioning of small and large enterprises, anticipating consumer choices and regulatory decisions, making the supply of resources and the prices more stable in each supply chain safer. Furthermore, sustainable global production fosters the combination of demand and supply of circular innovation.

The integration of Lean production with the Circular Economy allows the planning of a new – "sustainability oriented" business strategy, in line with the financial goal of the company.

Therefore, the previous analysis leads to a better understanding of relationships among Industry 4.0, Lean production and Circular Economy. Holistically considered, all of them can help companies to achieve a competitive edge in the market. On the other hand, all the stakeholders involved, from policy-makers to international institutions play a crucial role in the transition towards a circular economy-based and digitalised development, enhanced by the use of Reverse logistics.

In detail, it is feasible through the following activities:

• dematerializing and de-energizing both production and finished products, enhancing services throughout its life;

• promoting the use of low environmental impact materials by reducing emissions and dispersion of toxic substances during and, especially, at the end of life;

• introducing the qualitative and quantitative measurement and analysis of consumption and associated environmental loads of resources and energy, with particular attention to the part coming from recovery as secondary raw materials derived from reverse logistics processes;

• investing in eco-design by promoting the use of recyclable materials and enhancing both "Reverse Logistics" actions and the use of renewable energy and sustainable resources, capable of extending the useful life of a product;

• strengthening a model of "functional economy" aimed at replacing products with services, increasing the efficiency of production and finished products.

This is highlighted in Figure 19. By integrating the three pillars: Lean Production model, Circular Economy principles and Industry 4.0 environment, through Reverse Logistics, it is possible to improve process flows in supply chains and give rise to "digital, sustainable products and processes".

Such "digital sustainable products and processes" could meet the essential human needs by satisfying their requests. In fact, digital process flows would be more simplified and smarter. This would lead to a reduction of lead times and a delivery of products customised on consumer needs. Furthermore, this would imply more sustainable supply chains aiming at minimizing wastes and depletion of natural resources. In this sense, they would meet the goals of "functional economy" based on the optimization of the use (or function) of goods and services and thus the management of existing resources and energy (Stahel, W., R., 2005). Furthermore, the role of Circular Economy in these process flows would be that of a functional economy, where end-users pay for the use of products and not for their ownership (Urbinati et. al., 2017). In this sense, products with extensive lifecycles which can be easily dismantled and recovered at the end of their life as well as technology become the vehicles to provide a function and optimize their use.

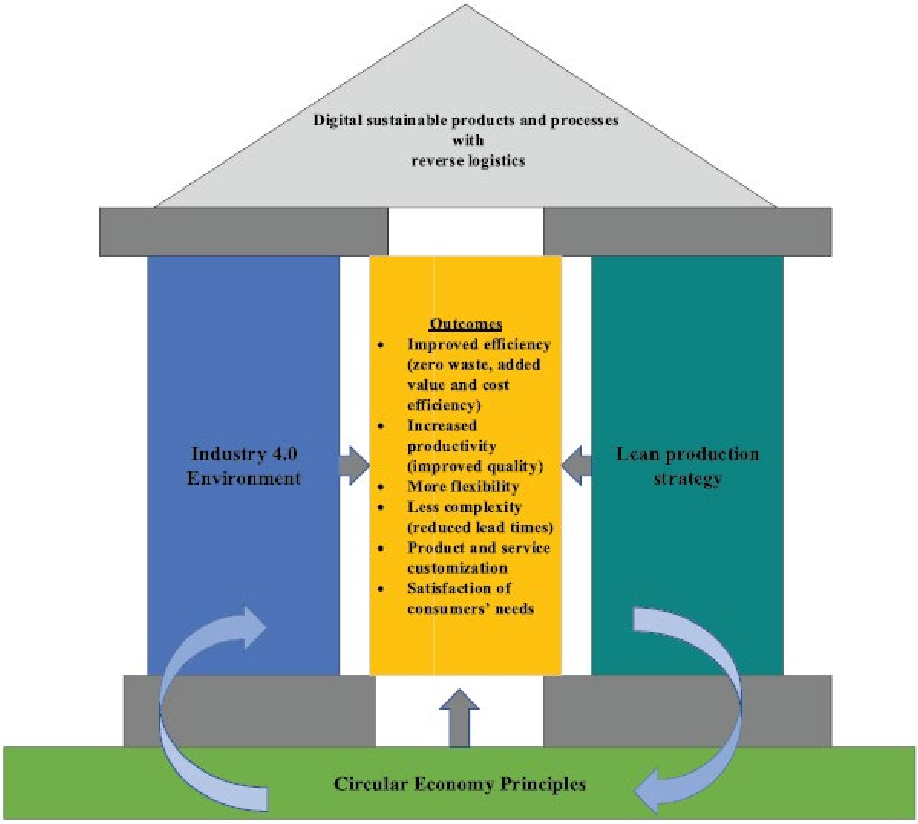

Figure 19. Conceptual framework integrating Lean Production, Circular Economy and Industry.4.0

In addition, the integration of Circular Economy principles within the lean philosophy improves its overall environmental contribution. Following Lewandowski's approach (2016), which groups sustainable production into four strategic operating areas: business models and processes, asset and product lifecycle management, resource and energy management and enabling technologies, future research should focus on expanding the existing horizons of lean management to contribute effectively to the application of circular economy principles in order to achieve sustainable development goals in all four areas. The digitisation of the supply chain through the integration of new technologies in logistics is certainly an essential contribution to the implementation of extended and sustainable management from "*cradle to cradle*" (Uemura Reche et al., 2020). In this regard, digitalisation supports Reverse Logistics, integrating the process with technologies and organizational elements that allow the system to be more efficient and flexible.

Nevertheless, this paradigm shift in manufacturing companies, is still far from being implemented, as most of the processes and products are not designed to integrate the principle of "flexibility and speed at customer request" into the Circular Economy.

Beside this, other weaknesses of the current analysis concern the fact that it is only a theoretical study that aims at integrating Industry 4.0, Lean production and Circular Economy. Thus, it would need further empirical investigations. Furthermore, a strong weakness of the topic tackled could regard the difficulty in engaging all the stakeholders such as Governments, international institutions and companies to advance the transition toward sustainable and digitalized process flows.

The innovative approach of Industry 4.0 can face the challenge precisely in terms of Reverse Logistics. In fact, through the intelligent sharing of spaces (i.e. warehouses, loading / unloading areas, docks, terminals), vehicles and loads, this change can have a disruptive effect on economic system, able to optimise the flows due to investments in the digitalisation of the supply chain. In this sense, Reverse Logistics can contribute in terms of access to sharing platforms in order to encourage resilient development.

Specifically, Lean Production can manage the Industry 4.0 model through an effective and integrated use of information technology (Superior Integration - Computer Integrated Manufacturing), artificial intelligence (AI) and robotics (Kagermann et. al., 2013). Hence, the implementation of a Lean Production model applied to Industry 4.0 can make a winning contribution to increase product quality, productivity and make processes fluid and efficient.

Lean production based on Industry 4.0 provides real-time tracking and monitoring of all the functions of the systems allowing identification, tracking, communication and control along the value stream. Management and communication information systems allow the development of an integrated end-to-end environment that connects digitally designed intelligent machines, storage systems and intelligent production structures throughout the organization (Sanders et al., 2016). In this advanced technological environment, through the extensive and pervasive use of Artificial Intelligence (AI), it is possible to accurately forecast customer requests and manage the entire supply chain from incoming logistics to production, outgoing logistics, marketing, sales and assistance (Flint et al., 2005; Kagermann et al., 2013; Klumpp, 2017).

Therefore, Industry 4.0 can integrate the principles of the Circular Economy, creating a successful business that is structured on the systemic use of technologies, such as digital (information technology), engineering (materials technology) and hybrids (a mix of those two).

Investments in digital infrastructures are necessary to enable the dissemination of digital services and technologies not only across Europe, but everywhere. Furthermore, the development of broadband plays a crucial role in the implementation of innovative and competitive digital systems, rebalancing public initiative interventions directly on the less connected areas (white and gray) to avoid the risk of increasing the digital divide.

Digital technologies allow the systematic exchange of information in real time between users, machines and management systems, with the aim of nurturing a widespread digital environment that supports a large, integrated and interactive supply chain. Hence, the advantage in terms of Circular Economy is the dematerialization of all physical activities and the reconfiguration of the value chain (Jankowski et. al., 2018; Urbinati et. al., 2017).

Measuring the performance of Circular Economy at micro level (in manufacturing) is affected by the lack of a single and common framework of indicators, the lack of data inventory and the lack of culture. In this sense, the cultural dimension concerns not only the business area, but also the market the behaviors and choices of customers.

The maturity achieved through new technologies and the greater availability and openness of companies allow us to conclude that sustainable production in the digital ecosystem can become a real driving force for companies committed to the transition towards a circular economy.

Smart technologies and the digital environment improve the potential of the entire manufacturing supply chain, but require greater awareness of the enhanced paradigms of human machine interaction.

In this regard, international and national program are investing in long-term policies that support a transition towards sustainable production. Future research must better promote cooperation between all stakeholders involved in the production chain, giving strategic importance to those involved in recycling and recovery activities. In conclusion, an original point of view with a preliminary "*fil rouge*" drawing and integrating the possible relationship between Lean Manufacturing, Circular Economy, and Industry 4.0 in order to stimulate productive discussion is proposed.

Chapter 2
Testing and Description of the Results

2. The MCDM model in the Supplier Selection Process

Supplier selection in the manufacturing sector is considered one of the most critical activities within a decision support system (DSS), which contributes to the success of purchasing management in the supply chain (Arikan, F., 2013). Manufacturing industries are striving to achieve cleaner production and sustainable processes and operations (Petković et al., 2022), viable when suppliers provide non-hazardous raw materials, ruled by environmental legislation and pursued by society (Mina et al., 2021). In the apparel industry, the issue of environmental pollution in terms of waste regarding manpower, materials, machinery and especially energy consumption is tackled (Lenzo et al., 2017; Nejat et al., 2021). To reduce operating costs, increase profits, improve service quality and increase customer satisfaction, enterprises should develop a decision-making model that meets their goals (Ragatz et al., 1997). In recent years, the selection of suppliers on behalf of firms must cope with the trade-off between the qualitative and quantitative criteria (Lin, 2012). They provide a supply of materials, raw materials and commodities in order to satisfy company's requests in a flexible way.

In this sense, they also contribute to the reduction in production costs and delivery time, help to improve product quality and fulfil customer requirements. In this scenario, supplier selection in sustainable supply chains, which are circular production systems with a zero-waste perspective, is a challenging problem (Alavi et al. 2021) which must be overcome to accomplish the Sustainable Development Goals (SDGs) of the 2030 Agenda. Consumers' attention to the environmental issues will push producers to shift toward more sustainable production systems, so that natural resources will be protected and handed down to the next generations (Tozanli et al. 2019). The more the environmental awareness increases, the more companies become conscious of their environmental duties. Thus, it is important to leave a sustainable world for future generations. In this context, both the regulations and the responsiveness to the environment resulted in a more responsible supplier selection. This viewpoint is expressed as Green Purchase (GP). In the European Commission's statement on Public Procurement for a Better Environment it is defined as, "*among the goods, services, and* *works that have the same basic function, they have less environmental impact than their counterparts throughout their life cycle*". In other words, green purchase is the choice of materials to be bought from recyclable, reusable or recycled materials (Sarkis, 2003). Therefore, the choice of the best supplier not only regards costs, but also a large set of selection criteria (Frej et al., 2017). Supplier selection also helps the implementation of a sustainable supply chain (Li et al., 2021) and quality programs in organizations such as Just-in-Time and Total Quality Management (Chen et al., 2021). The achievement of Just in Time implementation in any organization depends on different variables such as delivery time after order placed, reliability of supplier, capacity of supplier and quick response by supplier. A reliable supplier helps reduce the inventory cost of manufacturing, improving quality, which is the reason why supplier selection for manufacturing is a matter of greatest importance (Gözükara et al., 2019).

Starting from Dickson, (1966) who identified 23 criteria to be considered fundamental in supplier selection problems on behalf of purchasing managers, literature has extensively reviewed supplier selection criteria and techniques. Based on evidence provided by the literature, supplier selection cannot be considered a simple decision problem; indeed, it has to be considered a typical multicriteria decision issue (Liao and Rittscher, 2007).

Therefore, the main aim in a supplier selection process is reducing risks associated with long lasting relationships between buyers and suppliers. Furthermore, a choice of an accurate methodology could maximize the value of the purchaser. On the other hand, when conflicting factors affect an MCDM problem, trade-offs between them are to be examined by a purchasing manager (Farzad et al., 2008).

Thus, performances of each supplier over time, their financial positions and costs of supplying materials are to be evaluated by organizations in search for suppliers. In this sense, the supplier selection process represents a multiple criteria decision-making (MDCM) issue (Beil, 2009).

It constitutes a crucial area in the operational decision of a company.

Weber et al., (1991) claimed that the supplier selection process has been modified significantly thanks to the introduction of new technologies and environmental policies. They further highlighted that academic literature and purchasing practitioners have been examining criteria for supplier selection and methods for assessing performance suppliers since the 1960s. Conventionally, selection supplier criteria adopted internal logistic measures, such as price, on time performance, lead-time, responsiveness and damage.

Thus, cost, quality, delivery time and service, which are also common elements of Lean Manufacturing, were identified as main groupings in supplier selection (Lambert et al., 1997).

In the literature, the difficulty in ranking the criteria of cost, delivery and quality is also accounted for, which is highly considered in just-in-time environments (Narasimhan et al., 2001).

Van Weele, (2010) stated that interrelation among criteria is an inevitable conclusion and the probability of changing one criterion depends on the importance attributed to it by a company. In fact, increasing sustainability along the supply chain is fundamental for improving firms' green development behavior.

SMEs are increasingly pushed to adopt a more sustainable production supply chain. The implementation of a life cycle assessment (LCA) can help them overcome the obstacles present in the utilization of environmental actions (Testa et al., 2017).

There are different methods in supplier selection literature adopted to carry out an elimination process for the final selection of suppliers (Jankowski et al., 2019).

However, De Boer et al., (2001) highlighted that this portion of the supplier selection process concerns pre-qualification, which is more similar to a sorting process than a ranking one. Therefore, proposed methodologies for prequalification are categorical and concern data envelopment analysis, cluster analysis and case-based-reasoning systems. As a matter of fact, supplier selection is considered a typical multicriteria decision problem. De Boer et al., (2001) assumed the outranking model as an efficient procedure to adopt in MCDM with qualitative and quantitative characteristics to apply in case of a little or quite finite number of suppliers because not all the traditional decision-making techniques can work appropriately under this condition. Based on these considerations, the MCDM method has to be viewed as a critical system for selecting suppliers. In this regard, Dubey et al., (2015) asserted that an MCDM process facilitates companies in decision making, production cost and in improving competitiveness. This method, supported by mathematical techniques, was also adopted in agile environments as it helps to recognize the main factors affecting supplier selection.

Thus, an MCDM application aims to build a structure for solving decision-making processes with more than one condition. Furthermore, the implementation of hybrid methodologies resulted in the development of innovative MCDM methods suited for specific companies and leading to better results (Beikkhakhian et al., 2015).

In addition, the TOPSIS model, in comparison with other techniques, is referable, due to a large set of advantages it provides, such as the simple theoretical and mathematical framework, the high levels of efficiency in the computation process and the comprehensibility of the results it provides.

Furthermore, its integration with fuzzy set theory techniques allows us to deal with uncertainty.

Finally, the application of MCDM techniques for the selection of suppliers in the textile manufacturing industry of Vietnam has not been carried out; thus, there is an opportunity to fill this research gap.

The MCDM method is made up of four components: alternatives, criteria, the weight of each criterion and the calculated performance of each alternative with reference to the criteria (Tzeng and Huang, 2011). The underlying theory is the multi-criteria decision-making (MCDM), firstly developed by Keeney and Raiffa, (1976). Weber et al., (1991) claim that the supplier selection process has been modified significantly over the past twenty years due to an increased adoption of emerging technologies, more attention to environmental issues and better-quality policies.

Subsequently, literature has developed a multitude of formal approaches aimed at structuring information available to the decision-maker and evaluate potential decisions when facing problems with multiple and conflicting goals (Boffardi et al., 2021). Overall, Sonmez, (2006) noted that these techniques (i.e., analytic hierarchy process, analytic network process, technique for order preferences by similarity to an ideal solution, the elimination and choice translating reality method, preference ranking organization methods for enrichment evaluations) are extensively implemented in different company sectors as useful decision-making tools for a final supplier selection. Among these, AHP and TOPSIS present several attributes, advantaging their use in the concerned field. Indeed, both models are easy to be computed and understood since they directly provide definite value to the decision-makers willing to take a final and clear decision (Wang et al., 2009). Despite being both suitable to deal with supplier selection problems, comparative studies have shown that TOPSIS (especially if it is combined with fuzzy set theory) better adapts to this kind of problem, due to some intrinsic features (i.e., alternative changing, typology and number of criteria and agility) (Lima-Junior and Carpinetti, 2016; Junior et al., 2014).

Based on these premises, the present Chapter aims to develop a framework for a sustainable supplier selection through the adoption of a multicriteria decision-making model (MCDM). To do so, the supply chain operations reference model (SCOR) and fuzzy technique for order of preference by similarity to ideal solution (FTOPSIS) are combined. The proposed approach is tested on a real-life case study. Defining the decision problem has been the starting point of this analysis: the case company—a firm belonging to the textile and apparel industry—is willing to select the "best" supplier of raw materials from a set of three suppliers. More specifically, the research aims to (i) identify the key selection criteria for suppliers in the textile and apparel industry and those which can be developed from both literature and experts within the case company; (ii) assess how the three suppliers perform on these criteria; and (iii) select a potential supplier for the case company which performs the best on the criteria.

The novelty of the proposed methodology is that it integrates consolidated supply chain management criteria within the framework of fuzzy set theory and multicriteria decision-making model (MCDM), thus easing their application into practice. With this purpose, the supply chain operation references model is considered. It was initially proposed by the Supply Chain Council (SCC), a non-profit professional forum founded in 1996. The SCOR model has been adopted in different industries on the emerging issues of supply chain management, merging the methodology and the analytical techniques and recognizing benchmarks as standards to improve supply chain processes. According to this methodology, supply chain management was codified into combined processes including different steps such as plan, source, make, deliver, return from the suppliers' supplier to the customers' customer, and aligned with a company's strategy (Bolstorff and Rosenbaum, 2003). In this way, the SCOR model allows firms to conduct a very thorough fact-based analysis of all features in their supply chain (Huan et al., 2004). The combination of fuzzy theory and SCOR model has allowed scholars to address the issues of uncertainty, which strongly characterizes supplier selection problems (Chan and Qi, 2003).

2.1 Methods for the Selection of Criteria

Criteria to be used in the analysis are selected based on the performance section of SCOR model, a structure of performance metrics describing five different aspects such as reliability, responsiveness, agility, costs and asset management efficiency. Metrics measure the capacity of a supply chain to reach these goals (Supply Chain Council (SCC). SCOR: Supply Chain Operations Reference Model Revision 11.0., 2012). In order to identify reliable criteria for supplier selection, literature on SCOR metrics application is reviewed by considering the most recent development on the topic (from 2004 onwards). Stephens et al., (2001) was the first author to present SCOR and describe its development and applications. Since then, the SCOR model has been applied to describe the performance of several production sectors. The performance attributes of SCOR metrics are described as follows:

Reliability

Reliability requires two kinds of judgements, involving both external factors (i.e., national political conditions and exchange rate) and internal ones (such as trust and warranty policies) (Subhani and Osman, 2010).

On the side of trust (referring to vendors), frequently used measures involve quality and on time delivery of vendor, while warranty policies implemented by suppliers require standard terms, otherwise a reconsideration of supply chains on the side of buyers should be the most proper action (Lee, 2004). With reference to external factors, among others, the currency situation needs to be carefully studied by buyers, since higher exchange rates reduce the competitiveness of goods. Therefore, the host country is a fundamental factor which must be assessed when selecting suppliers (Subhani and Osman, 2010).

Responsiveness

Responsiveness and flexibility of volumes represent a basic need for firms, given the increased relevance of prompt access to products and services and punctual delivery in modern markets (Vickery et al., 1999).

In this framework, order cycle time is defined as the time period that specific flow units spend to go through a process, from entering to leaving (Jammernegg and Reiner, 2007). Therefore, the fundamental metric to assess the cycle time "*from customer order origination to customer order receipt*" is represented by the quantity of time spent, rather than by a quantitative measure of punctual deliveries. The delivery time is counted as the total time required from ordering to producing and shipping (Fülöp, 2005). This aspect is negatively influenced by several inefficiencies that might arise along production and transportation processes, as well as the flow of information among the main actors operating in a supply chain (Subhani and Osman, 2010).

Flexibility Factor

Environmental uncertainties in market dynamics require very high degrees of flexibility, intended as the capability of responding to short-term changes in demand, supply or other external disruptions and adapting in the new environment (Au and Wong, 2008). However, flexibility does not only deal with machinery, but also involves the capability of modifying production patterns and inventory, as well as supplying new jobs when needed, in response to the changeling nature of markets (Mentzer, 2004). Therefore, to understand supplier's flexibility, firms should analyse inventory availability, information sharing, negotiability and customization components. This way, better control over the supply chain is possible, thus allowing a competitive advantage over rival firms (Subhani and Osman, 2010).

Cost Factor

Considering that the main goal of global sourcing is to abate product prices and thus maximise benefits, cost factors (such as supplier selling cost, internal cost and the charge for invoicing and ordering) are central in determining production flows. Among cost factors, the price of two main inputs is central in supplier's asking price, namely labor and material rate, with the former accounting for almost 50–60% of the final production cost (Subhani and Osman, 2010). In this setting, firms located in areas with lower costs of labor and material input report a stronger competitive advantage compared to other subjects (Navarro, 2009). In the sourcing process, internal costs represent a central role in business profit, with a central role for service costs (such as those related to internal and external communication, promotion activities, payment systems, etc.). This is the reason why a large share of international firms have implemented online financial services, achieving faster, more competent and more profitable management schemes (Benitez et al. 2018).

Asset Management Efficiency

Together with cost factors, asset management attribute is dependent on the internal organization of firms, rather than on costumer behavior (as in the case of the other three groups of attributes). Asset management is often referred to as used/available capacity, and, similarly, SCOR methods rely on measures assessing the ability of boosting plants and equipment capacity with firms (Beamon, 1998).

In doing so, these interventions maximise those activities, fostering value added and, simultaneously, reducing time material and orders (including payment for orders) deployed for various processes. Low stock levels, fast transportation options and limited but well-utilised manufacturing facilities are useful aspects allowing one to evaluate operational adjustments and thus managerial abilities. In this vein, at Level 1, assets are operationally defined as total gross product revenue/total net assets.

2.2 Fuzzy Set Theory and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

2.2.1 Fuzzy Set Theory

In order to solve rising problems, the vagueness of human thinking has to be represented and treated and thus Zadeh, (1975) elaborated the fuzzy set theory.

This theory provides a mathematical representation of both vagueness and uncertainty and is an instrument to cope with decision imprecision. The fundamentals of fuzzy set theory have been elaborated by Zadeh, (1975), Buckley, (1992) and Kaufman and Gupta, (1991) and, more recently, by Zimmermann, (2010). The basic definitions are provided as follows:

Definition 1. *In a universe of discourse X, the belonging or not of an element to a set A is expressed*
(in numeric terms) by a membership function mA(x). It assigns a real number ranging between (0) and (1) to each element x. The grade of membership of x in A defines the value of the membership function (Malin and Reichardt, 2005).

Definition 2. *A fuzzy set A is convex if and only if X is convex and*

$$\mu A\ (\lambda\, x_1 +\ (1 - \lambda x_2)\ )\ \geq min\ (\mu A(\ x_1).\, \mu A(x_2))$$

Definition 3. *The height of a fuzzy set A on X is the maximum grade of membership reported by each element in the set. A fuzzy set A in the universe of discourse X is defined as normal when:*

$$Alt(A) = 1$$

where Alt(A) represents the height of A (Yuan, Y.; Shaw, 1995).

Compared with traditional binary logic (based only on true or false values), fuzzy variables assume values between 0 and 1. In doing so, fuzzy logic is able to handle issues deriving from the concept of partial truth, according to which truth can range from totally true to totally false.

The key idea of fuzzy set theory is that each element belongs to a precise set. Its degree of membership is evaluated through values between 0 and 1. A triangular fuzzy number (TFN) is defined by a triplet (i.e., three points: l, m, n). The membership function of this fuzzy number $\mu_{\tilde{A}}(X)$: $R\ \rightarrow\ [0,1]$ is given in Equation 1.

$$\mu_{\tilde{A}}(X) = \begin{Bmatrix} 0, for\ x < l, x > n \\ \frac{x-l}{m-l}\ for\ l \leq x \leq m \\ \frac{x-n}{m-n}\ for\ m \leq x \leq n \end{Bmatrix} \quad (1)$$

2.2.2 Fuzzy TOPSIS (FTOPSIS)

The technique for order preference by similarity to ideal solution (TOPSIS) was developed in 1981 by Hwang and Yoon. The idea underlying this technique is that, based on a set of selected criteria, the alternative to be chosen will be the closest to the positive-ideal solution and, simultaneously, the farthest from the negative-ideal one. As a consequence, alternatives ranking will be constructed by considering both closeness and distance from the two ideal solutions, which are artificial and identified as follows (Wang et al., 2009):

- Positive-ideal alternative: the alternative achieving the highest score with reference to all the attributes involved in the analysis, or say differently, "all best criteria values attainable". This solution leads to the maximization of all benefits and a minimization of costs.
- Negative-ideal alternative: by reporting the lowest level of the attributes considered, or say differently, "*all worst criteria values attainable*", this alternative results in benefit minimization and cost maximization (Krohling and Pacheco, 2015).

In doing so, TOPSIS might be considered a compensatory method, allowing trade-offs among the set of criteria identified, i.e., weak performance in terms of one or more criteria can be balanced by a strong one in another criterion. This categorization is confirmed by the nature of the best alternative resulting from the model, expressed as that with the shortest distance from the PIS and the opposite for the NIS (Pavić and Novoselac, 2013).

Due to the presence of ambiguities, vagueness and uncertainties related to the supplier selection process, it is employed fuzzy TOPSIS (FTOPSIS) for performance evaluation.

In this context, it is required a specification. According to Wątróbski et al., (2017), a temporal supplier evaluation model would imply inserting variability factors over time. In this model, the analysis of variability of decision factors over time and the analysis of the impact of that variability is taken into consideration. Despite the fact that it would be interesting to consider the variability of decision factors over time, in our study we decided to follow the classical MCDM theory, assuming the constancy of both the set of alternatives and the criteria for their evaluation in order to not affect the accuracy of the process.

This combination of techniques allows us to exploit linguistic variables, rather than numerical ones, providing a suitable tool to manage often imprecise criteria dealing with both qualitative and quantitative aspects (Lima-Junior and Carpinetti, 2016).

The application of FTOPSIS comprises the following steps:

Step 1: Generation of alternatives (m), determination of the evaluation criteria (n) and creation of a decision-maker pair (k).

Step 2: Decision about both linguistic terms assessing the importance of weights associated with each criterion ($\widetilde{w}_j = n_{ij}, o_{ij}, p_{ij}$) and linguistic ratings referring to the weights of criteria ($\tilde{x}_{ij}$).

Step 3: Creation of the aggregated fuzzy weight $\tilde{w}_j$of criterion C_i caused by the aggregation of the weight of criteria. Fuzzy rating $\tilde{x}_{ij}$ of alternative S_i under criterion C_j is provided by experts.

$$\tilde{x}_{ij} = \frac{1}{k}\left[\tilde{x}_{ij}^1 + \tilde{x}_{ij}^2 + \cdots + \tilde{x}_{ij}^k\right]; i = 1,2,\ldots,m; j = 1,2,\ldots,n \quad (2)$$

$$\tilde{w_{ij}} = \frac{1}{k}\left[\tilde{w}_{ij}^1 + \tilde{w}_{ij}^2 + \cdots + \tilde{w}_{ij}^k\right]; j = 1,2,\ldots,n \quad (3)$$

Step 4: Elaboration of the fuzzy decision matrix.

$$A = \begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ \vdots \\ S_m \end{bmatrix} \begin{bmatrix} C_1 & C_2 & C_3 & \cdots & C_n \\ y_{11} & y_{12} & y_{13} & \cdots & y_{1n} \\ y_{21} & y_{22} & y_{23} & \cdots & y_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ y_{m1} & y_{m2} & y_{m3} & \cdots & y_{mn} \end{bmatrix}; \tilde{w} = [\widetilde{w_1}, \widetilde{w_2}, \ldots, \widetilde{w_n}] \quad (4)$$

Step 5: Normalization of the fuzzy decision matrix through a linear scale transformation applied on the raw data, transforming criteria scales into a comparable one. It is denoted by $\tilde{R}$. In MCDM models, the normalization process serves to homogenize all the variables considered and to be able to compare them with each other (Shekhovtsov et al., 2022).

$$\tilde{\mathrm{R}} = [\tilde{\mathrm{r}}_{ij}]_{mxn}; i = 1,2,\ldots,m ; j = 1,2,\ldots n \quad (5)$$

$$\tilde{\mathrm{r}}_{ij} = \left(\frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+}\right); \text{ and } c_j^+ = max c_{ij} \text{(benefit criteria)} \quad (6)$$

$$\tilde{\mathrm{r}}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right); \text{ and } a_j^- = min a_{ij} \text{(cost criteria)} \quad (7)$$

Step 6: Creation of a weighted normalized matrix $\tilde{V}$ resulting from the product of the normalized fuzzy decision matrix $\tilde{r}ij$ and the weight $\tilde{w}ij$ of the evaluation criteria.

$$\tilde{V} = [\tilde{v}_{ij}]_{mxn};\ i = 1,2,\ldots,m;\ j = 1,2,\ldots,n; \text{ where } \tilde{v}_{ij} = \tilde{r}_{ij}(.)\tilde{w}_j \quad (8)$$

Step 7: Identification of the negative-ideal solution (NIS) and the positive-ideal solution (PIS):

$$Z^{+} = \{\tilde{v}_1^{+}, \tilde{v}_2^{+}, \dots, \tilde{v}_n^{+}\}; \text{ where } \tilde{v}_j^{+} = max\tilde{v}_{ij3}; i = 1,2,\dots,m; j = 1,2,\dots,n \quad (9)$$
$$Z^{-} = \{\tilde{v}_1^{-}, \tilde{v}_2^{-}, \dots, \tilde{v}_n^{-}\}; \text{ where } \tilde{v}_j^{-} = min\tilde{v}_{ij1}; i = 1,2,\dots,m; j = 1,2,\dots,n \quad (10)$$

where $d_v(\tilde{a}, \tilde{b})$ describes the distance between two fuzzy numbers $\tilde{a}$ and $\tilde{b}$.

Step 8: Calculate the distance of PIS (d_i^{+}) and NIS (d_i^{-}) using:

$$d_i^{+} = \{\sum_{j=1}^{n}(v_{ij} - v_j^{+})^2\}^{\frac{1}{2}}, i = 1,2,\dots,m \quad (11)$$
$$d_i^{-} = \{\sum_{j=1}^{n}(v_{ij} - v_j^{-})^2\}^{\frac{1}{2}}, i = 1,2,\dots,m \quad (12)$$

where d_i^{+} and d_i^{-} measure the distances of the worst and best conditions from the target alternative.

Step 9: Determination of the CC_i value:

$$CC_i = \frac{d_i^{-}}{d_i^{+} + d_i^{-}}; i = 1,2,\dots,m \quad (13)$$

Step 10: Ranking of the set of alternatives (suppliers), according to a decreasing order of (CC_i).

2.2.3 Results

By exploiting the criteria discussed in the previous sections, three experts were interviewed to test the proposed model. Through the interviews, a set of criteria to be included in the model and the potential supplier requirements were defined according to the SCOR metrics (Table 7).

Main Criteria	Sub-Criteria
Reliability (A)	On time delivery A1
	Geographic location a2
	Delivered the right quantity A3
Responsiveness (B)	Order fulfilment cycle time B1
	Processing time of returns B2
Flexibility(C)	Order fulfilment lead time C1
	Continuous quality improvement programs C2
	Certification C3
Cost (D)	Freight cost D1
	Processing cost of returns D2
	Cost of materials D3
Assets (E)	Cash-to-cash cycle time E1
	Asset turns E2
	Inventory value E3

Table 7. SCOR metrics, criteria and sub-criteria

Two project managers and a purchasing manager—decision-maker 1 (DM-1), decision-maker 2 (DM-2) and decision-maker 3 (DM-3)—were consulted to obtain information about purchasing decisions. They were required to select the preferred supplier(s) from a list of three potential suppliers: supplier 1 (S1), supplier 2 (S2) and supplier 3 (S3).

The decision-making process proceeds as follows. Table 8 describes the linguistic values and fuzzy numbers, while the calculated weights are reported in Table 9.

Linguistic Values	Fuzzy Number
Very low (VL)	(0.1, 0.1, 0.3)
Low (L)	(0.1, 0.3, 0.5)
Medium (M)	(0.3, 0.5, 0.7)
High (H)	(0.5, 0.7, 0.9)
Very high (VH)	(0.7, 0.9, 0.9)

Table 8. Linguistic values and fuzzy numbers

Criteria	Weights
On time delivery A1	(0.5,0.833,0.9)
Geographic location A2	(0.5,0.767,0.9)
Delivery the right quantity A3	(0.3,0.633,0.9)
Order fulfilment cycle time B1	(0.5,0.833,0.9)
Processing time of returns B2	(0.5,0.7,0.9)
Order fulfilment lead time C1	(0.7,0.9,0.9)
Continuous quality improvement programs C2	(0.3,0.7,0.9)
Certification C3	(0.30.567,0.9)
Freight cost D1	(0.3,0.6330.9
Processing cost of returns D2	(0.3,0.567,0.9)
Cost of materials D3	(0.5,0.833,0.9)
Cash-to-cash cycle time E1	(0.5,0.767,0.9)
Asset turns E2	(0.3,0.7,0.9)
Inventory value E3	(0.5,0.767,0.9)

Table 9. Weights of all criteria

After assigning a weight to each criterion, linguistic scale values for each criterion were collected with reference to all supplier alternatives. These values consist of five values: very low (VL), low (L), medium (M), high (H) and very high (VH). Table 11 reports the linguistic fuzzy evaluation matrix for the ranking of suppliers, as provided by the three decision-makers.

Criteria	Decision-Maker 1			Decision-Maker 2			Decision-Maker 3		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
A1	H	A	H	A	L	H	A	A	VH
A2	VH	L	VL	H	A	VL	VH	L	L
A3	H	A	VH	A	L	H	A	A	H
B1	A	H	H	L	A	A	VL	A	A
B2	H	VL	L	A	L	L	H	H	VL
C1	H	H	A	H	A	A	VH	A	A
C2	L	H	VH	A	VH	VH	L	H	H
C3	A	H	VH	A	VH	VH	L	H	VH
D1	VH	L	VL	VH	A	L	H	L	VL
D2	A	L	L	A	A	L	H	L	L
D3	A	H	VL	A	VH	L	A	H	VL
E1	A	A	VH	A	H	H	L	VH	VH
E2	A	L	H	A	A	VH	L	H	VH
E3	L	VH	A	L	H	H	VL	H	H

Table 10. Linguistic evaluation matrices for the ranking of alternatives

Following Table 2, linguistic values are converted into fuzzy numbers. Values provided in Table 2 are exploited by most studies dealing with linguistic values and fuzzy numbers. Linguistic values are converted as VL = (0.1; 0.1; 0.3), L = (0.1; 0.3; 0.5), M = (0.3; 0.5; 0.7), H = (0.5; 0.7; 0.9) and VH = (0.7; 0.9; 0.9).

Table 11 reports the linguistic fuzzy evaluation matrices for the ranking of alternatives.

	DM1			DM2			DM3		
Criteria	S1	S2	S3	S1	S2	S3	S1	S2	S3
A1	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.7, 0.9, 0.9)
A2	(0.7, 0.9, 0.9)	(0.1, 0.3, 0.5)	(0.1, 0.1, 0.3)	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)	(0.1, 0.1, 0.3)	(0.7, 0.9, 0.9)	(0.1, 0.3, 0.5)	(0.1, 0.3, 0.5)
A3	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)	(0.7, 0.9, 0.9)	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)
B1	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.1, 0.3, 0.5)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.1, 0.1, 0.3)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)
B2	(0.5, 0.7, 0.9)	(0.1, 0.1, 0.3)	(0.1, 0.3, 0.5)	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.1, 0.1, 0.3)
C1	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.7, 0.9, 0.9)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)
C2	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.7, 0.9, 0.9)	(0.3, 0.5, 0.7)	(0.7, 0.9, 0.9)	(0.7, 0.9, 0.9)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)
C3	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)	(0.7, 0.9, 0.9)	(0.3, 0.5, 0.7)	(0.7, 0.9, 0.9)	(0.7, 0.9, 0.9)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.7, 0.9, 0.9)
D1	(0.7, 0.9, 0.9)	(0.1, 0.3, 0.5)	(0.1, 0.1, 0.3)	(0.7, 0.9, 0.9)	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.1, 0.3, 0.5)	(0.1, 0.1, 0.3)
D2	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)	(0.1, 0.3, 0.5)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.1, 0.3, 0.5)	(0.1, 0.3, 0.5)
D3	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)	(0.1, 0.1, 0.3)	(0.3, 0.5, 0.7)	(0.7, 0.9, 0.9)	(0.1, 0.3, 0.5)	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)	(0.1, 0.1, 0.3)
E1	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.7, 0.9, 0.9)	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.1, 0.3, 0.5)	(0.7, 0.9, 0.9)	(0.7, 0.9, 0.9)
E2	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.7, 0.9, 0.9)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.7, 0.9, 0.9)
E3	(0.1, 0.3, 0.5)	(0.7, 0.9, 0.9)	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.1, 0.1, 0.3)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)

Table 11. Fuzzy decision matrices for alternative ranking

The subsequent step involves the creation of a weighted normalized fuzzy decision matrix, based on the normalized fuzzy decision matrix (Table 12) and the weights of criteria reported in Table 10. Weighting criterion in each row is multiplied to the fuzzy value of each row.

Criteria	S1	S2	S3
A1	(0.333, 0.630, 1)	(0.111, 0.481, 0.778)	(0.556, 0.852, 1)
A2	(0.556, 0.923, 1)	(0.111, 0.407, 0.778)	(0.111, 0.185, 0.556)
A3	(0.333, 0.623, 1)	(0.111, 0.481, 0.778)	(0.556, 0.852, 1)
B1	(0.143, 0.333, 1)	(0.111, 0.176, 0.333)	(0.111, 0.177, 0.333)
B2	(0.111, 0.158, 0.333)	(0.111, 0.273, 1)	(0.2, 0.429, 1)
C1	(0.556, 0.852, 1)	(0.333, 0.629, 1)	(0.333, 0.556, 0.778)
C2	(0.111, 0.407, 0.778)	(0.556, 0.852, 1)	(0.556, 0.926, 1)
C3	(0.111, 0.481, 0.778)	(0.556, 0.852, 1)	(0.778, 1, 1)
D1	(0.111, 0.12, 0.2)	(0.143, 0.273, 1)	(0.2, 0.6, 1)
D2	(0.111, 0.176, 0.333)	(0.143, 0.273, 1)	(0.2, 0.333, 1)
D3	(0.143, 0.2, 0.333)	(0.111, 0.130, 0.2)	(0.2, 0.6, 1)
E1	(0.143, 0.231, 1)	(0.111, 0.143, 0.333)	(0.111, 0.12, 0.2)
E2	(0.143, 0.231, 1)	(0.111, 0.2, 1)	(0.111, 0.12, 0.2)
E3	(0.2, 0.429, 1)	(0.111, 0.130, 0.2)	(0.111, 0.158, 0.333)

Table 12. Normalized fuzzy decision matrix

For constructing the weighted normalized fuzzy evaluation matrix, the same procedures are applied to the other supplier alternatives (Table 13).

Criteria	S1	S2	S3
A1	(0.1667, 0.525, 0.9)	(0.056, 0.401, 0.7)	(0.278, 0.709, 0.9)
A2	(0.2778, 0.709, 0.9)	(0.056, 0.312, 0.7)	(0.056, 0.142, 0.5)
A3	(0.1, 0.399, 0.9)	(0.033, 0.305, 0.7)	(0.167, 0.539, 0.9)
B1	(0.071, 0.278, 0.9)	(0.056, 0.147, 0.3)	(0.056, 0.147, 0.3)
B2	(0.0556, 0.111, 0.3)	(0.056, 0.191, 0.9)	(0.1, 0.3, 0.9)
C1	(0.389, 0.767, 0.9)	(0.233, 0.567, 0.9)	(0.23, 0.5, 0.7)
C2	(0.033, 0.285, 0.7)	(0.167, 0.596, 0.9)	(0.167, 0.648, 0.9)
C3	(0.033, 0.272, 0.7)	(0.167, 0.483, 0.9)	(0.233, 0.567, 0.9)
D1	(0.0333, 0.076, 0.18)	(0.043, 0.173, 0.9)	(0.06, 0.38, 0.9)
D2	(0.033, 0.1, 0.3)	(0.043, 0.155, 0.9)	(0.06, 0.189, 0.9)
D3	(0.071, 0.167, 0.3)	(0.056, 0.109, 0.18)	(0.1, 0.5, 0.9)
E1	(0.071, 0.177, 0.9)	(0.056, 0.109, 0.3)	(0.056, 0.092, 0.18)
E2	(0.0423, 0.161, 0.9)	(0.033, 0.14, 0.9)	(0.033, 0.084, 0.18)
E3	(0.1, 0.329, 0.9)	(0.056, 0.1, 0.18)	(0.056, 0.121, 0.3)

Table 13. Weighted normalized fuzzy decision matrix

The fuzzy PIS and fuzzy NIS for the given criteria are calculated using Equations 9 and 10 and reported in Table 14. Then, the distance between PIS, NIS and each proposed alternative is computed following Equations 11 and 12 (Tables 15 and 16).

Criteria	Z+	Z-
A1	(0.278, 0.709, 0.9)	(0.056, 0.401, 0.7)
A2	(0.278, 0.709, 0.9)	(0.056, 0.1412, 0.5)
A3	(0.167, 0.539, 0.9)	(0.033, 0.305, 0.7)
B1	(0.071, 0.278, 0.9)	(0.056, 0.147, 0.3)
B2	(0.1, 0.3, 0.9)	(0.056, 0.111, 0.3)
C1	(0.389, 0.767, 0.9)	(0.233, 0.5, 0.7)
C2	(0.167, 0.648, 0.9)	(0.033, 0.285, 0.7)
C3	(0.23, 0.5667, 0.9)	(0.033, 0.273, 0.7)
D1	(0.06, 0.38, 0.9)	(0.033, 0.076, 0.18)
D2	(0.06, 0.189, 0.9)	(0.033, 0.1, 0.3)
D3	(0.1, 0.5, 0.9)	(0.056, 0.109, 0.18)
E1	(0.071, 0.177, 0.9)	(0.056, 0.092, 0.18)
E2	(0.043, 0.162, 0.9)	(0.033, 0.084, 0.18)
E3	(0.1, 0.3289, 0.9)	(0.0556, 0.1, 0.18)

Table 14. Fuzzy PIS and fuzzy NIS

Criteria	S1	S2	S3
A1	0.125	0.248	0
A2	0	0.287	0.421
A3	0.090	0.194	0
B1	0	0.355	0.355
B2	0.364	0.068	0
C1	0	0.146	0.212
C2	0.251	0.030	0
C3	0.235	0.062	0
D1	0.451	0.120	0
D2	0.351	0.022	0
D3	0.397	0.474	0
E1	0	0.349	0.418
E2	0	0.014	0.418
E3	0	0.437	0.367
d_i^+	2.264	2.805	2.192

Table 15. Distance of di+ for alternatives

Criteria	S1	S2	S3
A1	0.150	0	0.248
A2	0.421	0.152	0
A3	0.133	0	0.194
B1	0.355	0	0
B2	0	0.350	0.364
C1	0.212	0.121	0
C2	0	0.227	0.251
C3	0	0.184	0.235
D1	0	0.419	0.451
D2	0	0.348	0.350
D3	0.077	0	0.473
E1	0.419	0.070	0
E2	0.418	0.417	0
E3	0.437	0	0.070
d_i^-	2.623	2.288	2.639

Table 16. Distance of di- for alternatives

For example, for supplier 1 (S1), the A1 criterion (on time delivery) is computed as (0.5; 0.833; 0.9), while fuzzy values are (0.333; 0.630; 1). Therefore, the corresponding value reported in the fuzzy weighted evaluation matrix is computed as follows: [(0.5 × 0.333), (0.883 × 0.630), (0.9 × 1)] = (0.1667; 0.525; 0.9).

Finally, based on the fundamental rule that, in the TOPSIS model, the best alternative will be the one that minimizes the distance from the PIS, while simultaneously maximizing the distance from the negative-ideal one, the ranking of alternatives is obtained based on the CCi. CCi is the closeness index, computed using Equation 13 and given in the following table (Table 17).

Supplier	d_i^+	d_i^-	CC_i	Ranking
S1	2.264	2.623	0.536	2
S2	2.805	2.288	0.449	3
S3	2.192	2.639	0.546	1

Table 17. Fuzzy closeness index and ranking of supplier alternatives

Based on this evidence, supplier 3 (S3) is selected as the best solution, being the closest to $di+$ (2.192) and the furthest from $di-$ (2.639), proved by the highest closeness index (0.546) (Figure 20).

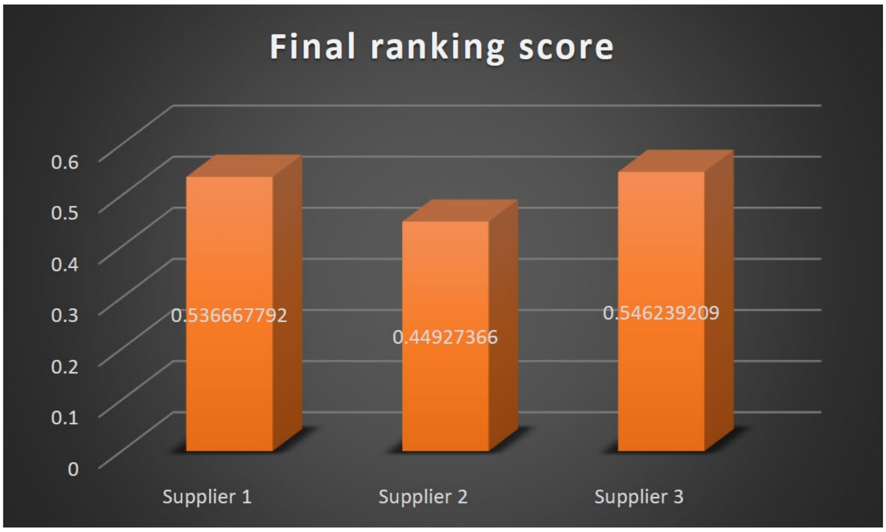

Figure 20. Final ranking score

2.3 Analysis

The aim of this chapter is twofold. A supplier selection model is proposed and implemented into practice through a multiple criteria decision-making method. To achieve the second objective, the determination of supplier selection criteria and a suitable multiple criteria decision-making method were two fundamental concerns. Both are faced and their importance in helping companies manage product sourcing in order to improve their whole supply chain is shown. Supplier selection model and supplier selection criteria are constantly expanding topics that, over time, are including different combinations of methodologies and this is contributing to the solution of many decision-making problems in various fields.

Through in-depth interviews and discussions with experts in the field of the research, the fashion industry, their current set of supplier selection conditions and methodologies were analysed.

It emerged the request by the managers involved in the research to adopt criteria aligned with Lean Manufacturing principles to keep up sustainable production and achieve more resilient and flexible process flows throughout the supply chain.

Furthermore, an effort to apply the set of supplier selection criteria into practice by using the fuzzy TOPSIS method was conducted.

Findings reveal that purchasing companies can adopt this model and the set of criteria to evaluate and choose the greenest and most sustainable suppliers and also those who adopting lean principles result more resilient to the companies' and market' needs. The model is also useful in helping pursue sustainable growth based on the green economy and is strategically competitive in the market.

Thus, this model, developed through the fuzzy TOPSIS method, provides decision-makers with wide-ranging evaluations in respect to the multiple criteria ranging the performance metrics.

The theoretical contribution of the proposed methodology is that it integrates classical supply chain management criteria within the framework of fuzzy set theory and multicriteria decision-making model (MCDM). This combination facilitates their application into practice. Furthermore, in the textile industry in Vietnam, there is still limited evidence of selection criteria and selection models and a consistent number of responses from textile industries are needed to generalize the obtained results to all Vietnamese textile manufacturing sectors.

In conclusion, the adopted model can serve as a precious tool for the examination of company purchasing activity and it can result in more sustainable production processes in lean environments.

Chapter 3

Practical Applications to Circular Supply Chain 4.0: Lean Six Sigma in the Italian Healthcare

3. The Voice of the Customer (VOC) in the Healthcare sector

In all business to consumer sectors, as in healthcare, the most important aspect is generating a satisfying customer experience.

Healthcare world, in addition to the industrial one, could benefit from that broad and consolidated disciplinary corpus that we could call operations management. In both sectors, quality of the service provided depends on a large jumble of decisions that are intertwined with each other and that we can group in the configuration choices and system management choices.

By configuration choices we mean all those choices that determine how the hardware (physical structure) and software (organizational structure) of the system are made and belong to the strategic or business level. Management choices, on the other hand, are medium-short term decisions typically made with a given configuration and belong to the operation and process level.

The dawn of Industry 4.0 technologies and the environmental issues such as the need of reducing energy consumption or the spread of health emergencies such as the pandemic Covid-19 involve both configuration choices and management ones. These factors have greatly modified the business environment and the business approach of an enterprise.

It is needed an implementation of robust and resilient methods to guide companies towards decisions reflecting the voice of the customers (VOC), before the implementation of Industry 4.0 emerging technologies. Lean Six Sigma methodology is based on data analysis and can be adopted by enterprises to solve complex problems. Despite it has traditionally been applied to manufacturing, in this chapter it is examined its adoption in the healthcare sector through the presentation of a case study.

3.1 Lean Six Sigma, Industry 4.0 and Circular Supply chain

Lean tools are focused on defining value and eliminating wastes whereas according to Harry et al., (2000) Six Sigma is "a business process that allows companies to drastically improve their bottom line by designing and monitoring everyday business activities in ways that minimize waste and resources while increasing customer satisfaction". Hence, Six Sigma aims at eliminating variability and achieving high level of quality.

On the other hand, Lean Six Sigma is a methodology of business improvement that is focused on the maximization of shareholder value by improving quality, speed, customer satisfaction and costs (George, 2003; Cherrafi et al., 2016).

Traditional information systems cannot successfully keep up with the growing number of data that companies are involved, without implementing new technologies (Gupta et al., 2020; Tissir et al., 2022). Industry 4.0 technologies can be treated as an infrastructure of the Lean Six Sigma methodology, focused on satisfying the needs of the new protagonists of the digital era, end-users such as consumers and patients in the healthcare sector (Ghobakhloo, 2020).

On the other hand, enterprises are focusing on circular supply chains to reshape the concept of "end of life" (Heyes et al., 2018; Lopes de Sousa Jabbour et al., 2018; Farooque et al., 2019). In this respect, Lean Six Sigma is technologically enabled to meet the needs of the circular economy of an enterprise by boosting the environmental performance at various level of the supply chain (Chen et al., 2022).

3.1.1 Lean Six Sigma and Circular Supply chain in the Healthcare sector

Despite Lean and Six Sigma are different methodologies, they operate well together in healthcare sector (Henrique and Godinho Filho, 2018). Lean Six Sigma provides a hands-on framework for continuous improvement in healthcare by monitoring costs, improving quality, and supplying better healthcare services (Sohal at al., 2022).

Govindan and Hasanagic (2018) identified healthcare sector as one of the areas in which circular supply chain management could facilitate production and service management. Circularity implies that the product disposal phase becomes the starting point of a new phase for a brand new product. Therefore, it increases the number of the product end-users.

3.2 An Italian Hospital case study

The case study focuses on the optimization of the waiting times and improvement of processes in the surgical unit of an Italian hospital.

The goal of the project is fulfilled through the implementation of the Lean Six Sigma methodology and management of end-to-end activities that take the patient from the hospital ward to the surgical unit and vice versa.

Problem statement

A consistent number of surgical interventions were delayed and planned surgical interventions were postponed. In this context, customer dissatisfaction, long waiting times, postponement of planned surgical interventions, waste of time and resources were some of the main reasons to intervene.

Methodology steps

Recognise Phase

In this initial phase, deployment of Lean Six Sigma methodology among employees was carried out. In this respect, a customised course was held to deploy Lean Six Sigma culture and philosophy to train people and make them aware of the cultural change they were going through.

Define phase

A cross-functional project team was created, led by two black belts, with the objective of using the define, measure, analyse, improve, and control (DMAIC) six sigma breakthrough methodology in order to reduce the waiting times and improve process efficiency.

Process mapping activities were started and all the internal processes between the hospital wards were officially defined.

Measure Phase

This activity allowed to identify 8 milestones, essential for planning data collection and development of solutions:

1.medical examination before surgery;

2.patient in the pre-operating room;

3.entrance to the operating room;
4.start induction of anesthesia;
5.patient ready for surgery;
6.surgical incision;
7.suture;
8.exit from the operating room.

Each of these milestones was monitored through the entrance and exit time. It is also defined a list of fundamental metrics impacting the times (Critical to Delivery), costs (Critical to Cost) and quality (Critical to Quality) of the services / treatments made available.

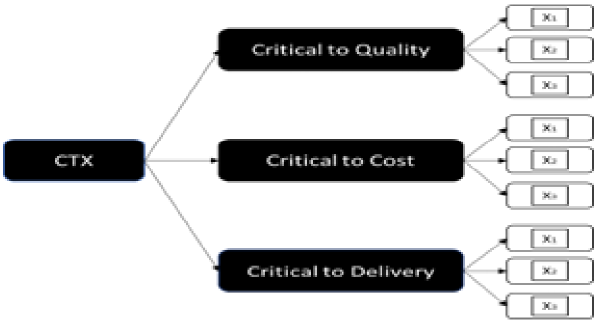

Figure 21. Fundamental metrics to be identified

In order to conclude the Measure phase it is essential to have a baseline of the performance of the process. For this reason, 7 indicators within the Operating Block were identified and their performance was measured.

Analyse Phase

The analyse phase consists in evaluating how the identified metrics impact on the various processes and if there is a degree of correlation between them. This activity will be preparatory to the improvement phase and will allow to focus on high leverage metrics.

Improve Phase

The improvement phase aims to find the tools and technologies that allow the three types of metrics, Critical to Quality, Critical to Cost and Critical to Delivery, to reach a higher quality level. The strategic objective to be aimed at is the fluid scheduling of elective surgery. Three improvement tools which aim to improve the management of all the processes of the Operating Block were developed:1. Planning of the operating rooms; 2. Plan Matrix; 3. Surgical intervention check list.

Control Phase

The control phase, on the other hand, is used to implement monitoring software and tools so that there is constant attention to preserving the quality levels achieved.

3.2.1 Analysis

The main managerial results deriving from the project were in terms of management's approach to Lean Six Sigma. The application of this methodology has to be preliminary to Industry 4.0 implementation in a company. Then, senior management became aware of the importance of the preparatory training for employees involvement in a cultural change of continuous improvement of an organization. In this case study it was observed:

• reduction of delays associated with patient preparation activities;

• risk reduction in the surgical process through the implementation of predefined safety standards;

• reduction of non-value added times of anesthetic activities;

• increase in the number of surgical interventions in the period between 2019-2020 (Fig. 22), that led the operating block to optimize activities and achieve a 13.2% increase in productivity.

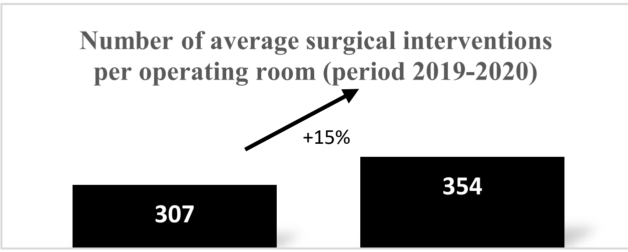

Figure 22. Average surgical interventions

Hence, key lessons to be learned are:

1.deployment of Lean Six Sigma culture is an essential part in process improvement;

2.implementation of Industry 4.0 technologies such as cloud computing has to be applied after the adoption of Lean Six Sigma in order to feed the technological support with an optimized product ready for digitalization;

3.a circular supply chain focused on zero waste is implemented.

Hospitals are increasingly struggling to provide high quality services to patients despite they have been facing different issues in the last few years such as the pandemic Covid-19 and the need to become environmentally-friendly.

In this case study, an Italian hospital with the aim of improving its waiting times for surgical interventions is introduced. Through Lean Six Sigma method and new technologies a dramatic improvement in efficiency is achieved. The number of interventions and the overall productivity are increased and a reduction in waiting times is achieved.

The case study illustrated within the paper offers interesting insights on the goodness of Lean Six Sigma in hospitals and the feasibility of creating a Supply Chain 4.0 enabled with the emerging technologies (Chen et al., 2022).

This kind of supply chain in the service sector of hospitals, in the light of the case study, can also become circular, in the sense that it is focused on eliminating wastes. In the specific case we dealt with, wastes are to be intended as long waiting times for surgical interventions, lack or reduction in productivity and, therefore, circularity is given by the standardization of the process's duration in flows with no wastes and the employees training. Future works have to be focused on the meaning of circularity in hospitals and its interaction with the implementation of Lean Six Sigma.

Chapter 4
Future Perspectives for Sustainable Production

4. Sustainable Production in the handicraft production

The traditional handicraft products are extensively produced throughout the world. The production of these products has created income and employment generation for many families as well as social wellbeing and maintained traditional cultural values in several countries (Yang et al., 2018). However, the current development of handicrafts is vulnerable due to mechanized industrial production. Today's machine-made products are very much identical to handmade products and available in several varieties in terms of design, size, color, styles, and shapes (Girón et al., 2007; McAuley & Fillis, 2005; Yang et al., 2018). Since industrial production rapidly introduces new products in the market, and due to dynamic capacity and cost-effectiveness, machine-made products are quickly capturing the market.

As a result, innovation is regarded as an essential factor for competitive advantage (Shafi et al., 2019a). Also, it is an important growth factor for handicraft firms (Shafi et al., 2019b; Yang & Shafi, 2020). However, what factors influence handicraft producers to adopt innovation? This remains unexplored in the literature. Innovation is usually considered imperative for every company to survive and sustain competitiveness in the market (Damanpour & Schneider, 2006; Engel et al., 2004; Goldsby et al., 2018). Also, other authors considered this as an important issue, such as: Hotho and Champion (2011), Kay (1993), Maier et al. (2020), Massis et al. (2016) and Cheba et al. (2020).

Innovation can also enable companies to reap their rewards in terms of higher sales, profits, market share, and business growth (Maier et al., 2020; Yang & Shafi, 2020). In other words, "*innovation is the lifeblood of successful businesses*" (Brown & Teisberg, 2003). By contrast, innovation also has a dark side (Chopra, 2013; Gravier & Swartz, 2009), and it can threaten to destroy the operating unit's profits and lose market share (Banbury & Mitchell, 1995; Chopra & Baldegger, 2014). Similarly, innovation in traditional handicrafts is considered both crucial and controversial (Alonso & Bressan, 2014; Shafi et al., 2019a; United Nations Educational, Scientific and Cultural Organization [UNESCO], 2005). Additionally, cultural traditions are often considered as a barrier to innovation (Yang & Shafi, 2020; Chen, 2020).

On the one hand, innovation is regarded as one of the essential strategies to help handicraft firms compete, grow, and survive in the market (Ahluwalia et al., 2017; Ghazinoory et al., 2020; Goldsby et al., 2018). Being innovative can also help in increasing product value, sales, profit (Liebl & Tirthankar, 2004; Littrell et al., 1992; Paige & Littrell, 2002). It also helps increase the employment leading to professional and personal satisfaction (Shafi et al., 2019a, 2019b; Yang & Shafi, 2020).

On the other hand, innovation in crafts raises a common concern about the authenticity of the products and also challenges the traditional nature of products (Cable & Weston, 1982; Mamidipudi & Bijker, 2018; Shafi et al., 2019a). Additionally, innovation accompanies the risks of loss of centuries-old traditional production knowledge and skills. As the handicrafts are produced using conventional methods with a strong base of traditions and cultural values, hence, adoption of innovation could adversely affect the traditional characteristics of crafts (Alonso & Bressan, 2014; Shafi et al., 2019a; Zhan et al., 2017).

In this established field of research, most prior studies concentrated on the positive role of innovation in stimulating business growth. Contrarily, the negative impact of innovation on businesses is less investigated, which is a significant literature gap. Even though relevant literature recognises risks and uncertainties associated with innovation (Love & Roper, 2015; Yang & Shafi, 2020), in the case of traditional handicraft industry, innovation is both an essential and contentious factor and there is a need to balance both innovation and cultural traditions. Consequently, the adoption of incremental innovation to help handicraft firms compete and survive in the market while maintaining cultural traditions is emphasised. Incremental innovation refers to small important changes, refinements, or extensions made in existing products or production processes that result in substantial aesthetic, functional or symbolic benefits to consumers (Banbury & Mitchell, 1995; Fuchs et al., 2015; Mendozaramírez & Toledolópez, 2014). Such innovation aims to satisfy customer's needs, demands, increase product value, improve production efficiency (ease, simplify, or speed up the production process) (Verganti, 2009). It also aims to save cost and usage of raw material (reuse or reduce the material use) (Mendozaramírez & Toledolópez, 2014; Stephen, 2005; Yang & Shafi, 2020). Moreover, these types of innovations are not only sustainable but also do not affect cultural traditions and have higher chances of acceptance by consumers (Chen, 2020; Fröcklin et al., 2018).

Incremental innovation is also one of the critical sources of differentiation regarded as a competitive advantage (Banbury & Mitchell, 1995; Ghosh et al., 2017; Porter, 1998).

Furthermore, there has been a growing interest among policymakers and researchers regarding the sustainable development of businesses, including handicrafts (Kern, 2011; Maier et al., 2020; Rezaei et al., 2019). Many handicraft firms have been criticised for damaging natural resources (Yang et al., 2018; Shafi et al., 2020). Some authors explained this issue in detail. They wrote about destroying different kinds of woods used in firing pottery crafts and using toxic and hazardous raw materials like lead and Azo dye (Dissanayake et al., 2017; Sánchez-Medina et al., 2015; UNESCO, 2005). These businesses must minimise environmental concerns and adopt sustainable development practices through creative means (Sánchez- Medina et al., 2011; Lourenço et al., 2012, Throsby, 2017).

Moreover, the recent growth in fair trade movement has increased greater awareness for following sustainable practices in producing handicrafts (All India Artisans and Craftworkers Welfare Association [AIACA], 2017; Dissanayake et al., 2017; Isar, 2017). Hence, innovation should have a positive effect on the environment (De et al., 2020; Wanniarachchi et al., 2020). Incremental innovation helps handicraft firms to develop their business sustainably (Boons & Lüdeke-Freund, 2013; Chesbrough & Crowther, 2006; Fröcklin et al., 2018). Innovation has been recognised as a key mechanism for addressing sustainable development concerns (Kuzma et al., 2020; Maier et al., 2020; Seebode et al., 2012). Moreover, radical innovations are highly uncertain and embody the risks; contrarily, incremental innovations can generate positive economic, social, and environmental outcomes (Duxbury et al., 2017; De et al., 2020; Sánchez-Medina et al., 2011). Further, incremental innovation in the low technological sector, such as handicraft industry, can deliver substantial competitive benefits and better market results (Bhaskaran, 2006; Shafi et al., 2019a; Yang & Shafi, 2020). Hence, incremental innovation helps the development of handicraft firms in terms of economic, social, and environmental sustainability (Glavas & Mish, 2015; Yang & Shafi, 2020; Zhan et al., 2017). In this regard, companies and small handicraft firms are committed to the European Green Deal. It aims at greenhouse gas reduction and leveraging technology and digitalization at making Europe climate neutral by 2050. This means that the Green Deal requires green infrastructures to accomplish the goal of reducing negative environmental effects deriving from unsustainable production (UNESCO, 2008; Arbolino et al., 2018; Gavurova et al., 2021).

4.1 Innovation and Industry 4.0 technologies in handicrafts as an efficient synergy towards sustainable development

Austrian economist Joseph Schumpeter coined the term innovation in 1934 as the formation of new combinations (Schumpeter, 1934). Since then, several scholars have studied it from various perspectives (Love & Roper, 2015; Marques et al., 2019; Wijngaarden et al., 2019). However, in terms of its concept, the meaning of innovation is determined by the context where it is used.

Therefore, several authors defined innovation from different perspectives (OECD & Eurostat, 2005; Shafi et al., 2019a, 2019b). Nevertheless, Fagerberg (2004) argues that innovation generally means the "*successful introduction of something new and useful*". Hence, most of the scholars believe that innovation involves something new or significant changes aimed to help firms survive and compete in the market (Silvestre & Ţîrcă, 2019; Wijngaarden et al., 2019; Zhao et al., 2020).

Similarly, in the case of cultural creative industries, Wijngaarden et al. (2019) argue that innovation is based on three distinct patterns "*innovation as something completely new, innovation with a social impact and innovation as a continuous process of renewal*".

To a certain extent, this latter definition reminds to the sustainability topic introduced by Elkington (1998). The notable scholar first integrated the economic aspects with the environmental and social dimensions in a unique framework called "Triple Bottom Line" (TBL). Sustainability occurs only when these three dimensions are fulfilled (Wątróbski, 2019). In a similar way, innovation has three dimensions: economic as a mean to grow market share; social to improve human well-being and environmental as continuous improvement of processes till to become eco-innovation.

It is interesting to note innovation could be an outstanding enabler for sustainable production.

Furthermore, in the context of traditional handicrafts, some authors defined innovation from different perspectives. For instance, Yang and Shafi (2020) explained innovation as the "*introduction of new or significantly improved products or processes involved in the production of handicraft products*". According to Chand et al. (2014), "*innovation in handicraft businesses refers to entrepreneurs' ability to introduce unique products into the market*". The authors argue that the uniqueness of traditional products determines the competitiveness of producers. Although the traditional crafts are more decorative and unique, however, sometimes uniqueness is not enough to sustain competitiveness in the market (Marques et al., 2019). Donkin (2001) argues that the nature of handicrafts is not fixed, and over time it changes. Besides, the creation and nature of crafts change over time as societies become industrialized (Ela, 1988). Hence, handicraft producers must adopt innovation to revitalize this industry. Innovation has been frequently regarded as a vital source of a firm's competitive advantage (Schumpeter, 1934; Chand et al., 2014; Dunk, 2011). For these reasons, manufacturing firms and, especially, handicrafts, need to keep up with the new industrial challenges in order to maintain a competitive edge on the market (Girón et al., 2007; Yang & Shafi, 2020). The combination of disruptive technology and craftsmanship is crucial.

Industry 4.0 technologies allowed entrepreneurs in the manufacturing sector to overcome the problems of distances and physical barriers and bring the excellence, such as Made in Italy, to the world. Therefore, adopting the emerging technologies does not mean work in series and destroy authenticity of the single piece. Instead, it is a tool that enhances the creativity of entrepreneurs and allows handicrafts to find new business opportunities (Agendadigitale.ue). In fact, implementation of Industry 4.0 technologies in handicraft firms improve production processes' efficiency and maximise the customisation of products (Weller et al., 2015; Porter & Heppelmann, 2015).

Many scholars agree on the fact that emerging technologies increase firms' productivity, provide more efficient performances, reduce environmental impacts and give rise to more sustainable process flows (Yeo et al., 2017).

4.2 Rationale, catalysts and barriers to innovation

Factors that may influence handicraft producers to adopt innovation are highlighted. Table 18 outlines the rationale behind the adoption of innovation in traditional crafts, factors that lead to the introduction of innovation, barriers to it and relevant key references.

Rationale towards innovation in handicrafts	Description	Reference
Availability of substitute products and the low market demand for traditional handicrafts	Industrialization, mass production, increased global competition and rapid changes in customer's tastes have threatened the handicraft industry because industrial products are not only cheap, cost-effective, and satisfy the needs of the customers but are also substituting the handicrafts.	Yang et al. (2018), Scrase (2003, 2005), McAuley and Fillis (2005), Shafi et al. (2019b)
Price increase of raw materials and the shortage of natural ones	Due to the increase of price of raw material price, such as that of brass, metals, wood, shells, artisans use substitutive material easily accessible all the year, enabling them to produce crafts continuously. For instance, the traditional patchwork (Ralli) which was produced from cotton, during the last few years, the cheap polyester silk has replaced cotton. Furthermore, available natural raw materials are also in danger of extinction. Therefore, handicraft producers search for new materials.	Yang and Shafi (2020), Sachan et al. (2013), Scrase (2003), UNESCO (2005), United Nations Industrial Development Organization [UNIDO] and UNESCO (2007), Sánchez-Medina
Low efficiency of traditional technology	Handicrafts are produced through old-age traditional tools, equipment, and machines that are inefficient and uncompetitive in comparison with the modern machine-made substitutes; hence, these products are diminishing and losing their marketplace. Futhermore, modern industrialized products are generally cheap and produced in huge quantities with less time, effort, and cost, consequently, handicraft producer's try-out new ideas for improving production efficiency to achieve competitiveness in the market. Many old traditional tools also have some flaws in terms of production capacity, speed and quantity, which adversely affect purchasing orders. Particularly, when products are produced for international export, global traders require consistent quality of products with a large volume. Therefore, handicraft producers turn their focus to innovation for improving production efficiency.	UNESCO (2005), Yang and Shafi (2020), Liebl and Tirthankar (2004), Yang et al. (2018), Cable and Weston (1982), Mendozaramírez and Toledolópez (2014), Sánchez-Medina et al. (2011)
Replacement of hazardous raw materials	Many artisans still use hazardous materials to manufacture the products, which is not only harmful to the environment but also for consumers'health (i.e., in pottery, the glaze (lead) is detrimental, in textiles, the Azo dyes, due to its toxicity has hazardous effects and, they have been banned by the European Union). Handicraft producers are required to reduce or abolish the use of such dangerous materials and substitute them with environmentally friendly ones. For this reason, artisans should adopt innovation to reduce environmental concerns.	UNESCO (2005), Sánchez-Medina et al. (2015), Sánchez-Medina et al. (2011)
Higher price of traditional products	As traditional products are expensive, many retailers prefer machine-made and similar substitutes, often identical to the traditional ones. Hence, handicraft producers adopt innovation to reduce the cost of production and launch new products to attract customers. Therefore, innovation has a key role for artisans to survive and compete in the market.	Torres (2002)
Catalyst to innovation	**Description**	**Reference**

Competition with industrial products	Handicraft producers should focus on implementing innovation in their firms to meet consumer's tastes, needs, and demands. Artisans have slower lead times and more inferior quality of products than industrial companies. Innovation is a golden opportunity to compete in the market.	Ghazinoory et al. (2020), Liebl and Tirthankar (2004), Yang et al. (2018), Yang and Shafi (2020), Cable and Weston (1982)
Competitive advantage	Innovation is regarded as a key element for handicraft firms to achieve a competitive edge in the market, enhance performance and improve quality of products. Furtehrmore, product differentiation is one of the important competitive strategies that firms can adopt to outperform competitors.	Bhaskaran (2006), Freeman (1994), Shafi et al. (2019a, 2019b), Yang and Shafi (2020), Bhaskaran (2006), (1998), Barney (1991, 2001), Peteraf (1993)
Growth opportunities	Innovation in handicraft products improves a firm's performance in terms of growth in sales, profit and employment.	Littrell et al. (1992), Paige and Littrell (2002), Shafi et al. (2019a, 2019b), Yang and Shafi (2020), Chand et al. (2014), KPMG (2016), Smallbone and North (1999)
Barriers to innovation	**Description**	**Reference**
Loss of traditional characteristics in products	One of the most adverse effects of innovation in traditional handicrafts could be the elimination of their traditional characteristics and the loss of the added value. Therefore, it raises questions concerning product authenticity. In fact, whether the traditional characteristics and features of products are modified significantly handicraft products may not be considered as traditional and typical of that community.	Alonso and Bressan (2014), UNESCO/ITC (1997), Zhan and Walker (2018)
Loss of traditional knowledge and skills	Handicraft products involve centuries-old knowledge, skills, and methods of production. Therefore, innovation in products or production techniques may be harmful to the cultural values and tradition. For instance, the chemical dye industry has adversely affected the authenticity of textile traditions by replacing plant dying processes. Handicrafts constitute an essential part of local communities' identity that must be preserved and protected from the change that may lead to dilution of traditions.	Cable and Weston (1982), Mamidipudi and Bijker (2018)
Consumer rejection of innovated products	Consumers may not necessarily accept every innovated product. In some cases, even minor innovations may involve some resistance to acceptance, and if changes are perceived as disadvantageous, they will be resisted. Even, it has been reported that consumers reject and resist innovation in traditional products.	Dunphy and Herbig (1995), Cornescu and Adam (2013), Dasgupta and Chandra (2016), Pine II and Gilmore (2007), Mamidipudi and Bijker (2018)

Risk of losing the authenticity of products	Innovation also involves risk and uncertainty. An essential factor in the success of traditional products is their 'authenticity' because it characterizes the customer's subjective judgment about the product's authentic value. Therefore, if products are modified significantly (such as changes in the traditional features or characteristics of the products), such innovation will erode products' authenticity. For instance, in textile crafts, producers use traditional techniques and technologies, such as handmade threads, fabrics, and plant dyes for dyeing including manual spinning and weaving. Therefore, there are higher chances of losing authenticity of traditional products if they are modified substantially.	Pine II and Gilmore (2007), Wherry (2008), Kovács et al. (2014)
Risk of increasing unemployment	The adoption of innovation could also result in a loss of jobs. For instance, the use of high technology, including computers, means that a limited number of artisans will be involved in the production. Since most artisans belong to rural and underdeveloped areas, and they are neither highly educated nor possess computer skills; consequently, those artisans that are not skilled in using machines or computers could lose their jobs. Hence, the adoption of innovation in terms of using high-technology and computers could lead to unemployment.	Alonso and Bressan (2014), Banbury and Mitchell (1995), Chen (2020), Chopra (2013), Chopra and Baldegger (2014), Gravier and Swartz (2009), UNESCO (2005), Zhan et al. (2017)

Table 18. Theoretical framework

4.3 Deterrents to the implementation of Industry 4.0

In Figure 23 are illustrated through a SWOT analysis, which is a tool that can allow us to deeply understand what the enabling factors of Industry 4.0 are, barriers that hinder its implementation in handicraft firms, opportunities and threats.

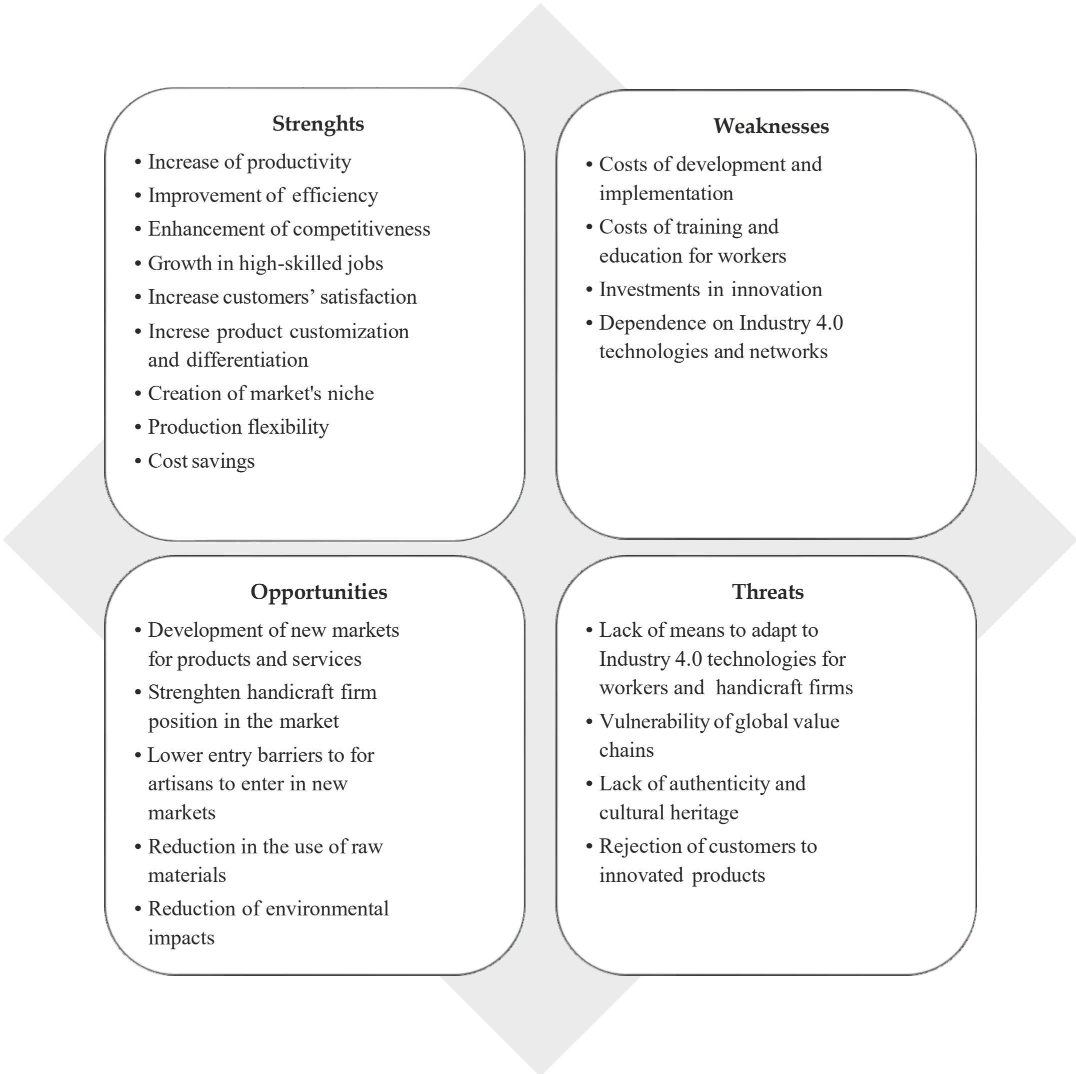

Figure 23. SWOT analysis conducted on the basis of the reviewed theoretical framework

Even though relevant literature highlights the importance of innovation in handicrafts, few studies explored the factors influencing handicraft producers to adopt innovation. In this regard, Shah and Patel (2017) conducted a research study based on interviews to a sample of handicrafts from Gujarat (India), famous for handicraft products such as embroidery, bead- work, textile printing, Bandhani (tie-dye), leather work, pottery, woodwork, stonework, etc. It was found the main reasons for artisans to not implement innovation and the emerging technologies were due to lack of training and education in this field, lack of financial aid and lack of capital, lack of knowledge about new technologies, absence of market intelligence and lack of institutional laws (Yang et al., 2018).

Similarly, Bettiol et al. (2022) presented a study about Industry 4.0 in the North Italian SMEs' production system based on a structured questionnaire. Findings revealed the adoption of the emerging technologies is still low because of a cultural thinking and strategic attitude. Furthermore, Ghazinoory et al. (2020) in their study based on interviews with key actors in the Lalejin (Iran) ceramics and pottery industry, highlighted crucial barriers to the implementation of the emerging technologies are lack of training and research in ICT technologies, low technology level, lack of knowledge and culture of innovation processes.

4.4 A balance between innovation and cultural traditions

Though the handicrafts represent the local culture and tradition, it has been argued that the customers may not demand the artistic vision that craft producers intend to express; therefore, the artisans may have to compromise their vision to match market demands in terms of product attributes (Torres, 2002). Further, the commercial success of products is not always the most important goal of production (Wijngaarden et al., 2019). Besides, we know that traditional crafts are unique, attractive, appealing, and rich in cultural traditions; however, the production of many handicrafts has been stopped. In this vein, Marques et al. (2019) argue that the uniqueness of these products is not sufficient for producers to sustain competitiveness because many crafts have been disappeared and are no more produced today. The idea of innovation is basically to perpetuate the life and richness of traditional art forms to prevent decay on account of stagnation (Deepak, 2008). In other words, handicraft producers must link their past to present by using their traditional knowledge, skills and history to make handicrafts more creative. Innovation by combining traditions enable firms to adopt strong knowledge and solutions to consumer's needs (Kivenzor, 2007; Massis et al., 2016). Similarly, Kivenzor (2007) pointed out that brands that adopt innovation through traditions can create higher product sales, and consumers not only tend to buy these brands but are also willing to pay more.

Therefore, it is extremely important to balance both innovation and cultural traditions in handicraft products. Handicraft producers should choose limited types of innovation by using their creativity and traditional knowledge to make small essential changes in the handicrafts to adapt customer's needs and demands. Moreover, due to resource scarcity, most of these businesses cannot afford the substantial investment in high-technology (Liu et al., 2020; Yang & Shafi, 2020); thus, incremental innovation is suitable for these types of low-technology firms to keep the local culture and traditions alive and achieve better market results. Additionally, it has been argued that involvement of newness or significant changes in products, services, or practices is specific to firms adopting the innovation (Bhaskaran, 2006; Johannessen et al., 2001; Penrose, 1959). This is particularly relevant for handicraft firms because small changes perceived as new to operating units or customers and still adds value for them is sufficient to enhance the competitiveness of businesses (Johannessen et al., 2001; Penrose, 1959; Shafi et al., 2019a). Most importantly, traditional handicrafts satisfy not only the functional and aesthetic needs of consumers but also symbolic needs.

For instance, Fuchs et al. (2015) argued that handicrafts "*might be perceived to contain (and perhaps even transmit) the artisan's "essence" in the form of his or her love for a product and production process in a way that machine-made products cannot*".

Hence, it becomes obligatory for handicraft producers to maintain the cultural traditions to satisfy the consumers' functional, aesthetic, and symbolic needs (Verganti, 2009).

Therefore, innovation must necessarily retain cultural values besides satisfying consumers' needs.

In other words, the innovation that maintains cultural values and traditions can be regarded as "*innovation through tradition*" (Massis et al., 2016; Yang & Shafi, 2020).

Further, as argued before, many factors influence handicraft producers to adopt innovation; therefore, it is necessary to innovate handicrafts in order that these businesses may survive in the market.

Banbury and Mitchell (1995) maintain that firms "*that do not introduce important incremental innovations eventually suffer declining market share and ultimately tend to exit the industry, either by shutting down their businesses or by selling them to other firms*."

Hence, handicraft firms should adopt incremental innovation and new technologies to compete, grow, and survive in the market. However, caution is necessary to preserve the cultural traditions while embracing innovation.

Although it is clear from the above discussion that innovation must be carefully adopted while protecting cultural heritage embodied in crafts, this chapter provides an overview of several suggestions for balancing both factors. Particularly, innovation and tradition can be balanced by adopting incremental innovation that benefits consumers and fulfill their needs, demands, increase product value, improve production efficiency (ease, simplify, or speed up the production process), or save cost and usage of raw material (reuse or reduce the material use) (Mendozaramírez & Toledolópez, 2014; Stephen, 2005; Yang & Shafi, 2020). Furthermore, the aim of incremental innovation must be to improve the products and make them more creative, useful and attractive while retaining traditional values.

There are many ways through which handicraft producers not only can adopt incremental innovation by making small essential changes in products or production processes but also keep the traditions alive.

For instance, Yang and Shafi (2020) argued that adding unique tassels or buttons to handmade clothing can create value for consumers, depending on their needs. Additionally, the border on a shawl or scarf drawn from the culture makes it unique from other craft pieces (Barber & Krivoshlykova, 2006). Moreover, new designs can be introduced based on the needs and demands of customers provided cultural features to remain intact. For instance, Marques et al. (2019) reported that in Portugal, artisan introduces new designs in traditional kitchenware and decorative pottery to revive their business while maintaining the cultural identity of the products. In addition, incremental improvement in the size of the product is also very important because handicrafts are not only sold in the domestic market but also exported worldwide. Hence, the adjustment of product size could help in transportation from one place to another (Mendozaramírez & Toledolópez, 2014; Shafi et al., 2019b). Moreover, in the case of non-primitive narrow looms, Cable and Weston (1982) contend that a simple pulley (for warp) and changed reeds will allow artisans to weave greater widths of fabric and wider lengths of warp. This, in turn, will enable handicraft producers to not only reduce preparation time but also keeping thread under a cover whole year (Cable & Weston, 1982).

Moreover, the spinning wooden wheel can be replaced with a bicycle wheel in pottery crafts to accelerate the process as it is lighter in weight and requires less force (Mendozaramírez & Toledolópez, 2014; Sánchez-Medina et al., 2011).

Besides increasing the production speed and productivity, these incremental changes also enable artisans to standardize their products to give a better finishing (Cable & Weston, 1982; Mendozaramírez & Toledolópez, 2014; Oyekunle & Sirayi, 2018).

Furthermore, greater use of eco-friendly raw materials also makes handicraft products more valuable, economical, and sustainable.

Moreover, to address the rejection of innovation in traditional handicrafts (Cornescu & Adam, 2013; Dasgupta & Chandra, 2016; Pine II & Gilmore, 2007), it is extremely important that the innovation must be perceived as advantageous and must not compromise the traditionality of products. When the traditional handicrafts are carefully linked with modernization and aesthetics, they will find consumers and gain value.

4.4.1 Incremental innovation and sustainable development

Innovation and sustainability establish an essential association in the quest for economic, social and environmental development; moreover, innovation is considered a necessary tool for achieving sustainable development (Kuzma et al., 2020; Seebode et al., 2012). Therefore, handicraft producers must continuously invest in innovation processes to achieve business sustainability (De et al., 2020; Maier et al., 2020; Wanniarachchi et al., 2020). Incremental innovation in handicrafts has a significant impact on the sustainable development of craft businesses.

Hence, relationship between incremental innovation and sustainable development of handicraft firms in terms of economic, social, and environmental sustainability are discussed.

4.4.2 Incremental innovation and economic sustainability

In comparison to radical innovation, incremental innovation is widely adopted, relatively easy, inexpensive and can be implemented very quickly leading to the growth of more competitive and profitable small firms (Bhaskaran, 2006; Herrera & Sánchez-González, 2012). Besides, in comparison to radical innovation Kim et al., 2011, it requires less time, resources and involves little or no risk (Garcia & Calantone, 2002; Shafi et al., 2019a; Yang & Shafi, 2020). Hence, it can be considered an economically viable option for the economic sustain- ability of handicraft firms.

Further, incremental innovation can help to reduce cost, increase efficiency, functional improvement of tools or equipment such as ease of use, higher user-friendliness, and production capacity enhancement. For instance, an improvement in product design can mean less use of materials, which not only improves product appearance and utility but also reduces cost, and, thus, the selling price (Oyekunle & Sirayi, 2018). A simple modification in tools can also help handicraft producers to achieve higher productivity gains. In the case of jewelry, the existing cutting and polishing methods are very slow, the small incremental changes such as the adoption of electric machine could help artisans to increase the productivity and better finishing of the products (Cable & Weston, 1982). In a similar manner, incremental changes in production techniques can also lead to the economic sustainability of handicraft businesses. Marques et al. (2019) reported that black pottery artisans in Portugal innovated the firing process by making shelves in the kiln and firing pottery in a traditional way with wood without keeping products on top of each other as was once customary.

Moreover, the incremental innovation in handicrafts is one of the most important activities in terms of economic benefits such as an increase in sales and profit (Barber & Krivoshlykova, 2006; Yang & Shafi, 2020). Thus, incremental innovation is one of the best choices to maintain cultural traditions and achieve economic sustainability.

4.4.3 Incremental innovation and social sustainability

The incremental innovation enables handicraft firms to obtain several social benefits such as improving quality of life, achieving personal and professional satisfaction, and also as- sist in maintaining craft and cultural orientation (Shafi et al., 2019a; Yang & Shafi, 2020). The incremental innovation also yields economically viable livelihoods with minimal capital investment – while using "traditional" technology with partial modification and producing high-quality products (Mamidipudi & Bijker, 2018; Mendozaramírez & Toledolópez, 2014). In this way, handicraft producers not only can compete in the market but also keep the cultural traditions alive and motivate the young generation to choose this line of work willfully for maintaining social sustainability. Besides, it will also promote and protect the identity of the local community that help to create, foster, and enable cooperative development among community members (Wanniarachchi et al., 2020). As specific communities produce the handicrafts in a region, hence, incremental innovation can help in the social development of local communities through generating higher employment and income opportunities.

Thus, incremental innovation helps handicraft producers to increase income and employment opportunities, which, in turn, enable them to not only pay off debts but also cover basic food and health needs (Sehnem et al., 2020; Toledo-López et al., 2012; Yang & Shafi, 2020). Moreover, it will also improve the social identity of local communities because handicrafts are strongly linked to a particular place (Vandecandelaere et al., 2010; Howard & Pinder, 2003).

4.4.4 Incremental innovation and environmental sustainability

Incremental innovation also promotes environmental sustainability through reuse, recycling or remanufacturing. For instance, in the case of textile crafts, fabrics of the product can be re-dyed, depending on the compatibility of the exiting color of the textiles, in other words, after using textile products, consumers can return it to the artisan and get it re-dyed with a new look (Wanniarachchi et al., 2020). Furthermore, handicraft producers also attempt to reuse materials that they employ (Barber & Krivoshlykova, 2006; Yang & Shafi, 2020). In many countries such as Sri Lanka, there is a market for reusing handicrafts such as sarees (a type of clothing around 5 meters worn mostly in South Asia); particularly, handmade sarees can be reused by upgrading to manufacture other products such as dresses or skirts (Dissanayake et al., 2017; Wanniarachchi et al., 2020). Incremental innovation also helps to reuse waste (Sánchez-Medina et al., 2015). For instance, discarded textile crafts can be converted into valuable by-products, even left-over fabric of textiles can be reused to create by-products such as handmade soft toys, bed runners, pillowcases, tablecloths, and various types of other accessories (AIACA, 2017; Dissanayake et al., 2017; Wanniarachchi et al., 2020). In addition, even the waste threads can be reused to decorate or make products more useful and unique such as creative lampshades in various shapes and attractive colors (Dissanayake et al., 2017). Moreover, the small left-over pieces of cloths, including uneven pieces, can be reutilized very creatively to produce useful, decorative, unique and attractive patchwork such as quilts.

Sánchez-Medina et al. (2011) also argue that many handicraft firms are very well aware of the environmental concerns, and they adopt innovation by using lead-free clay and lead-free enamels to reduce the adverse impact on the environment. Further, in the case of textile production, earlier cotton was overly used as raw material, and now sustainable fibers (such as banana and bamboo fibers) are increasingly used (Wanniarachchi et al., 2020). There is also an increasing demand of naturally dyed products, therefore, the handicraft producers are now looking for developing new means of using natural dyeing processes (Wanniarachchi et al., 2020). Similarly, Mutua et al. (2004) argue that few textile craft producers are now using recyclable materials, such as colored plastic paper, to decorate baskets to address the shortage of raw materials. This is a positive approach to the problem of a reduced supply of raw materials and environmental protection. As natural raw materials are limited, handicraft producers use new and renewable resources (Sánchez- Medina et al., 2011; Yang & Shafi, 2020).

However, as it had been said by F. Halila, there are at least two good reasons why we should support the adoption and diffusion of environmental sustainability and eco-innovations. One argument from an environmental point of view is that successfully managing the environment is the greatest challenge. Another argument, from an economic point of view, is that the eco-industry is one of the most growing industries in the world (Halila & Hörte, 2007).

4.5 Analysis

Although innovation has been regarded as one of the necessary ingredients for firms to survive and compete in the market, previous studies did not identify the factors that influence handicraft producers to adopt innovation in a holistic way.

Many scholars considered that identical mass-produced products, low market of traditional products, increasing raw materials price, inefficient technology, substitution of toxic raw materials, and higher price of traditional crafts influence handicraft producers to adopt innovation (Brown & Teisberg, 2003; Engel et al., 2004; Goldsby et al., 2018). Further, most prior relevant studies are directed towards the positive nature of innovation (Hotho & Cham- pion, 2011; Kay, 1993; Massis et al., 2016). Contrarily, the adverse impact of innovation in traditional industries is less understood (Alonso & Bressan, 2014; Banbury & Mitchell, 1995; Chen, 2020). Especially handicrafts industries are being not necesseraly mixed with innovation activity in general (Chopra, 2013; Chopra & Baldegger, 2014; Gravier & Swartz, 2009).

On the one hand, innovation can help handicraft producers to compete, grow, and survive in the market. On the other hand, it accompanies the risks of loss of ancestral knowledge, skills, and cultural heritage embodied in crafts. Besides, the innovation in handicrafts may damage the authenticity and traditional nature of handicrafts (Alonso & Bressan, 2014; Zhan et al., 2017; UNESCO, 2005).

This Chapter also argues that innovation should be adopted with caution because changes to a certain extent could result in the loss of products value that is mainly due to the traditional nature of handicrafts. Arguably, handicraft producers must embrace a balancing approach by adopting an incremental innovation strategy to survive and achieve competitiveness while maintaining and preserving cultural heritage. It will allow them to not only capture market share, earn more income, and grow their business but also promote, reinforce and protect local cultural traditions. Further, the introduction of incremental innovations will increase the chances of business survival and achieving financial and non-financial benefits leading to the promotion and continuation of cultural traditions, ethnic artefacts, customs of local communities and geographical features of crafts produced with love (Fuchs et al., 2015; Sehnem et al., 2020; Shafi et al., 2019b). Additionally, the combination of incremental innovation and cultural traditions is the driving force behind the revival of the handicraft industry (Marques et al., 2019). Firms that continuously adopt incremental innovation are likely to survive and sustain competitive advantage (Banbury & Mitchell, 1995). Moreover, the incremental innovation adopted by firms with strong links to tradition, culture, and history will have higher chances of acceptance by consumers (Chen, 2020). Hence, handicraft producers must use their past traditional knowledge and skills to satisfy consumers' needs by adopting incremental innovations.

Although the innovation is essential to innovate the products successfully, the traditional production processes have been handed down for many years, which is the added value of handicrafts that can only be adjusted appropriately but cannot be omitted (Jia, 2018). Similarly, handicraft producers also do not intend to diminish their cultural traditions; there- fore, they are also reluctant to adopt radical innovation. Instead, they prefer to preserve and promote their traditional identity, cultural aspects and only embrace incremental innovation. For instance, Mendozaramírez and Toledolópez (2014) contend that handicraft producers are aware of the importance of cultural traditions and are also reluctant to change; therefore, they only adopt incremental innovation to simplify and ease the production processes. Hence, the innovation should only involve small important changes to satisfy customer's needs, demands, increase product value, improve production efficiency (ease, simplify, or speed up the production process), or save cost and usage of raw material (reuse or reduce the material use) (Mendozaramírez & Toledolópez, 2014; Stephen, 2005; Yang & Shafi, 2020).

Theoretically, there are also several possibilities to introduce incremental innovation with tradition in handicraft products without compromising the essential traditional characteristics of the products (Kivenzor, 2007; Massis et al., 2016; Molina et al., 2014). In general, innovations that improve quality, functions, aesthetic, and symbolic value of products are reasonably accepted, provided they maintain cultural traditions (Verganti, 2009; Yang & Shafi, 2020). However, consumers mostly reject innovations that alter authenticity, traditional motifs, and emotional link between products and peoples (Chen, 2020; Fuchs et al., 2015).

This Chapter provides several recommendations for policymakers and practitioners in making decisions when implementing innovation in traditional handicrafts. Mainly, handicraft producers must not forget their past, instead should combine their old knowledge and traditions with current market trends and adopt incremental innovation to satisfy consumers' needs and demands, leading to the promotion and preservation of local cultural traditions (Massis et al., 2016). Moreover, although handicraft firms face resources scarcity, they are rich in traditional knowledge and skills (intangible resource). Following the resource-based view of firm theory (J. Barney, 1991; J. B. Barney, 2001; Peteraf, 1993), the inherited cultural traditions are distinctive and immensely unique resources of handicraft firms. The deeply rooted religious and cultural connotations make an imitation of these resources more difficult, thus contributing to their rarity and competitiveness (Teec & Pisano, 1994; Teece et al., 1997; UNESCO/ITC, 1997). Therefore, it is extremely important to combine innovation, also through the emerging technologies, by utilizing past knowledge to achieve sustainability and competitive edge in the market (Blundo et al., 2018). This balancing approach will enable practitioners to discover new opportunities and leverage current capabilities to allow handicraft firms to succeed and compete in the market.

Besides balancing innovation and traditions, incremental innovations also contribute to the sustainable development of handicraft firms in terms of economic, social, and environmental sustainability. Further, buyers prefer to buy those handicrafts that have a minimum adverse impact on the environment (Sánchez-Medina et al., 2015), therefore, when adopting incremental innovation, handicraft producers must follow sustainable practices including the use of recyclable, local, environmentally friendly, and reused material wherever possible to obtain sustainable results (J. Brown, 2014; Mutua et al., 2004; Sánchez-Medina et al., 2015).

The key to balance innovation and tradition is making important small changes instead of a few big ones. Most of the previous studies usually focused on the positive aspects of innovation. However, this study confirms that innovation in handicrafts is both imperative and controversial. Since cultural traditions are deeply rooted in handicraft products and innovation is an essential factor for business survival and growth; therefore, both are necessary to achieve competitiveness. Additionally, cultural traditions that lack innovation are likely to become obsolete, while growth without foundations may lead to precarious- ness. Although innovation is one of the essential factors for business growth, it is hard to balance this growth with cultural traditions. Therefore, handicraft producers must carefully adopt incremental innovation, as discussed in this study, to survive, grow, and achieve better market results as well as maintain cultural values, identity, and history of local communities. Consequently, it will enable handicraft enterprises to differentiate between their products and those of competitors (mass-produced) and offer intangible advantages leading to improving their value and increase the likelihood of acceptance in the marketplace.

A more holistic view of innovation in traditional handicrafts to help policymakers and practitioners to streamline their strategies for sustainable development of the handicraft industry is carried out. Mainly, for policymakers and practitioners involved in the production of traditional crafts, this study offers several practical insights. First factors influencing handicraft producers to adopt innovation help us to understand the justification for embracing innovation. Second, positive and negative aspects of innovation enable the producers to gain deeper insights about the nature of innovation and its effects on the traditionality of products. Third, the balanced combination of incremental innovation and cultural traditions deeply rooted in crafts can help handicraft firms to achieve competitiveness and sustainable development. Understanding the nature of multifaceted innovation and retaining cultural values in products is essential for the sustainable development of handicraft companies.

Further, incremental innovation not only ensures the survival of both tangible and intangible cultural heritage for next generations but also help handicraft firms to achieve economic, social, and environmental sustainability because sustainable development of firms is only possible by creating new ideas through cultural traditions. Moreover, carefully implemented incremental innovations benefit not only handicraft firms but also the society and environment. Additionally, handicraft firms can create higher value in the mind of consumers and enhance their market position by balancing innovation and tradition.

Discussion

The integration of Industry 4.0 technologies, Lean Manufacturing and Circular Economy join the traditional aspects of sustainable production with the need to digitalise supply chains and better understand the social, environmental, economic and managerial challenges of the growing demand for smart production, rapid and resilient process flows and for greener products and processes (Luthra et al., 2018).

Therefore, the novel integrated managerial approach identified and analysed in Chapter 1, based on Study I and Study II (Ciliberto et al., *Forthcoming publication*; Ciliberto et al., 2021) may support companies to improve processes and operations in the shift towards zero waste production through the adoption of Lean Manufacturing methodologies in supply chain and endorses the existing theoretical literature on the role of "enabler" attributed to Industry 4.0 technologies (Ghobakhloo and Fathi, 2020).

Indeed, Industry 4.0 technologies, reviewed in Chapter 1, make it possible to:

- improve production processes;
- support industrial automation processes;
- facilitate collaboration between companies.

Thus, the new production processes are based on:

- production technologies using new materials;
- robotics;
- mechatronics;
- ICT technologies for process virtualisation;
- people enhancement systems.

In this regard, automation symbolises a help, not a loss of work, as it reduces/eliminates repetitive work, not intellectual work, prompting staff to focus on the use of intellectual skills and not physical ones. New automated solutions include:

- interconnected and easily programmable robots;
- 3D printers linked to digital development programmes;
- augmented reality tools to be applied to production processes;
- simulation between interconnected machines to improve processes;
- vertical and horizontal integration for the integration of information along the entire value chain, and thus to further improve partnerships with suppliers;

- multi-directional communication;
- management of huge amounts of data within open systems;
- cloud network and open systems security;
- analysis of a wide range of data to improve products and processes.

At the same time, the Multicriteria Decision Making model (MCDM) used in the Testing phase (Chapter 2) demonstrates that the supplier selection is a complex issue that requires systemic thinking in which Lean Manufacturing principles and economic, social, environmental and technological dimensions play a decisive role.

In this regard, it emerged that the enabling factors that may lead towards Sustainable Production processes are those supported by Lean Manufacturing principles and the emerging technologies, as considered in Chapter 2 supported by Study III (Caristi et al., 2022).

Therefore, implementing Lean Manufacturing and Circular Economy principles through the support of Reverse Logistics in supply chains, as a strategic business model for solving waste elimination and cost containment problems, the features of the Circular Supply Chain, as examined in Chapter 1, 2, 3 and 4 can be extrapolated:

- adoption of quality principles to increase customer satisfaction;
- management of production following the pull logic (and no longer push as in the past), according to which it is the customer who pulls the production of a given product; the organisation initiates the production process as soon as its demand manifests itself on the market;
- elimination of warehousing, thanks to the reduction of raw materials purchased with each delivery; the supplier delivers to the customer's plant only the quantity that has been ordered corresponding to that required to manufacture a given product;
- application of Just in Time within the supply chain, connected with the elimination of the warehouse is the ability of all suppliers to deliver the quantity required by the customer at the right time;
- continuous improvement, all actors in the chain must strive to improve both within their organisation and within the chain by collaborating with others to adopt and implement common actions;

- flexibility and resilience, the supply chain must not be static and wait for things to change but must be reactive and flexible in order to be able to anticipate, when possible, changes in demand and immediately implement a response, whether it consists of simply changing the product or designing a new one;
- establishment of mutually beneficial relationships with the actors of the chain, the creation of a chain (even if in some cases it is a real network) implies that real relationships based on trust and collaboration are created between its members; survival is given by the ability of all to act for the common good;
- exchange of information, actors should exchange all necessary operational and strategic information; the creation of trust should push organisations to be more willing to share sensitive information together with skills and past experiences;
- removal of waste and eco-efficiency along the entire chain, the main objective of Lean Production and Circular Economy also plays a decisive role in the Circular Supply Chain;
- cost containment, linked to the previous point, is the continuous search for cost containment solutions without detriment to the quality to be offered to the customer for his satisfaction.

Thus, the enabling factors, domains and goals of the circularity of supply chain in production and operations, specified in Chapter 3, suggest that, despite the crucial role of the implementation of Industry 4.0 technologies, it is essential improve process efficiency through Lean Manufacturing methodologies both in terms of Lean waste and in terms of variance in order to digitise already optimised processes.

To conclude, from an economic perspective, Circular Supply Chain increasingly reduce energy use and material waste, while simultaneously moderating times and costs production (Kamble et al., 2018; Kusiak, 2017; Fosso Wamba et al., 2015). At the same time, Industry 4.0 technologies allow flexibility towards customer requests and increase productivity without burdening company finances with additional expenses (Luthra et al., 2019). However, the significant costs of designing, installing, integrating, maintaining and reprogramming the emerging technologies may constitute a barrier for Small and Medium Enterprises (Shafi et al., 2019a), also taken into account in Chapter 4.

In this regard, incremental innovation made up of continuous and small technological improvements could represent a viable solution for Small and Medium Enterprises.

According to the literature on the environmental and social impacts, a Circular Supply Chain is one that tries to limit negative environmental and social impacts at all stages: from the manufacture of a product and its storage to delivery to the customer (Geissdoerfer et al., 2020).

Indeed, a Circular Economy Rebound effect may occur. It happens when a Circular Economy practice, which reduces per-unit production impacts, causes increased levels of production and consumption that offset the environmental benefits (Zink and Geyer, 2017) and may lead firms engaged in circular strategies to overstate their environmental performance, indulge in greenwashing, and undermine their economic prosperity and sustainability.

To achieve its intended objectives and avoid this phenomenon, Circular Economy requires reshaping production and consumption patterns through circular Operations and Supply Chain Management strategies, such as the establishment of circular production systems (Zerbino et al., 2021).

The "State of Supply Chain Sustainability 2020" study by the Massachusetts Institute of Technology (MIT) argued that circularity can be achieved through sustainable resource management (energy, water, raw materials, etc.) and the use of renewable energy. To do this, it requires the collaboration of all players involved in the supply chain, from the suppliers of raw materials, packaging to the transport agencies responsible for order distribution (Hussain and Malik, 2020). All of them must unify their efforts, promote concrete actions such as the use of raw materials of sustainable origin or the rationalisation of the resources used.

Contributing to the circularity of the supply chain provides important benefits:

- Lowering costs. Companies that reuse raw materials manage to significantly reduce their expenses.
- Improved corporate image. Companies that are truly concerned about the environment, and implement environmentally-friendly strategies accordingly, will gain reputation and be more competitive.
- Innovation and progress. The strategy of circularity in the supply chain consists of introducing new processes and redesigning distinct organisational practices. As a result, products can be improved and new business opportunities can be found, contributing to the progress and innovation of companies.

It is clear that a Circular Supply Chain is no longer just a matter of image, but has become a necessity and a strategy that benefits companies, as well as strengthening their relationship with the environment and society.

Conclusion

The results of the Thesis, explained in the five papers that constitute the research, provided the following observations to the research questions concerning the analysis of the trilateral relationship among Industry 4.0, Lean Manufacturing and Circular Economy to achieve sustainable production and the empirical demonstration on the crucial role of lean principles and emerging technologies at micro-level in Circular Supply Chain:

1. the proposed integration of Industry 4.0 technologies, Lean Manufacturing and Circular Supply Chain management to achieve sustainable production processes is able to overcome the limitations that the traditional approach has had to encounter;
2. Lean Manufacturing embedded with Industry 4.0 technologies and Circular Supply Chain Management represents an advanced Circular Production Strategy towards zero-waste and an enabler for technological innovation in Supply Chain 4.0 and in business models;
3. Industry 4.0 is a productive formula which introduces innovation and represents the new bridge between human and machine interactions and a facilitator towards the achievement of Circular Economy business strategies;
4. before digitalising and robotising it is crucial improving efficiency both in terms of Lean waste and in terms of variance and efficiency for Six Sigma in order to be able to "feed" Industry 4.0 with a product that is already optimised and ready for digitalization;
5. incremental innovation (i.e. implementation of Industry 4.0 technologies) is the key to balance innovation and tradition and head towards sustainable production;
6. in order to achieve circular performances in industrial processes, managers should be pushed to reach a smarter and more circular production system in their companies through the simultaneous implementation of emerging technologies, Lean Production methodologies and Circular Supply Chain management principles and, policy makers must be made aware on the need to implement policies that aim at enabling the digital transition and foster digitisation also in Small and Medium enterprises, preserving, at the same time, cultural heritage.

As regards the first objective, Chapter 1 confirm the significant role of Lean Manufacturing and jointly with Chapter 2 and Chapter 3 endorse that Industry 4.0 tools, adopting Lean Manufacturing and Circular Economy principles, through the support of Reverse Logistics, exploiting data collection and inventory information, are able to help companies achieve sustainable production and carry out evaluations of environmental, economic and social impacts.

In this sense, both academic and industrial sectors must focus on finding optimal strategies that will adopt new digital technologies enabling the promotion of sustainable development principles as a competitive business strategy. In this productive environment the supply chain can be flexible, smart, integrative, resilient and responsive thanks to technology and Lean Manufacturing. At the same time, it can be lead towards zero-waste and circularity through the adoption of Circular Economy principles and with the support of Reverse Logistics.

With regard to the second objective concerning the empirical evaluation of the novel holistic approach on the simultaneous integration of the emerging technologies, the importance of Lean Manufacturing was tested and evaluated in Chapter 2, with reference to the proposal and analysis of an MCDM model for suppliers' selection, applied to a case study, regarding a Vietnamese textile industry. It was elaborated a framework of five main criteria and 14 sub-criteria, through interviews to the three managers of the company case study. These criteria, included in the supplier selection process, resulted to be in line with the Just-in-Time principles drawn from the Lean Manufacturing theory. In this sense, they were adopted in the model to reduce lead time, rapidly satisfy customers' needs and, therefore, achieve a sustainable supply chain, which is a circular production system with a zero-waste perspective.

At the same time, the results of Chapter 3 confirm that Lean methodologies are able to reach zero defect manufacturing and zero waste and have beneficial effects on circularity in a technology-driven supply chain of an Italian hospital. In addition, it is crucial to adopt incremental innovation in Small and Medium Enterprises, as prospected in Chapter IV, to gain sustainable production processes, lead entrepreneurs towards the technological and environmental shift and foster the systemic and holistic integration of this novel and intertwined approach.

Thus, the theoretical contribution of the Thesis consists in the expansion of the traditional Lean Manufacturing theory including environmental aspects and in contributing to highlight the positive role of Industry 4.0 as an essential environment where redesign flows, processes, and targets. Furthermore, Lean methodology becomes a crucial aspect of the effective implementation of Supply Chain Management with regard to cost and time containment and responsiveness to customer needs.

At the same time, the thesis contains managerial implications pushing managers and entrepreneurs to adopt a different managerial approach to ease the shift towards the environmental and digital transition and increase the resilience of Small and Medium enterprises (SMEs), coping with change management and innovation. The novel approach they are called to implement, consisting in the integration of Lean Manufacturing, as methodological support to Supply Chain Management, Industry 4.0 technologies, as a technological environment and, Circular Economy, as a management strategy to achieve sustainable production and Circular Supply Chain in which including Reverse Logistics, may help companies to gain a competitive edge in the global market.

Furthermore, managers should consider deployment of Lean culture and methodologies a decisive point that may lead to breakthrough improvements in implementing novel business strategies in their companies.

In addition, the Thesis offers potential insights on the need for policy-making interventions at national and European Union level able to lead the production model from a linear one to a "Circular Economy" model. Policy-makers should take into consideration the need to fight digital divide, lack of implementation of Industry 4.0 technologies in SMEs through appropriate policies able to preserve local and national cultural heritages.

Limitations are also present. First of all, limited generalizability of the study. Thus, in terms of future perspectives, most of these aspects can lead to further research directions regarding both the empirical evaluation of Circular Supply Chain, also through multiple case studies, and their development in practice.

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