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Master Thesis

The Role of Digitalization in Achieving Sustainable and Resilient Supply Chain

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To my dear family…

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ABSTRACT

The rapid adoption of digital technology in the supply chain due to the Industry 4.0 revolution has accelerated the need to restructure and redesign the processes of the traditional supply chains. However, in today's hectic and competitive markets, technological transformation alone cannot guarantee success. In contrast to the conventional thinking which establishes supply chain strategies solely taking into account the financial aspects such as lowering minimizing costs, accelerating delivery time, etc., supply chain performance managers (SCPM) have to consider sustainability practices as well, since market demands have shifted in such a manner that a company's environmental and social performance are now seen by customers as being just as significant as its economic success.

On the other hand, the COVID-19 epidemic heavily disrupted supply, demand, and logistic infrastructure all around the world, further proving to the supply chain managers that considering resiliency to evaluate a supply chain's performance is an inevitable fact. Taking into account both sustainability and resiliency, a major conflict arises since sustainability generally focuses on efficiency, while resilience seeks effectiveness. In this regard, scholars and practitioners have redirected their focus on creating a more sustainable and resilient supply chain.

Therefore, it is necessary to analyze the intersection of supply chain sustainability and resilience as well as the role of digital technology in empowering the enablers of both sustainability and resiliency. While both digitalization and sustainability concepts in the supply chain are more established and general agreement on their theoretical foundations exists, the literature on supply chain resilience is relatively immature. There are some studies on the application of industry 4.0 in both areas while there is no clarity on what practices could jointly advance both areas, and how digitalization, sustainability, and supply chain resiliency can be linked. To bridge this gap, a systematic literature review (SLR) has been conducted to examine the potential research contribution, main concepts, integration, and directions of digitalization, sustainability, and resiliency in the supply chain and most importantly the role of industry 4.0 on improving resiliency enabler's and sustainability is clarified. The study will be also useful for future studies in identifying research directions based on existing literature covered in this paper in the field of the supply chain.

Keywords: Digitalization, industry 4.0, sustainability, resilient supply chain, resiliency

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1. INTRODUCTION

The global spreading of COVID- 19 causes numerous impacts on the sustainability of worldwide production and consumption of various commodities. It shed light on previously unseen vulnerabilities of supply chain. Many organizations have suffered employee shortages and losses due to COVID-19. As an instance, during pandemic the sever disruption happened for Asian suppliers and propagated downstream in the SCs, leading to material shortages and even the shutdown of facilities on other continents (Hosseini and Ivanov, 2020). Food supply systems were soon affected by the epidemic, and the variety of products were limited. Therefore, customers panicked and bought products more than their actual need (Ozdemir et al., 2022). Although the concept of resiliency exists many years ago, according to the distribution of articles over the years, we saw that it stated to gain more attention in 2016 and again saw a sharp increase in 2019 which COVID-19 outbreak disrupt many enterprises all around the world. The COVID-19 outbreak has simultaneously impacted supply, demand, and logistical infrastructure, underscoring the need for a change in the established supply chain paradigms. Hence, it increased attention to the resilience and its related subjects (Golan et al., 2020). Companies spent a lot of time during the epidemic discussing the idea of resilience, which has since become one of the main viewpoints in Supply Chain Management (SCM). On the other side, COVID-19 pandemic appeared as an additional proof of the interdependence between the three sustainability dimensions. Supply chain disruptions had impact on many different industries' economies, after decrease in tension, some industries haven not fully recovered. As quarantine affected the lifestyle of individuals, new social sustainability standards appeared. For instance, social distance has led to a rise in remote and virtual work, a decrease in in-person interactions, closing non-essential businesses, canceling sporting events, conferences, cinemas and etc. (Sarkis, 2020). During the pandemic, some industries emerged as clear winners, and practitioners and academics work to assist firms in returning to their prior performance levels or even gaining a competitive advantage and achieving superior performance. Other controversial subject during COVID-19 was around digitalization. There is debate over whether the deployment of digital technologies actually improves performance, particularly supply chain performance (Ralston and Blackhurstb, 2020). Borrett, (2021) reported that the enterprises that have been quick to deploy digital technologies appear to experience higher revenues and better performance during outbreak. According to Westerman et al. (2013) digitalization will increase revenue by 9%, profitability by 26% and market value by 12%.

Since the importance of sustainability and resiliency is even more clear today, this in this article we try to shed light on the main concepts and further examine the crucial role of digitalization on SC resiliency and sustainability through extensive systematic literature review. The systematic literature review (SLR) approach is built on a scientific, explicit, specific, and rigid set of guidelines with the aim to clarify specific issues in-depth and give academics and practitioners a holistic view regarding that issue (Tranfield et al., 2003; Briner and Denyer, 2012). Therefore, to improve methodological robustness and coherence of the review, in this study we follow the five-step guidelines of Denyer and Tranfield (2009) to conduct SLR (see Figure 1). Based on this guideline in the first step the review questions must be carefully established, to avoid ambiguity.

In the second step, the methods for finding studies, such as the databases that are used, must be mentioned. In the third step, the inclusion and exclusion criteria must be specified. In step four, studies are analyzed individually and ultimately will be grouped based on the similarities, differences, and relationships between their main elements. Finally, in step five, the study questions will be answered based on the data extracted in the former steps (Ali et al., 2017). Grounded on the five-step guidelines of Denyer and Tranfield (2009), the rest of the study is organized as follows:

In **Section 2**, the research objectives are defined. In **Section 3**, we evaluated the theoretical underpinnings of the key concepts connected to our study and presented the key conceptual categories upon which we based our review. **Section 4** presents the methodology of the review study. In **Section 5** the results of the analysis of the reviewed literature are presented. Finally, in **Section 6** conclusions are drawn based on the findings, the research questions are answered and further research directions, stemming from the study's limitations are mentioned.

2. RESEARCH OBJECTIVES

Although the ideas of digitization and sustainability in the supply chain are more well-established and there is widespread consensus over their theoretical underpinnings, the literature on supply chain resilience is still in its infancy. There have been several studies on the use of industry 4.0 in these two sectors, but it is unclear what practices may help these sectors grow simultaneously or how digitalization, sustainability, and supply chain resiliency can be related. In order to close this gap, a systematic literature review (SLR) has been carried out to look at the main ideas, integration, and future directions of digitalization, sustainability, and resiliency in the supply chain. Most importantly, the impact of industry 4.0 on strengthening resiliency enablers and sustainability has been clarified. We contribute to the literature by reviewing the challenges of current research, and, more importantly, identifying and proposing future research directions.

2.1. Research Question Formulation

As mentioned in the introductory section, the initial stage of a SLR study is to specify the study's objectives by formulating the review question (Rousseau et al., 2008). To this end, we organize our study around the following main research questions (RQ):

RQ1: What is the magnitude and sign of the effect of digitalization on sustainable-resilient SC?

RQ2: What are the main technologies that have the most effects on sustainability and SCR?

RQ3: In which way digitalization, sustainability, and supply chain resiliency can be linked?

More specifically, in this study, we argued that how digital transformation under the umbrella of Industry 4.0 technologies will revolutionized the SC specially in terms of sustainability and resiliency. Former articles only focused on digitalization effects on particular part of supply chain while the focus of this study is on sustainable-resilience paradigm. Using peer-reviewed articles we will extract the magnitude and direction of this effect. More importantly we drive which technologies are considered more effective for this purpose and finally, in which way they can be linked to result in superior KPIs and competitive advantage.

3. THEORITICAL BACKGROUND

3.1. Supply Chain Resilience Concept

In this section we will discuss the theories that is used to define Supply Chain Resilience (SCR) in connection with digitalization. Resilience is a multidisciplinary concept and there are many different definitions regarding its concept, despite the differences in the proposed SCR definitions, certain similarities can be seen, such as being prepared for disruptions by anticipating them and their effects, enduring disruptions, responding quickly to disruptions, and recovering from them. Usually, articles investigate SCR in two different phases, pre-disruption (proactive) and post-disruption (reactive) stages (Chopra and Sodhi, 2014; Hosseini et al., 2019; Elluru et al., 2019), however, other papers analyze SCR in even more phases and count the period during the disruption as a separate phase (during-disruption) (Ali et al., 2017; Singh et al., 2019; Zavala-Alcívar et al., 2020).

Supply chain resilience concept itself is examined based on resilience capacity framework or based on the elements of SC. Initially, the concept of resilience capacity established by Vugrin et al. (2011) which define resilience as the "ability to reduce efficiently both the magnitude and duration of the deviation from targeted system performance levels". According to this framework, resilience capacity is consisting of three main capacities, Absorptive Capacity, Adaptive Capacity, Restorative Capacity. Therefore, the capacities in this framework are correspondent to the similarities in the SCR definitions. disruptions, and returning to steady state conditions. Absorptive Capacity is defined as the ability of a system to absorb the impact of disturbances and limit the effects of it with low effort, and it is pertained to the reactive stage of supply chain. Supplier separation, use of several sourcing strategy, inventory positioning, and numerous modes of transportation are some of the actions that will enable absorptive capacity (Torabi et al., 2015; Hosseini and Barker, 2016; Ivanov et al. 2017a,b; Ivanov, 2018). Adaptive Capacity is defined as the degree to which a system can adjust itself and try to overcome disturbances by applying nonstandard efforts (attempt different from normal condition), backup supplier, rerouting, communication, and replacement are actions that promote adaptive capacity, some articles considered it as after-disruption capacity while others considered it as a capacity that is useful during the phase that system is facing disruption. While some scholars regard it as post-disruption capacity, others consider it as a capability that is beneficial while the system is experiencing a disruption (during-disruption phase) (Hosseini and Barker, 2016; Hosseini and Khaled, 2016; Jabarzadeh et al. 2018; Wang et al. 2016). Absorptive and Adaptive capabilities are respectively the first and second layer of defense against interruption, if they are not able to neutralize the effect of disruption, the system must reconfigure itself to retrieve the acceptable level of performance (performance level before disruption). Enablers of restorative capacity include financial stability, reconfiguration of resources, and supplier adjustment (Turnquist and Vugrin, 2013; Hosseini and Barker, 2016a; Sahebjamnia et al., 2018). Differently from resilience capacity framework, some scholars may concentrate on specific section of the supply chain and extract the appropriate resiliency strategy related to that section, Ivanov et al (2019) considered physical supply chain with four sections namely: supplier, factory, wholesale and retail, and analyzed the impact of digital transformation on supply chain resilience. Ho et al. (2010) and Jabarzadeh et al. 2018

studied resiliency only under supplier section by solving By resolving the supplier selection problem and examining its impact on resiliency.

3.2. Supply Chain Sustainability Concept

development that satisfies present demands without compromising the ability of future generations to satisfy their own needs is considered as sustainable development (Seuring and Müller, 2008). Supply chain managers have traditionally focused on cutting costs, assuring just-in-time delivery, and reducing transportation time. However, the rising consumer demand for eco-friendly products and the rising environmental, social, and economic consequences of traditionally operated supply chains have prompted many firms to view supply chain sustainability as a new metric of effective management. Although there are many ways to analyze sustainability, the three dimensions, which sets minimal standards for performance in the environmental, economic, and social spheres, is a key idea that helps operationalize sustainability (Elkington et al, 1999). The firm will have a competitive advantage if the environmental dimension is integrated into the strategic plan and operational processes (Sarkis, 2003). These triple bottom lines are interconnected, Sarkis (2020) examined supply chain sustainability in the post-COVID-19 environment extensively, he mentioned additional proof of the interdependency among the three sustainability factors that comes from the COVID-19 pandemic. Additionally, he highlighted technological innovations, such as big data for decision planning, collaborative technologies such as blockchain for supply chain support and technology advancement with the purpose of increasing agility as post covid development brought by COVID-19 outbreak which will also increase sustainability. Social, environmental, and economic sustainability should all be considered in sustainable development.

Social Sustainability. Balaman, (2019) defined social sustainability as “Identifying and managing both good and negative effects of organizations, processes, systems, and activities on individuals and social”

Economic Sustainability. Since the Middle Ages, accountants have used the generally accepted definition of economic sustainability, "maintenance of capital," or "keeping capital intact," to help merchant traders determine how much they can use without reducing their tradability. Economic sustainability can thus be defined by Hicks' definition of income, which is "the amount one can consume during a period and still be as well off at the end of the period". Economics measures everything in monetary terms and it is difficult in this context to represent the value of natural capital and intangibles such as air. (Hicks, 1975; Goodland 1995)

Environmental Sustainability. Despite the fact that environmental sustainability is a human necessity and that it has its roots in social issues, environmental sustainability itself aims to enhance human welfare by reducing waste of the sources (e.g., raw materials) to meet human needs. The biophysical environment's limitations must be learned by humanity (Goodland et al., 1995).

3.3. Digitalization Concept

Conducting business has been revolutionized by the arrival of the digitization concept and industrial value chains are embracing the fourth industrial revolution, known as Industry 4.0. The

majority of industry professionals considered it a beneficial shift, according to BCG and PwC reports, Industry 4.0 will boost productivity by 15-20% and generate more than 20% of global revenue over the next five years (Parida et al., 2019). Industry 4.0 has been characterized by scholars in a variety of ways, even if there are numerous commonalities. Wang et al., (2016) believed Industry 4.0 raised industry standards by utilizing newly developed technologies and quick development of equipment and machinery. Ivanov et al., (2019) referred to the term "Industry 4.0" as a smart manufacturing networking concept in which machines and products communicate with one another autonomy. Schumacher et al., (2016) described Industry 4.0 as a vast network of cutting-edge technologies through the value chain which by exploiting technologies such as Automation, Artificial Intelligence Robotics, Internet of Things, and Additive Manufacturing started a completely new age of production. While some writers classify all digital technologies as being part of Industry 4.0 (Tay et al., 2018), other research focuses more on how Industry 4.0 technology may be used to individualize production and increase industrial flexibility. Many digitalization supply chain frameworks are proposed by scholars to model the supply chain behavior in presence of digital technologies (Ivanov et al., 2019; Parida et al., 2019; Garay-Rondero et al., 2020), one of the wildly used framework for digitalization in supply chain is SCORE model. The SCOR framework, which was first created by the Supply Chain Council, simplifies the complicated business operations that a firm must do to satisfy customers based on the main sections in the value chain namely plan, source, make, and deliver. The SCOR model is frequently applied in real-world settings to analyze activities such as corporate objectives and procedures, evaluating and quantifying performance, and benchmarking (Bolstorff and Rosenbaum, 2003). Association for Supply Chain Management (ASCM) improved the SCOR model and build more comprehensive model named Digital Capability Model (DCM) for Supply Networks based on capability building blocks which is more dynamic and comprehensive model (Association for Supply Chain Management, 2022). Grounded on SCOR model, Ivanov et al., 2019 proposed digitalization applications to Supply Chain Management (SCM) as follows:

1) Digital Planning (main technologies: Big Data Analytics)

2) Digital Manufacturing (main technologies: IoT, smart products, AR & VR, and robotics)

3) Digital sourcing (main technologies: additive manufacturing/3D printing)

4) Digital logistics (main technologies: RFID, sensors, and blockchain)

Although the various articles based on their area of concentration describe varied technologies and technological clusters linked to digitalization, Artificial Intelligence, Machine Learning, and Advanced Simulation are mostly among them.

3.4. Introduction of Categories

Based on our objectives we performed initial research and found the huge number of papers about the subject under the review, approximately more than 600 articles, it is due to the fact we are examining three broad concepts in this study. Therefore, to better extract the commonalities, conflicts, and relations among the main elements of the articles, we decided to divide the subject under study into three main categories and a target category, as follows:

Category1: The articles related to Digital Resilient Supply Chain.

Category2: The articles related to Digital Sustainable Supply Chain

Category3: The articles related to Sustainable Resilient Supply Chain

Target Category: The articles related to Digital Sustainable Resilient Supply Chain

In the first category, we only take into account publications that discuss both digitalization and supply chain resilience. We also looked at how the digital revolution effects on enablers of supply chain resiliency. In category two, we only considered articles related to digitalization and sustainability, to analyze the contribution of digital transformation on sustainability practices, in the third category we analyzed the interconnections, similarities and differences between concept of sustainability and resiliency. The results of these three categories are therefore combined to form the notion of a digital supply chain that is sustainable and resilient. In order to boost the findings from the previous three categories with our main focus and arrive at well-established and reliable conclusion, we also examined the publications that discussed our target focus, which is a digital sustainable resilient supply chain. (see Figure 1).

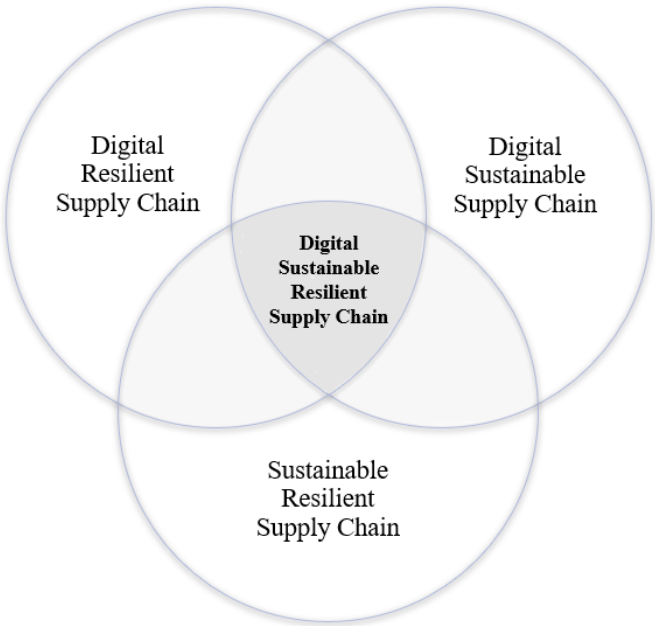


Figure 1. Review categories

4. METHODOLOGY OF REVIEW

4.1. Process of Systematic Literature Review

We conducted a comprehensive review of the literature on the supply chain, focusing on three controversial terms in the context of the supply chain: resilience, digitization, and sustainability. According to (Tranfield et al., 2003) a literature review is considered 'systematic' if the research is conducted on relevant studies with the goal to evaluate their quality based on explicitly articulated questions and summarizing the results using specified methods. This study aims to understand the role of resiliency, digitalization, and sustainability within the supply chain; therefore, the systematic literature review (SLR) is the best approach. In fact, this study is composed of three separate reviews to address the main concentration of the paper and formulate all the aspects related to the digitalized sustainable resilient supply chain. This study follows the methodology instruction in the study of Hosseini et al. (2019) and Lagorio et al. (2020) to develop robust and reliable research. In this section, the process of the literature review is explained in detail, starting from initial research through the database to the final analysis and reporting results (see Figure 1).

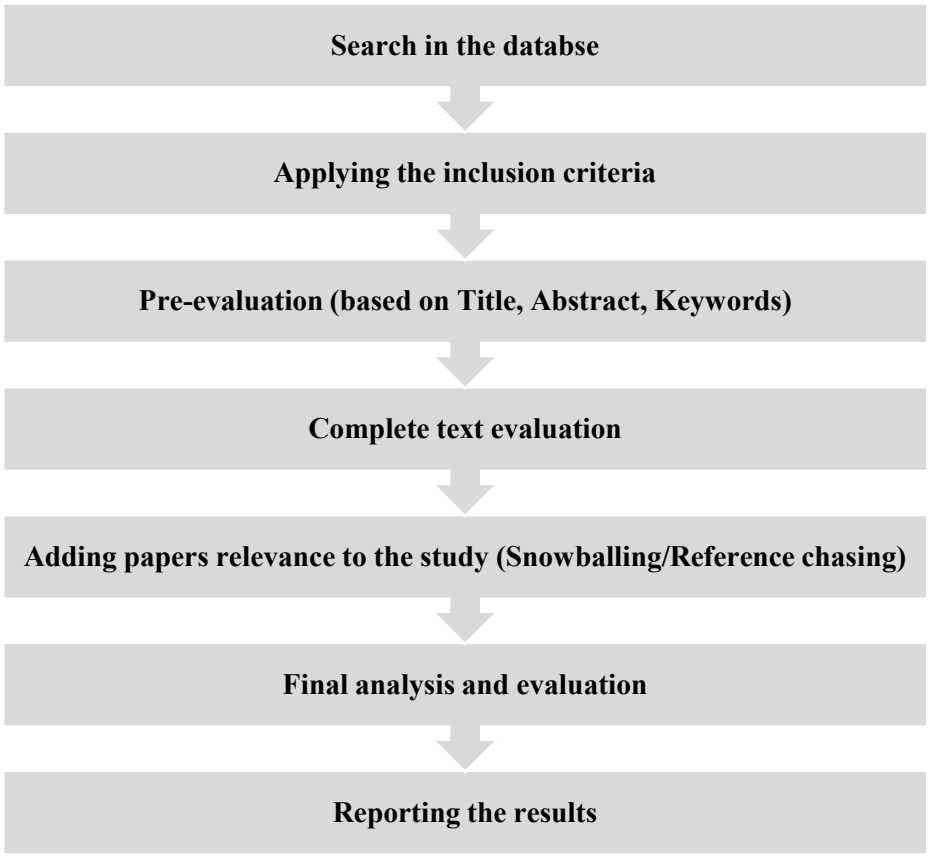


Figure 2. Process of systematic literature review

4.1.1. Search in the database

As mentioned before, to conduct a comprehensive study, we targeted three main clusters of studies therefore to be more cohesive we applied some criteria to exclude or include articles in the review. The SCOPUS database which is one of the most complete and well-known bibliometric databases was selected to identify the relevant papers, it also SCOPUS offers broader coverage of journals in comparison with the Web of Science, which is also a well-known database (Singh et al., 2021). The SCOPUS database contains scientific papers, books, conferences and from various peer-reviewed journals and different famous publishers such as Elsevier (www.sciencedirect.com), Springer (https://link.springer.com/), Taylor & Francis (http://www.tandfonline.com/), Emerald (www.emeraldinsight.com), IEEE (https://ieeexplore.ieee.org/Xplore/home.jsp) and many other publishers, electronic libraries and books. We searched in the electronic database using Boolean keyword combinations in each category to collect articles, as it is shown in Table 1. we limited the search engine to only find keywords in the title, abstract, and keywords of the papers. For the Digital Sustainable Resilient SC category (fourth category), to minimize the error of neglecting related article, the search is done using an asterisk that shows all combinations of words containing the referred prefix. At first, the search was done without any criteria to evaluate the scope of the study, then the results were checked by scholars to determine the proper inclusion criteria that we should apply to achieve a manageable and meaningful number of papers to find the trends in each category and analyze the results.

Category	Definition	Search String	Results limited to (English and year from 2010 to 2021)	Results Limited to (Journal, Article, English, Years from 2011 to 2021)	Results Limited to (Years from 2011 to 2021, Journal, Article, English, Subject area**)
1	Digital **AND** Resilient SC	("supply chain resilience" OR "supply chain resiliency" OR "resilience supply chain" OR "resilient supply chain" OR "supply chain disruption") **AND** ("digital" OR "digitalization" OR "digitalize" OR "industry 4.0" OR "Big data" OR "RFID" OR "IoT")	169	87	74
2	Sustainable **AND** Resilient SC	("supply chain resilience" OR "supply chain resiliency" OR "resilience supply chain" OR "resilient supply chain" OR "supply chain disruption") **AND** ("sustainability" OR "sustainable")	193	120	87
3	Digital **AND** Sustainable SC	("supply chain") **AND** ("digital" OR "digitalization" OR "digitalize" OR "industry 4.0") **AND** ("sustainability" OR "sustainable")	886	383	272
4	Digital Sustainable Resilient SC	("supply chain" **AND** "resili*" **AND** "sustain*" **AND** "digital*")	73	This is the main section of this paper concentration; therefore, we do not apply all inclusion criteria and we read all the abstracts to filter them	

Note: The asterisk (*) indicates the set of derived words starting with the referred prefix; ** subject area Business, Management, Accounting, Engineering, Computer Science, Decision Sciences, Economics, Econometrics, and Finance

Table 1. Research Strings

4.1.2. Applying the inclusion criteria

Primary research was performed without applying any criteria, we then limited the initial results with our inclusion criteria. For this article, we focused on English peer-reviewed journals from 2010 to 2021, articles prior to 2010 were excluded unless they have an important role in defining the main concepts related to the research topics. Books, conferences, and other types of publications are excluded unless they are crucial for the topic. To achieve more concentrated and cohesive results, as a field of study, we concentrated on Business, Management, Accounting, Engineering, Computer Science, Decision Sciences, Economics, Econometrics, and Finance.

Criteria	Description
Language	English
Publication type	Articles
Source type	Journals
Time interval	Jan. 2010 – Dec. 2021
Relevance	Articles relevant to the topic of research found in the citations
Subject area	Business, Management, Accounting, Engineering, Computer Science, Decision Sciences, Economics, Econometrics, and Finance

Table 2. Systematic literature review inclusion criteria.

as previously stated, the topic under the review is quite wide, we initially grouped the main concepts into three distinct categories: (1) Digital Resilient Supply Chain, (2) Digital Sustainable Supply Chain (3) Sustainable Resilient Supply Chain, and, then we reviewed the articles which were contributed to our target category Digital Sustainable Resilient Supply Chain. In the first three categories, we applied all inclusion criteria such as years, language, type of the article, and subject area, while for our target category (fourth category) we considered English and years as inclusion criteria to be more precise and to minimize the error of eliminating important papers related to our target study. The largest number of articles were related to the Digital and Sustainable SC category with 272 articles after applying all inclusion criteria.

4.1.3. Pre-evaluation

In this phase, all the articles in the first three categories were analyzed considering the title, abstract, and keywords of the papers, and the papers that lay outside the research scope were excluded. The main purpose of reviewing the first three categories is to add valuable and significant points to the final category which is our target, therefore we reviewed the first three categories more strictly. For instance, in the Digital and Resilient SC category, if the concentration of the article is not clarifying the role of technology in the resiliency of SC it is excluded even if the concept is mentioned partially. Finally, the authors rejected () articles that did not adhere properly to our objectives. The results were then double-checked by three scholars to ensure the reliability of the final number of papers.

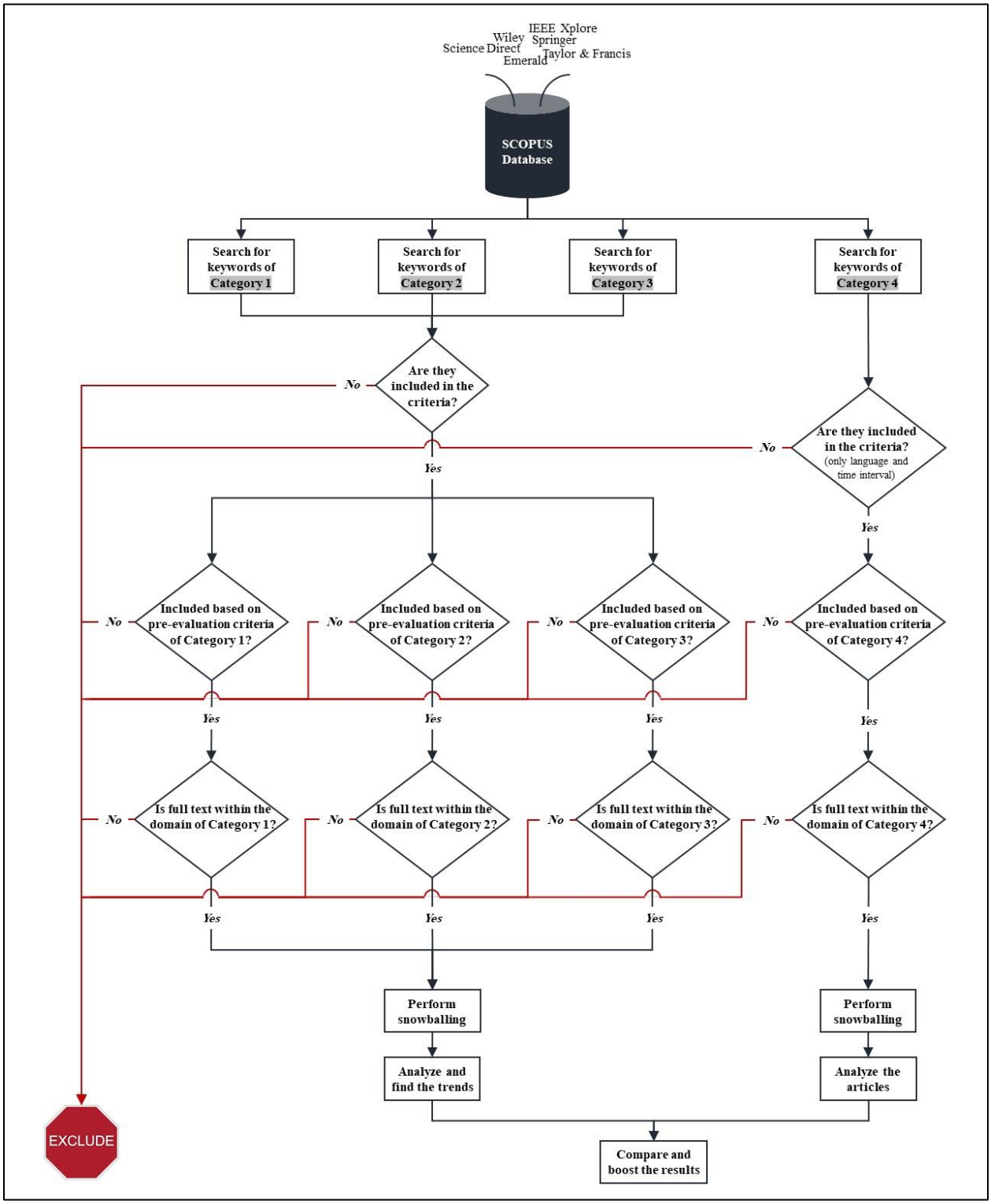
4.1.4. Complete text evaluation

After removing some articles considering the title, abstract, and keywords of them we started evaluating papers based on their full text. Also, some articles from the pre-evaluation step were added to this step for further evaluation considering their full texts. Although in the abstract of some articles, the role of our target constructs such as technology, resilience, and sustainability were mentioned, by reading their full text it turns out that they are out of the scope of this paper. This procedure was repeated for all four categories separately. As a result, all irrelevant papers were filtered out. Moreover, papers were excluded in case the full text of the paper was not found. The entire list of publications included in this review is available from the authors upon request through email.

In category 1, papers which directly examined the effect of digital technology on one of the supply chain resilience enablers or supply chain resilience as whole are accepted. There are several papers that just state that having digital technology may increase supply chain resiliency, but they do not explain how digital transformation plays a role in this. As a result, they have been rejected. Also in category 2, many papers conclude that digital technology may be effective on increasing sustainability, but the linkages and contribution of the digitalization is not clarified, and no particular technology is recognized, therefore we exclude the paper since our main concern was out of the context of those papers. While in third category have been looking for papers that explained the tradeoffs between two main feature of supply chain, resiliency and sustainability, we concentrated on the papers which mentioned special enabler or driver to be able to better integrate the results with two former categories. Since the target category is still relatively new and in its immaturity phase, we took into account all articles in this category, even if they made only a minor contribution to our main target. By doing this, we are able to assess the topic more effectively.

4.1.5. Adding relevant papers (Snowballing/Reference chasing)

Snowballing is the practice of identifying other articles by leveraging a paper's reference list or citations (Wohlin, 2014). Therefore, having the final number of papers in each category, we performed further reference chasing to track down important references and add them to our research. Then instead of blindly adding all the references find through the snowballing procedure, we read the abstracts and contents of new references identified to ascertain whether they might also be relevant to this study. As mentioned earlier, we also added some articles which were published before 2010 since they shared important contributions to our target points. The output number of papers from this phase would be the final number of papers that are reviewed.



Note: Own illustration based on Hosseini and Ivanov 2020

Figure 3. Research methodology process framework

5. RESULTS AND DATA VISUALIZATION

This section is dedicated to the analysis of the results obtained from the systematic literature review (SLR) process. First, we present a visualization-based analysis to evaluate the current state and recent developments in each category of review as well as the target category of focus. Then descriptive and qualitative analysis results related to each category is presented. Finally, the results obtained from each category is compared to better understand the similarities and differences within categories and boost our final implications. Figure 4 illustrates, the results of analysis in each category and final number of papers which comes to 193. In this figure all categories and 4 steps of SLR is shown. By analyzing first category we derived main links between digitalization and resiliency as well as driving main technologies that affect resilience capacity of SC. In the second category the relation between digitalization and supply chin as well as focal technologies which significantly impacts on sustainability are analyzed. In category 3, two main concepts of SC and the links between them is discussed to drive the sustainable-resilience paradigm. At last, based on articles in the target category all three concepts are analyzed, and the results are compared with results obtained from analyzing former categories. The results of all analysis would be the answer to our main concern in this article which is clarifying the linkages and role of digitalization in achieving sustainable and resilient supply chain.

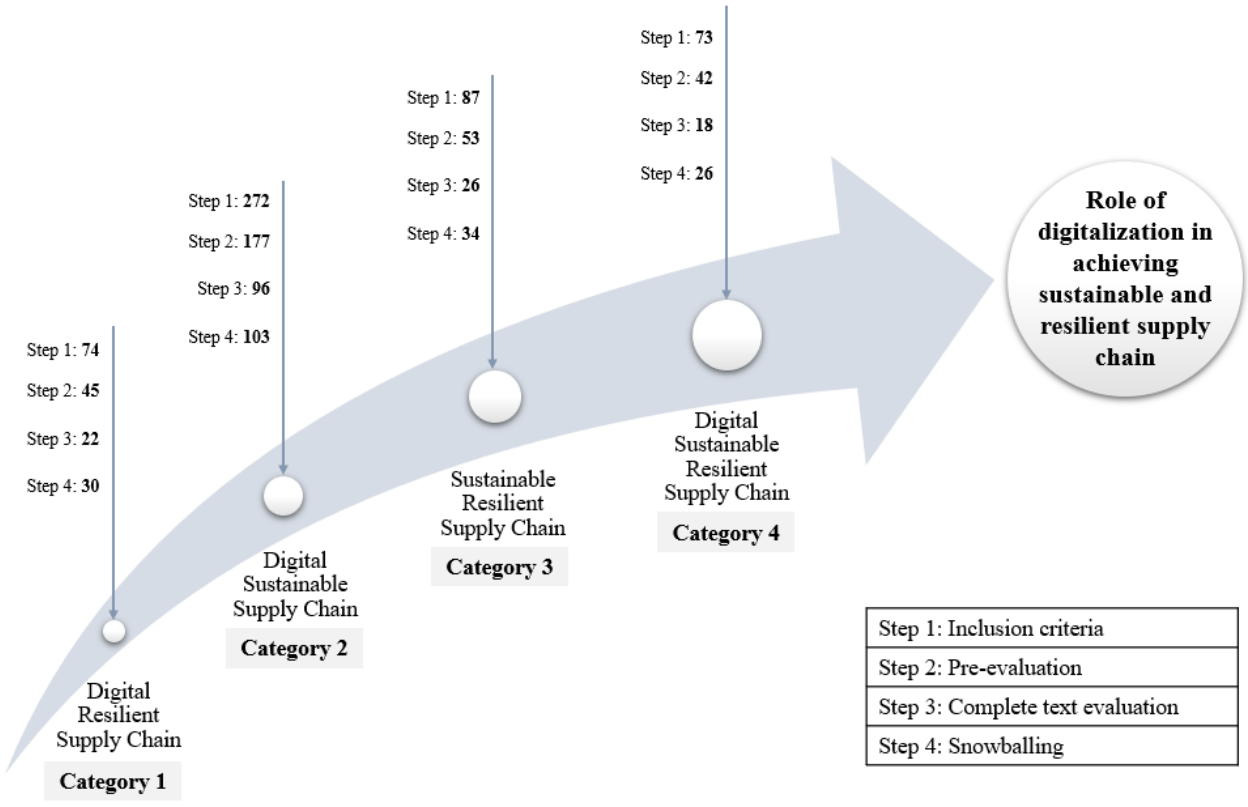


Figure 4. Results of SLR selection process

5.1. Category 1 (Digital Resilient Supply Chain)

Most Frequent Journals. Based on an initial search in the SCOPUS database, the International Journal of Production Research, Benchmarking, International Journal of Logistics Management, and IEEE Transactions on Engineering Management journal are the most important journals that published article related to the digital resilient supply chain.

Most Important Areas. The areas that journals of this category were mostly published are Business, Management and Accounting, Engineering, and decision science respectively, only 33% of the articles belong to other areas such as computer science and social science.

Most Productive Authors. It was determined that the most productive authors in this category are Ivanov, D., Dolgui, A., Agrawal R., Hosseini S., and Belhadi A.

Distribution of Papers. As it is illustrated in Figure 5 most of the papers in this category have been published in the last three years. That can be translated as a severe impact of COVID-19 epidemic disruption on industries which shed light on the necessity of improving the resiliency of the supply chain and remind the vulnerability of the supply chain.

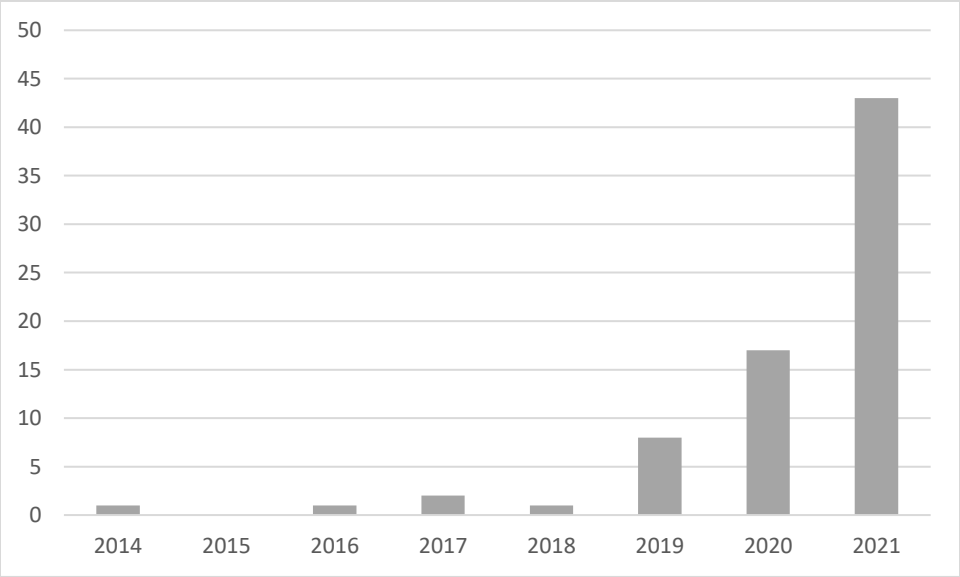


Figure 5. Paper distribution by year (based on keywords)

Methodology of Study. Digitalization itself is a broad subject, integrated with resiliency, it would result in even bigger category, some articles investigated the issue based on quantitative methods, while some others used conceptual and qualitative approaches such as optimization and decision-making techniques. The resiliency and its enablers are latent variables, means it is not possible to measure them directly, but rather are inferred by a mathematical model using other observable variables. It is also true for digitalization to some extent, for example, someone may measure application of digitalization in an enterprise by the amount of financial investment in the digital technology, but this measure is not widely accepted and may be subject to measurement bias. Therefore, most of the papers used advanced regression-based analysis such as Structural Equation Modeling (SEM) (Singh et al., 2019; Zouari et al., 2020; Bahrami et al., 2021; Belhadi et al.,

2021; Frederico et al., 2021). For example, Singh et al., (2019) investigated the role of big data analytics (BDA) capabilities in increasing the risk resilience, by proposing a path model containing four latent variable, and supply chain risk resilience as target variable of model, they conclude empirically that BDA capabilities can improve financial performance and develop competitive advantage. Bahrami et al., (2021) proposed even more comprehensive path model, and beside supply chain resilience added "firm performance" as a main node to the model and illustrate that BDA capabilities positively affects supply chain resilience through mediating effects of "innovative capabilities" and "information quality", they also considered "firm size" and "industry size" as two control variable which proved to be insignificant in their model. Zouari et al., (2020) using SEM approach with a sample of 300 mangers, proved that supply chain digitalization is characterized by the degree of digital maturity and the adoption of supply chain digital tools. Also, Belhadi et al., (2021) used SEM approach in their study and considered "supply chain resilience" and "supply chain performance" as their final nodes, they collected data from 279 firms in different sizes, sectors, and countries with the aim of measuring directed and indirect impact of Artificial Intelligence (AI) on SC resilience and performance. In the study of Frederico et al., (2021) SCR itself is not considered as a variable in the path model, instead they added SCR enablers integration, collaboration, responsiveness, and transparency to the model to analyze the effect of disruptive technologies.

Other scholars used different approaches such as SLR, for example in the study of Vivaldini et al., (2021) the concentration is on the weakness of blockchain connectivity and its effect on supply chain interaction and resilience. The ability of blockchain technology (BT) to provide connectivity to SCs depends on the technical and organizational interoperability between BT and the SCs. Razak et al., (2021) reviewed the concepts related to traceability in supply chain, and the influence of Industry 4.0 technologies on traceability in supply chain. Naz et al., (2021) performed comprehensive SLR study based on 162 articles to evaluate the trends and association of AI in SCR. while Spieske et al., (2021) systematically reviewed various technologies under the umbrella of Industry 4.0 to analyze the effect of them on SCR. Hosseini et al., (2019) performed an extensive study on the qualitative and quantitative approaches to analyze SCR literature, unsurprisingly, many of the studies that were analyzed in the paper assessed the relationship between digitization and supply chains. As aforementioned, resiliency is a concept therefore some scholars developed conceptual framework, to describe its linkages with digitalization (Min , 2019; Fertier et al., 2021; Ivanov et al., 2021). In the comprehensive study of Ivanov et al., (2019) they clarified the impacts of digital technologies on supply chain management (SCM) and SCM on the ripple effect which is defined as the disruption effect when cascades downstream it is opposite of bullwhip effect (Hosseini et al., 2020), therefore indirectly the effect of digital transformation on SCR is explained. Peng et al., (2021) suggested a digital supply chain risk analytics framework for resilient manufacturing and examined it through a sample of 48 industrial cases which prevented the pandemic effect by increasing SCR. Other studies chose case study (Rajesh, 2016), simulation (Lohmer et al., 2020; Burgos et al., 2021) and interview based (Doetzer and Pflaum, 2021) approaches.

Technologies. Various technologies related to SCR are covered in articles of this category and they were not necessarily among keywords and abstracts of the papers, We took into account the

technology on which the writers had based their study's analysis. In this section we assess how selected technologies are connected with SCR, tradeoffs, and benefits will be explained. Majority of articles considered digitalization as a whole and only mentioned focal technologies inside Industry 4.0 paradigm. The two most studied topics in this category were BDA (Singh et al., 2019; Bahrami et al., 2021; Frederico et al., 2021; Spieske and Birkel 2021) and AI (Belhadi et al., 2021; Fertier et al., 2021; Ivanov, 2021; Naz et al., 2021; Peng et al., 2021; Spieske and Birkel 2021). A system is able to alter its behavior depending on its own experience with the help of intelligence technologies. Bahrami et al., 2021 considered Machine Learning, Deep Learning, Decision Tree, Natural Language Processing, Artificial Neural Network, Genetic Algorithm, Support Vector Machine, Bayesian Network, Fuzzy Logic, Robotics, and Computer Integrated Manufacturing all as AI torniquets benefits SCR. Belhadi et al., (2021b), performed the study using AI-based algorithms like as Wavelet Neural Networks (WNN), Fuzzy Systems, and Evaluation based on Distance from Average Solution (EDAS) to power the multi-criteria decision-making (MCDM) process, by the aim of discovering trends in AI methods for creating various SCR strategies, their funding suggests that AI-based algorithms such as fuzzy logic programming, machine learning, big data, and agent-based systems are the most promising techniques used to promote SCR. Because data analytics can handle large amounts of data in real-time, the term "big data" has come to refer to a subset of this technology. Tracing and tracking systems, machine learning, predictive analytics, modeling, simulation, knowledge decision-making techniques such as multi-criteria decision making (MCDM), data visualization techniques and Geographic Information Science (GIS) are all linked to the BDA. In the smart and digital systems, a prominent feature is generating and collecting data, to be sort, stored and utilized for system improvement, in our case for supply chain resiliency enhancement. Basically, all technologies that generates data will need BDA for the analyzing and processing stage. Autonomy, machine learning, intelligence control, which brings responsiveness, flexibility, agility, robustness and accuracy to the system are all in the cluster of AI, it can further explain the reason that AI is wildly used in many articles of this section (Mittal et al., 2019).

Peng et al., (2021) considered cloud computing, 5G, additive manufacturing/ 3D printing, and XR (extended reality) as supporting technologies for SCR. Fertier et al., (2021) performed a vast study using AIC information system which Acquires, Interprets and Contextualizes events and underlies on big data, complex event processing (CEP), event processing agent (EPA), decision support systems, and metamodeling. Razak et al., (2021) introduced a groups of Industry 4.0 technologies such as Matrix code (2D barcode), Datalogger, DNA-based tracers, Magnetic markers, Barcode (1D barcode), Nano-capsules, RFID, Stable isotopic technology, Wireless sensor network (WSN) that are useful for enhancing traceability and ultimately resiliency in SC. Fertier et al., 2021 divided disruptive technologies in relation with SC into five groups, Internet of Things (IoT), Cloud Technology (CT), Platforms Technology, BDA tools, Cyber-Physical System (CPS), and Cyber Security (CS) within SC. According to Ivanov and Dolgui, (2021) Digital twin technology is described as “computerized models that represent the network state for any given moment in time”. Although it appears to be identical to simulation models, system complexity, real-time connection, and decision-making integration are three areas where they diverge. Other technologies that were mentioned in the articles are namely Information processing, IT infrastructures and capabilities, Track and trace systems, Early warning systems, Collaborative supplier portals.

Resiliency Enablers. Characteristics, enabler, driver, principle are terms that are used interchangeably to describe the factors that form the concept of resiliency in SC. We decided to use the term enabler, and in this section, enablers used in category 1 articles are analyzed. Some paper analyzed resiliency based on resilience capacity framework (Hosseini et al., 2019; Bahrami et al., 2021; Belhadiet al., 2021; Golan et al., 2021). They may have used different terms such as readiness (proactive, pre-disruption), response, and recovery (reactive, post-disruption) but the concept they want to focus on is the same. Figure 6, illustrates the distribution of enabling factors for resiliency among articles of category 1. In this category we looked at the enablers of SCR which digital transformation affects the most. The outcomes are almost consistent with what Hosseini et al., (2019) discovered in their review research for the key SCR enablers. They mentioned Agility, Visibility, Flexibility, Collaboration, and Information sharing as the five most important enablers of SCR in general.

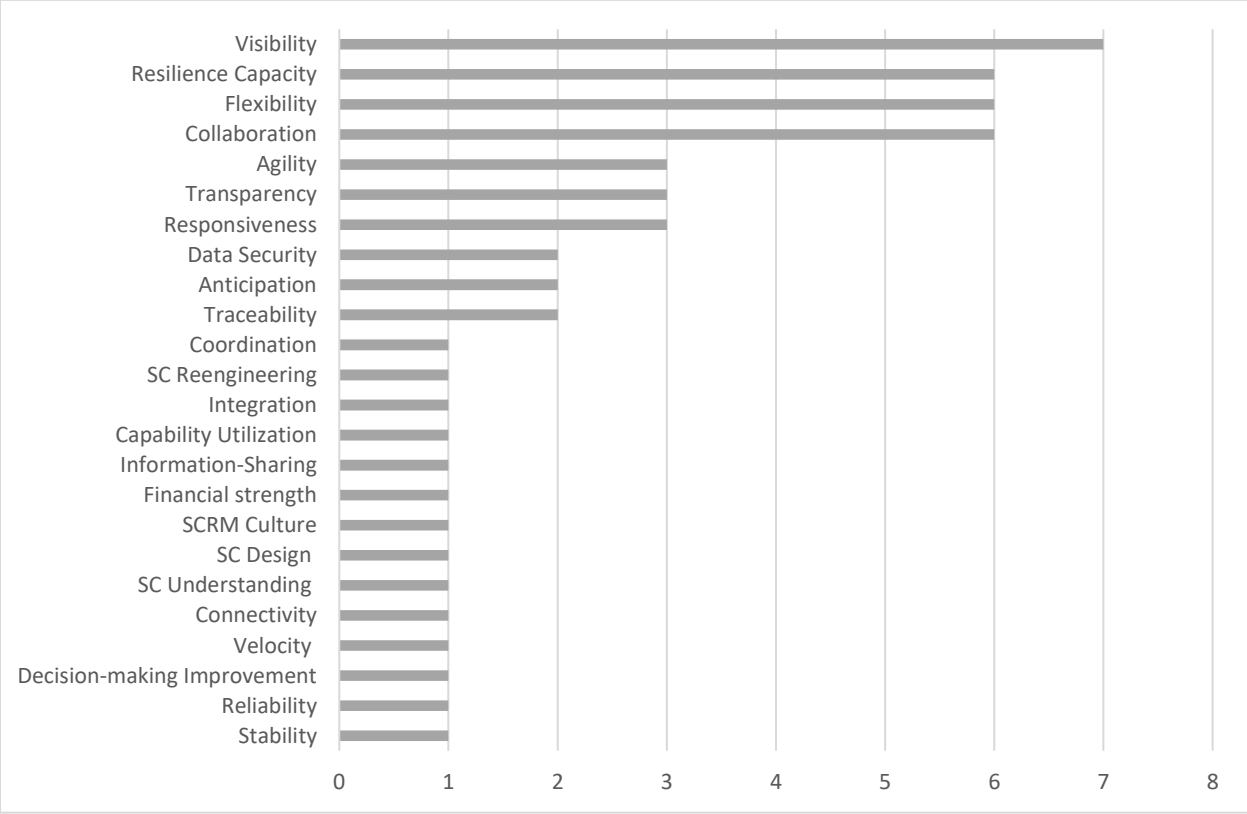


Figure 6. Distribution of resiliency enablers in the articles

Visibility is the most important enablers based on our data, followed by resilience capacity. According to Min, (2019) BT increase Visibility across the supply chain as a result of improved transparency brought about by publicly accessible open ledgers. Ivanov, (2021c) Performed comprehensive study on building end-to-end visibility in supply chain during COVID-19 pandemic, and believe it is a key skill for managing with significant disruptions. Visibility serves as a warning mechanism that gives businesses crucial time to alter their capabilities to prevent negative effects and provide information on state of the supply chain's operating resources and environment (Tang, 2006). On the digitalization side the role of data and technologies such as

BDA and AI which translate and transform data are significant, hence it is expected that enablers such as visibility, transparency, traceability, anticipation which rely more on data become more important in our study. Despite, digitalization has substantially benefited SCR enablers, it also raises new concerns such as coordination complexity increase due to global Industry 4.0 SC, data safety and security demand increase due to the need for coordination, collaboration, information sharing, and visibility, relying on single sourcing increase due to the technologies such as additive manufacturing/ 3D printing which reduce the number of SC layers, and higher flexibility causes complex coordination and ultimately higher time risks (Ivanov et al., 2019). Therefore, digitalization effect on supply chain resilience is not always positive but managers should consider the tradeoffs and enablers which is needed to be improved to successfully increase resiliency by means of digital transformations.

5.2. Category 2 (Digital Sustainable Supply Chain)

Most Frequent Journals. The most important journals that published articles related to digital sustainable supply chain, according to our research in the SCOPUS database, are the Journal of Cleaner Production, Resources, Conservation and Recycling, Production Planning and Control, International Journal of Production Research, and International Journal of Supply Chain Management.

Most Important Areas. Approximately 25% of articles in this category belongs to Business, Management and Accounting area which shows its importance in these areas, followed by Engineering, Decision Sciences, Computer Science, and Environmental Science respectively which share almost 50% of the contribution. Only 8.5% of the examined papers belongs to Environmental Science areas.

Most Productive Authors. It was determined that the most productive authors in this category are Luthra S., Tsolakis N., and Sarkis J based on the number of papers that were included in our selection.

Distribution of Papers. Differently from former category the majority of the publications in this category, as shown in Figure 7, have been published mostly in the past six years, since the concept of the sustainability was introduced long ago. The Brundtland Report from 1987 introduced the first "official" concept of sustainable development. Like category 1, number of articles saw sudden increase from 2019. The social, political, and economic chaos caused by COVID-19 is evident. In this condition society's recovery efforts only focus on economic and social sustainability, hence environmental sustainability initiatives may experience the rebound effect crisis (Sarkis, 2020). Therefore, scholars during pandemic focused on different sustainability bottom lines especially economic and social dimensions.

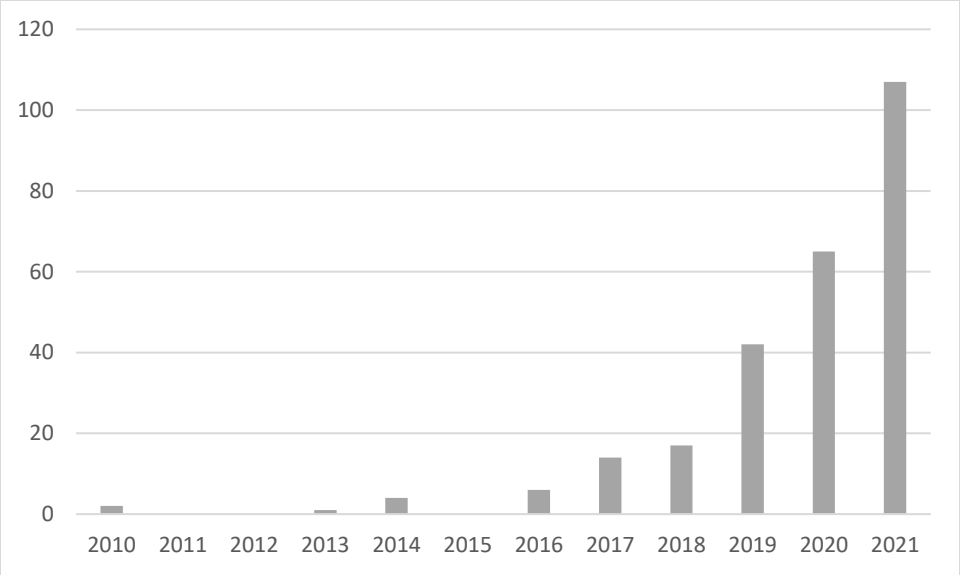


Figure 7. Paper distribution by year (based on keywords)

Methodology of Study. There are several methods to study Industry 4.0 in the context of sustainability as depicted in Figure 8. Obviously, based on our data, various decision-making techniques are the most popular methodology to study industry 4.0 effects on sustainability. Various MCDM approaches were presented in the literature to overcome the complexity of this problem such as Best Worst Method (BWM) (Gupta and Singh, 2021; Kusi-Sarpong et al., 2021), Bayesian BWM (Liu et al., 2021), Robust Best Worst Method (RBWM) (Yadav et al., 2020), trial and evaluation laboratory (DEMATEL) methods (Luthra et al., 2020; Sharma et al., 2021;), Analytic Hierarchy Process (AHP) (Kumar et al., 2021)and Elimination and Choice Expressing Reality (ELECTRE) (Yadav et al., 2020b), Fuzzy methods (Joshi and Sharma, 2021; Kumar et al., 2021), VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) (Kusi-Sarpong et al., 2021). MCDM techniques are also wildly used at articles that examined effect of Industry 4.0 technologies on sustainable supplier selection. We separated BWM and DEMATEL methods into different groups in the graph to highlight their significance, since numerous publications in category 2 employed these methods for their research. Usually, initial step of MCDM analysis is extracting critical factors and variables by conducting literature review on the topic under concentration, then based on the nature of the problem the most appropriate approach will be selected. To quantify concepts such as sustainability and digitalization it is more practical to apply fuzzy numbers rather than definite numbers to address the ambiguities and haziness in human perceptions and judgments (Ozkan-Ozen, et al., 2020). Consequently, MCDM techniques and fuzzy approaches are frequently combined. The DEMATEL approach analyzes complicated issues by determining how the variables are related to one another and resolving the causality between the assessment criteria and multiple real-world components (Kumar and Dixit, 2018). Many academics use the AHP technique because it allows for the application of both qualitative and quantitative criteria. It effectively traces the choice and uses consistency indices to guarantee quality (Kumar et al., 2021). All MCDM approaches have pros and cons and should be applied according to case of study. Systematically Literature Review (Muñoz-Villamizar et al., 2019; Yau

et al., 2020) and Bibliographic Review (Acioli et al., 2021) area second most popular methodology following by Structural Equation Modeling. According to Hair et al., 2021 SEM is "Multivariate analysis involves the application of statistical methods that simultaneously analyze multiple variables", there are various kind of SEM, namely Covariance-based SEM (CB-SEM) and Partial Least Squares (PLS-SEM) which is applied depending on the path model which is defined in the article. Proposing frameworks and conceptual models and validating them based on case studies (empirical analysis) is also popular methodology among papers of this category, for example Song et al., 2021 considered China's economy data (thirty province in China) and examined the connection between the digital economy and sustainable development prior to the pandemic using time-series data from 2002 to 2019 using unconstrained VAR model.

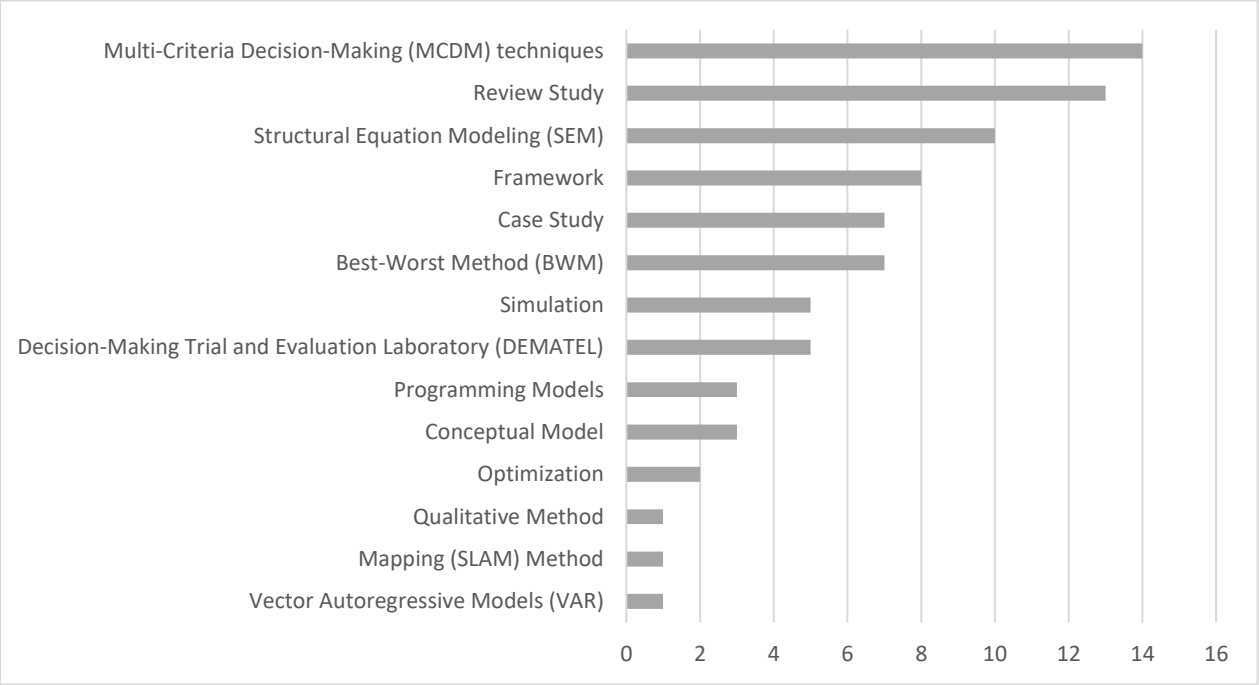


Figure 8. Distribution of methodologies used in articles

Technologies. Most of the studies examined digitalization under the term of Industry 4.0, as mentioned before, Industry 4.0 and digital transformation are used interchangeably, and their concepts cover extensive, wild range of technologies. In examined studies, they mostly used term digitalization and named some of the main technologies inside it. Some studies investigated the role of more than one technology on sustainability. Unlike former category (category 1), the relationship between digital technologies and sustainability is defined differently. In former category the role of AI and BDA was crucial, while the most prominent technology based on Figure 9 in category 2 is Blockchain Technology, followed by Internet of Things (IoT) and BDA. It is important to mention Industry 4.0 technologies are closely connected to each other and looking at one technology in isolation may not be the best approach to evaluate the usefulness of that technology.

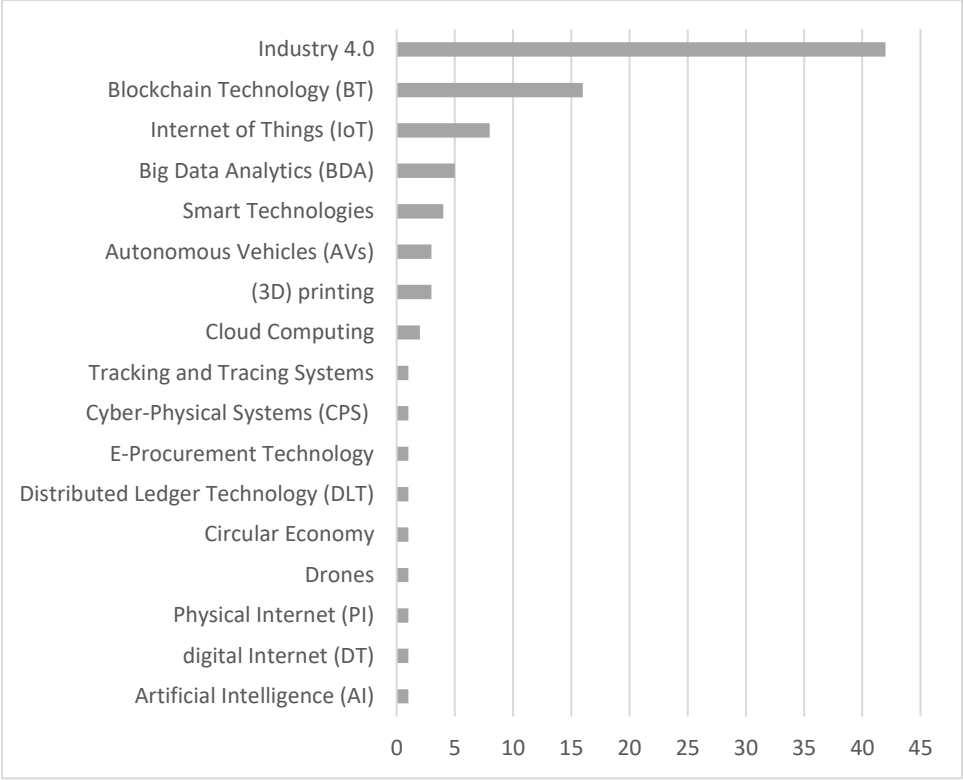


Figure 9. Distribution of technologies used in articles

But why BT has seen mostly in the articles of category 2, Esmaeilian etal., 2020, answered to this question in their study, they suggest that blockchain offers solutions for achieving advanced sustainability in four key areas: (1) enhancing customer green behavior using mechanism such as tokenization (2) improving visibility across the entire product lifecycle (3) lowering the cost of operations and simultaneously enhancing the efficiency of system (4) promoting sustainability monitoring and tracking performance throughout supply chain networks. Applying BT alone would not grantee business success. Organizations can leverage BT to gain competitive advantage and strengthening their market position. To decide if they require or would adequately profit from the use of blockchain, managers must carefully consider the nature of their goods, services, and supply networks. Moreover, it's critical to have the human capital and knowledge needed to create, deploy, and fully benefit from implementations of this technology (Cole et al., 2019). Saberi et al., (2019) looked into how companies might get beyond obstacles to the adoption of blockchain technology for supply chain management and introduced four blockchain technology adoption barriers; inter-organizational, intra-organizational, technical, and external barriers. Rejeb, A. and Rejeb, K., (2020) studied digital innovation's disruptive effects on supply chain sustainability, believed that the majority of publications, primarily discussed the financial impacts of BT on the supply chain. While blockchain improved the social aspects of supply chain by building teachworthy connection among supply chain participant resulting in increased safety among food supply chain, supporting humanitarian logistics, and enhancing social equity. As aforementioned, many studies of this category belong to environmental area, BT is proved to be beneficial in the food supply chain, fashion industry, farming and agriculture industry and most importantly

Circular Economy (CE), it will confirm the reason that BT has gain lot of attention in this section (Ali et al., 2021; Huynh, 2021; Khan et al., 2021; Mukherjee et al., 2021; Tsolakis et al., 2021). Also, Internet of Things (IoT) is frequently employed in the context of sustainability. It relatively new manufacturing idea, that enables interaction between digital and physical devices using the Internet and is based on information technology infrastructure, these technology uses in combination with other technologies such as sensors, RFID and BT to collect and distribute data and may have a substantial impact on the effectiveness and performance of production systems (Manavalan and Jayakrishna, 2019; Mastos et al., 2020; Jagtap et al., 2021). Additive manufacturing, also known as three-dimensional printing (3DP), is recognized as an eco-friendly and sustainable method of production that enables circular manufacturing since the waste and products from 3D printing can be recovered for use in subsequent 3DP processes (Sun et al., 2020). A cutting-edge technology for managing warehouse inventories is drones. They have potential to reduce operating expenses for supply chain stakeholders while enabling real-time, 24/7, quick, and accurate inventory listing. Drones at the social component reduce the possibility of human injuries at the location. They are able to autonomously communicate with IT infrastructure and therefore provide a web-based multifunctional interface for monitoring inventory, ultimately it can be inferred that they increase, traceability, visibility and agility (Karamitsos et al., 2021). Examined the relationship of Industry 4.0 practices and recycling using electric vehicles and their traction batteries as case study, they suggest that using robots for decision-making the disassembly of traction batteries (Kintscher et al., 2020). Autonomous Vehicles (AVs) such as Autonomous Mobile Robots (AMR) and Cobots, Cloud Computing, Tracking and Tracing Systems, smart technologies, and E-Procurement Technology are among important technologies that scholars studied in relation with sustainability of supply chain (Li et al., 2020; Gunduz et al., 2021; Kumar et al., 2021; Singh et al., 2020).

Sustainability Concentration. We analyze the papers based on the triple bottom-line (TBL) sustainability concept of Elkington et al, 1999 who for first time suggested this model. The TBL framework illustrates the interconnections between the three key components (Figure, 10). The intersection of only two bottom-lines is not considered to be sustainable for example, viable intersection relies on the assumption of a robust economy and a robust environment but ignores issues related to society (Slocum, 2015). Some articles concentrated on only one aspect of sustainability, while other may consider all aspects (Azadi et al., 2021). Nantee and Sureeyatanapas, (2021) performed research with the aim to better understand how automated warehouse systems used in Logistics 4.0 efforts affect the social, environmental, and economic aspects of a company's sustainability performance. They suggest that considering Economic dimension, profit (cost and revenue), productivity and efficiency, product quality, customer satisfaction, marketing and strategic planning increases due to the applying Logistics 4.0 technologies while it also has cost. Although it increases fuel consumption, air pollution, electricity consumption, solid waste disposal (can be considered either positive or negative) and therefore is negatively affects Environmental dimension. Considering social dimension, by using Logistics 4.0 technologies, employee stress (due to job insecurity) increases, and some job position will be eliminated (while it also can make new opportunities) while ICT competency, employee health and safety, and most importantly information sharing (also raise concern for information security) and transparency develop. Some scholars considered even more dimension for sustainability, for

example, Sharma et al., (2021) considered five dimensions; technical, organizational, economic, environmental, and social, to study Industry 4.0 effects on sustainability in multi-tier manufacturing supply chain, ultimately, they proposed 37 drivers and 21 obstacles for it.

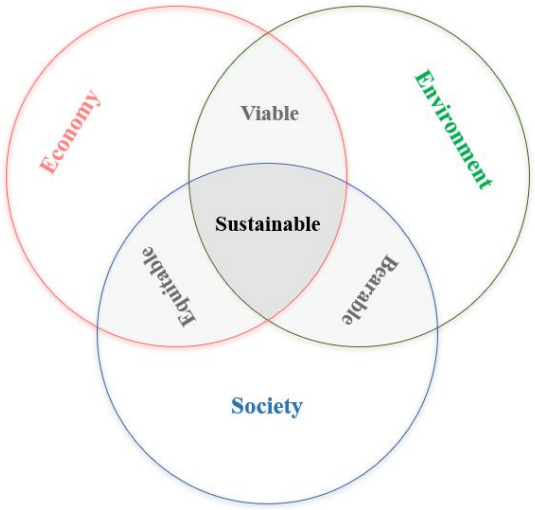


Figure 10. A triple bottom-line sustainability framework adapted from Elkington et al, (1999)

Mastos et al., (2020) validated extensive framework of Manavalan and Jayakrishna (2019) sustainable supply chain management (SSCM), their findings support that Industry 4.0 solutions have the potential to enhance supply chain management's social, environmental, and economic sustainability, among other things. Luthra et al., 2020, studied industry 4.0 as an enabler of sustainability they listed the most important drivers and empirically test them. They suggest main effects of Industry 4.0 on sustainability as: collaboration and transparency among supply chain members, management support and effective governance, development of infrastructure and information technology (IT) based facilities, competitiveness, improved information sharing system and resource development, reduction in waste and improved cost efficiency, workforce knowledge and expertise in managing resources, government supportive policies, adoption of innovative business models. Other important concept that used interchangeably with sustainability in this category is the concept of Circular Economy (CE), it is opposite of traditional view of "take, make, use and dispose". The CE provides a unique viewpoint on the organizational and operational systems of production and consumption, one that is centered on retrieving the value of used resources. It is suggested that like sustainability CE approach can positively affects economy, the environment, and society (Geissdoerfer et al. 2017). Hence many papers in this category considered effects of Industry 4.0 and digital transformation on CE rather than sustainability (Ćwiklicki and Wojnarowska, 2020; Kintscher et al., 2020; Gupta and Singh, 2021; Kazancoglu et al., 2021; Khan etal., 2021; Kumar etal., 2021; Kusi-Sarpong et al., 2021; Lopes et al., 2021; Upadhyay et al., 2021; Zhang et al., 2021). Grounded on Resource-based View (RBV), Stakeholder theory, Institutional theory, and ecological modernization concept, Lopes et al., (2018) extracted the matrix of the relationships between CE, Industry 4.0, and sustainable operations management.

5.3. Category 3 (Sustainable Resilient Supply Chain)

Most Frequent Journals. According to an initial search of the database, the most important journals that published articles related to the sustainable resilient supply chain are Computers and Industrial Engineering, Resources, Conservation and Recycling, International Journal of Production Research, and International Journal of Logistics Management.

Most Important Areas. Approximal half of the papers (47.4 %) belongs to Business, Management, Accounting and Engineering area respectively, as it is expected Environmental Science, Decision Sciences, and Social Sciences area which are more related to sustainability each contributes a lion's share of papers in this category.

Most Productive Authors. It was determined that the most productive authors in this category are Singh S.P., Ivanov D., Rajesh R., and Kaur H.

Distribution of Papers. Differently from two former categories, publications increased dramatically started in 2021. As soon as epidemic effects start to decrease, scholars such as Sarkis, (2020) began to ask, "What will happen to sustainability in supply chains – post-COVID-19?". Consequently, post-COVID-19 situation can be seen as opportunity to learn our lesson and concentrate not only on sustainability but also on resiliency. By utilizing sustainability to lower risk and increase resilience, the crisis provides a transformative opportunity.

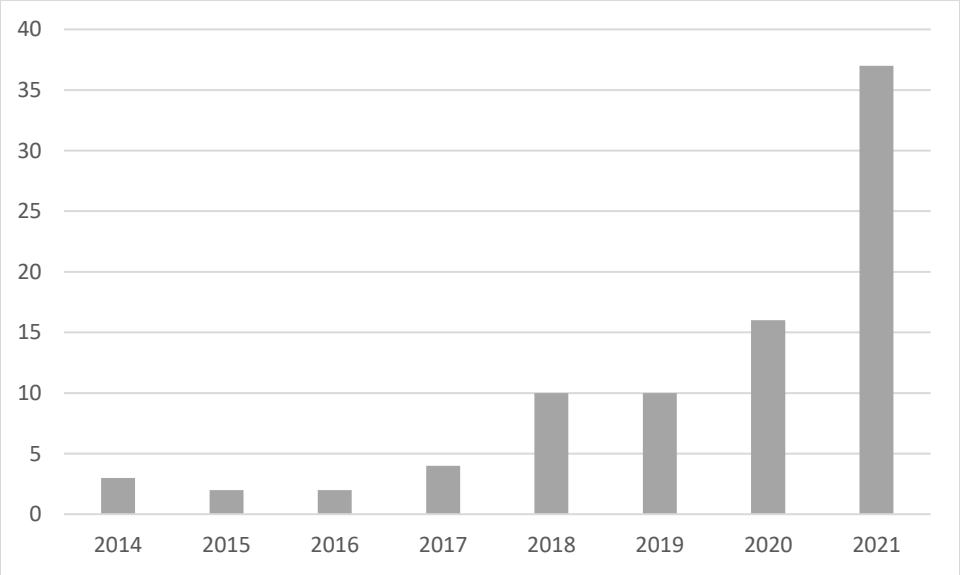


Figure 11. Paper distribution by year (based on keywords)

Methodology of Study. In this category, methodologies of studies are more dispersed in comparison with former categories. Similar to second category (digitalization and sustainability category) MCDM techniques are more common to study interactions of SCR and Sustainability. Mohammed, (2020) by combining the concept of green and resilient supply chain, introduced "gresilient" supply chain performance measures using multi-criteria decision making (MCDM) algorithms. Kaur et al., (2020) solved a supplier selection problem, considering uncertainty, resiliency and sustainability using fuzzy-MCDM, Mixed Integer Linear Program (MILP), and

Mixed Integer Non-Linear Program (MINLP). In order to create a supply chain that is resilient, the study suggests an autonomous and integrated production and procurement model that takes sustainability and uncertainty into account. Costa et al., 2018 applied ELECTRE TRI-nC method on a sample of India suppliers to sort and categorize them, considering resiliency and sustainability.

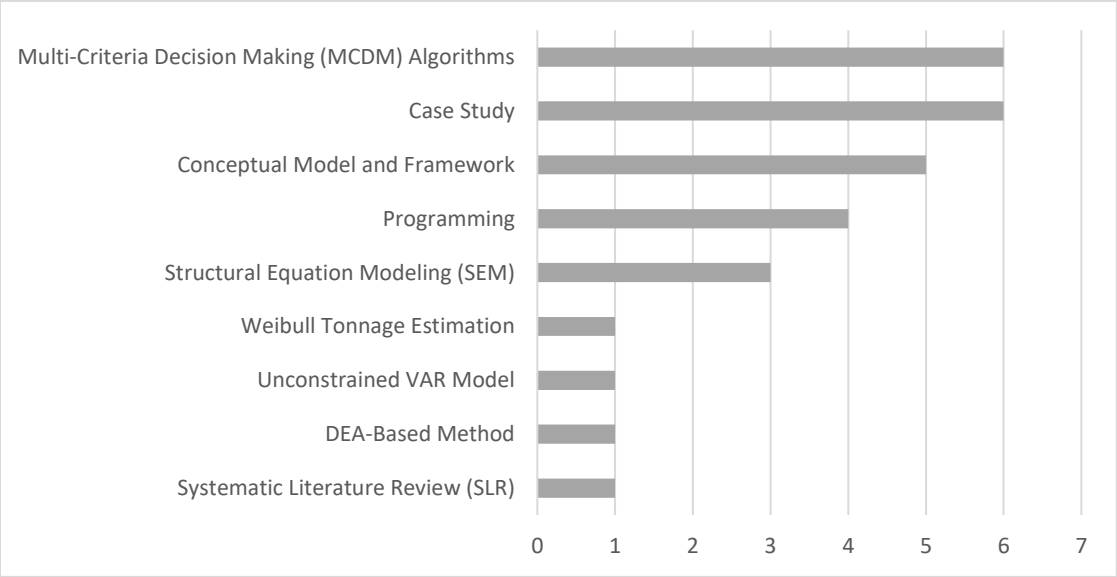


Figure 12. Distribution of technologies used in articles

Ramezankhani et al., (2018) applied a hybrid method using Quality Function Deployment (QFD) together with Decision Making Trial and Evaluation Laboratory (DEMATEL) and validated the framework by data from automotive manufacturing sector. They conclude that integrating sustainability and resilience at operational level is inevitable for supply chains in order to thrive in the challenging, rapidly evolving, and fiercely competitive market. Sadeghi et al., (2021) proposed a multi-objective mathematical model for creating a supply chain that is resilient and sustainable. They considered capacity redundancy, lead time ratio, and customer de-service level as proactive resiliency measures while considering social, economic and environmental dimensions of sustainability as well. Negri et al., (2018) performed a comprehensive Systematic Literature Review (SLR), to clarify simultaneous concern regarding SCR and SC sustainability. Bechtsis et al., (2021) focused on supply chain security, resilience, and sustainability, and suggests a conceptual framework by reviewing related literature, and used a case study of the organic food supply chain in the actual world to validate their framework. Differently from other studies, Sharma et al., (2020) used Twitter data from of 100 firms in the NASDAQ Stock Market which is based in New York to extract major issues firms faced during COVID-19 pandemic, they concluded that firms experienced difficulties to make sustainable resilient supply chain.

Sustainability and Resiliency. As previously stated COVID-19 disruption escalate attention toward the importance of having sustainable and resilient supply chain. While two aspects were often examined individually, COVID-19 proved that considering both resiliency and sustainability simultaneously as the objective functions is a must. Rajesh et al., (2018) Listed categories of

supply chain as Lean SC, Agile SC, Leagile SC, Green SC, Resilient SC and Sustainable SC. He suggested Agility, Responsiveness, Visibility, Redundancy, Flexibility, Reduction of uncertainty, Reduction of complexity, Integration/Operational capabilities, Collaboration, and Transparency as core concepts of SCR and Lean management, Delivery speed, Safety, Efficiency, Adaptability, Labor equity, Reusability/Reverse logistics, Strategic partnerships, Environmental concerns, Social issues as core sustainability aspects. He concluded that implementing sustainability-focused strategies at the upstream of the supply chain is preferable, whereas resilience-focused methods perform best in the downstream of the network. Ruiz-Benitez et al., (2018) investigated sustainable, resilient, and lean approaches all in one frame. He came to the conclusion that resilience techniques only enhance the economic and environmental aspects of sustainability and may have limited impact on social dimension, for example disaster recovery strategy, may improve the working environment's safety and health and therefore may increase social aspects of sustainability as well. Pavlov et al., (2019) suggests that effective resource use is a key component of sustainability therefore they focused on analyzing the relationship between effective resource redundancy and resilience. They suggest network redundancy optimization model which enables the explicit inclusion of resource consumption dynamics for the implementation of contingency plans in the presence of disruption scenarios. Kaur and Singh, (2019) used a cap-and-trade approach to reduce carbon emissions in logistics and procurement of raw material and ultimately design sustainable supply chain management for disaster-resistant procurement. Hence, case by case investigation of effective factors is needed to achieve a practical sustainable-resilience SC design. Some scholars consider green practices similar to sustainability, while in fact the focus of green practices is more on environmental dimension of sustainability. Green production practices include all stages of supply chain such as product design, procurement, manufacturing, distribution, marketing, recycling, life cycle management, and other processes. Xiong et al., 2020 discuss the capabilities that a resilient supplier should have in order to develop selection metrics that are introduced in their article in relation to the two aspects of vulnerability and recovery. Recovery referred to the system's ability to absorb damage while a disaster is occurring and to recover after the disaster, whereas vulnerability focused on the system's readiness before disasters occur. In this article vulnerability and recovery concepts are similar to absorptive, adaptive, and restorative capacity in the of SCR capacity framework. They considered Eco-design, Green procurement, Pollution production, Green packing, Green image and Life cycle management as criteria of greenness, and Surplus inventory, Factory segregation., Reliability, and Reorganization as criteria of resiliency for supplier selection problem. Talukder et al., (2021) introduced the concept of lean, agile, sustainable, resilient and nutrition (LASRN) paradigms. They included not only sustainability and resiliency but also other factors such as lean and agile feature and used dairy supply chain as case study. They defined four division for supply chain, planning, transportation management, warehouse management/ distribution management, and customer service/ order-to-cash division. The four supply change management divisions each have different responsibilities. As an instance, supply chain planning is in charge of forecasting, which results in a sales plan, manufacturing plan, inventory plan, finance plan, and so on. Route and network optimization are used by transportation management to ensure the safe and secure transfer of the ordered products. The section responsible for warehouse management and distribution centers receives and stores final products, keeps correct inventory records, selects, packs, and loads orders

for delivery, and takes care of worker safety, among other things. The order-to-cash division is responsible for keeping track of warehouse orders and customer services. Finally, Ivanov (2017) examined the connections between sustainability and resiliency in SCM with the goal of constructing a resilience SC as well as reducing uncertainty and improving sustainability. His study revealed three main implication (1) single sourcing worsen ripple effect (2) facility fortification positively affects sustainability and decreases ripple effect, (3) a decrease in storage facilities in the supply chain downstream of a disruption risk facility increases sustainability but causes the ripple effect. As mentioned so far, many scholars believed that resiliency is positively linked with sustainability (Papadopoulos et al., 2017) and some suggest sustainability is a prerequisite for resiliency (Gouda, and Saranga, 2018; Jain et al., 2017). Others claim that while sustainability and resiliency are related, they are not always correlated, thus enhancing one does not necessarily enhance the other. What practices may jointly progress these fields is unclear. Since sustainability often emphasizes efficiency and resilience promotes effectiveness (Negri et al., 2021).

5.4. Target Category (Digital Sustainable Resilient Supply Chain)

As previously stated, the study's major focus is on examining the impact of digitalization, namely industry 4.0, in constructing a sustainable and resilient supply chain. Because this is such a broad subject to look at, we decided to break it down into three distinct categories. On the other side, we studied the target category individually. Eventually, we compared the findings to those discovered in the target category research individually.

Most Frequent Journals. At the aggregate level, articles were published in 50 different peer-reviewed journals approximately, as it is illustrated in figure 13 (which only depicted the most frequent journals), the highest number of articles belongs to the International Journal of Production Research followed by Production Planning and Control. Among all categories, the digital sustainable resilient supply chain category has the least commonality with the other categories in terms of journals. The variety and frequency indicated in this part of the analysis demonstrate that the subject under investigation is quite broad and comprises multiple divisions, hence the use of distinct categories to examine this subject was a suitable method.

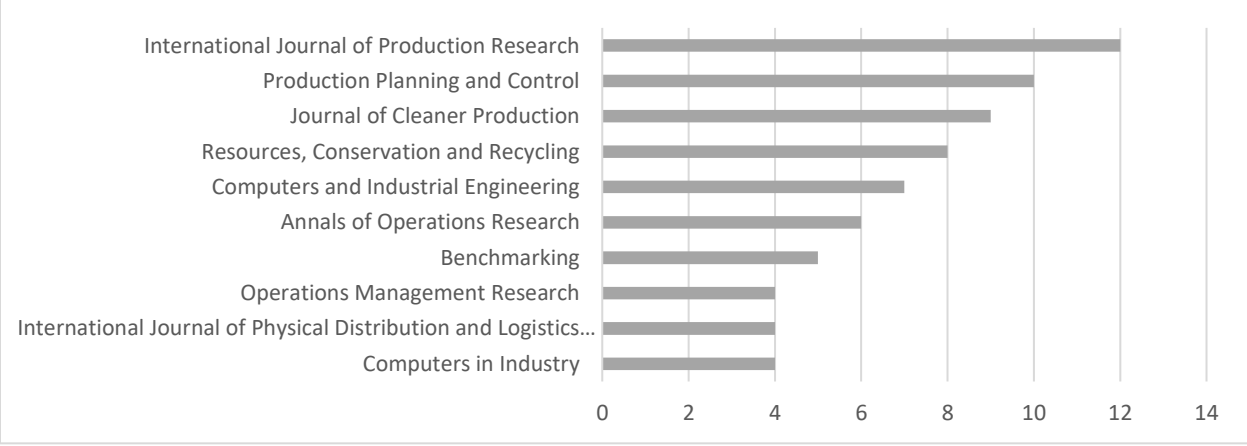


Figure 13. Distribution of articles in journals

Most Important Areas. Opposed to earlier categories, majority of papers in target category belongs to Decision Sciences (18.1 %), followed by Business, Management and Accounting with 17.6%**,** Computer Science (14.9%)**,** Engineering (14.9%)**,** and Social Sciences (10.6%), which shape almost two third of the pie.

Most Productive Authors. It was determined that the most productive authors in this category are Ivanov D., Dolgui A. Zekhnini K., and Cherrafi A. Although many scholars shed light on the concepts of resiliency, digitalization, and sustainability, based on our inclusion criteria and analysis in each category, Ivanov D. and Dolgui A. are among prominent researchers in the first and third categories which their studies are mostly related to the resiliency of the supply chain and the role of digitalization.

Distribution of Papers. Figure 14 compares the number of published publications in all categories from 2014 to 2021 (after applying inclusion criteria, most articles before 2014 were excluded). In general, it is obvious that the digital sustainable supply chain category (third category) has the most publications in this timeframe and reached its peak of more than 40 articles in 2021. The sudden increase in the number of publications in our target category demonstrates the subject's growing importance.

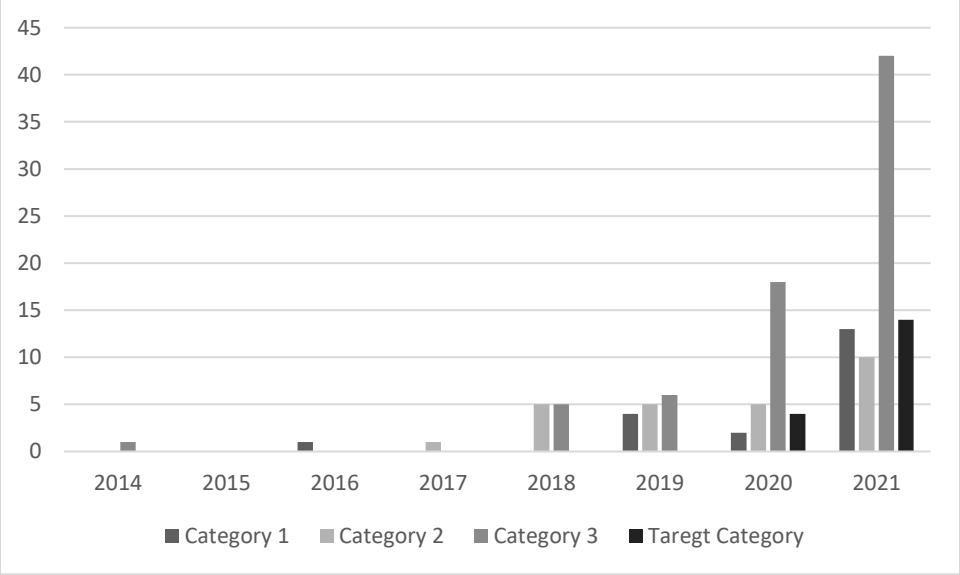


Figure 14. Results Comparison for paper distribution by year (after applying inclusion criteria)

Methodology of Study. Majority of papers in our target category concentrated on developing models or conceptual framework based on extensive literature review, some scholars also validated their model through a real-world problem as case study. For example, Bechtsis et al., (2021) initially studied the obstacles and barriers that SC experienced during COVID-19 outbreak and reported three main gaps: the effects of security on supply chain operations, cost-effective resilience techniques and practices, and the social and labor aspects of sustainability, then based on data from organic food SC he clarified the role of data-driven digital technologies on the aforementioned gaps. Song et al., (2021) validate their model through data from China digital economy during pandemic. To explain the role of Big Data on supply chain resilience and

sustainability, Papadopoulos et al., (2017) proposed a theoretical framework using unstructured Big Data, which is based on 36,422 items gathered in the form of tweets, news, Facebook, WordPress, Instagram, Google+, and YouTube, as well as structured data obtained from 205 managers who participated in disaster relief efforts following the 2015 Nepal earthquake. Joshi and Sharma, (2021) examined crucial success factor (CSF) to develop resilient and sustainable agri-food supply chain (AFSC), using combination of Fuzzy Delphi and fuzzy decision-making trial and evaluation laboratory (DEMATEL) methods, their funding revealed that Digital Technologies (DT) is among most important CSFs for achieving sustainable-resilient agri-food supply chain. Amentae and Gebresenbet, (2021), also considered agri-food supply chain as case study to examine the contributions of digitalization on agri-food supply chain and ultimately listed problem addressed by digital technology. Review study are also important methodology in this category, since this topic is still in its fancy phase therefore it is helpful to extract the theoretical foundation and concepts from the literature (Alhawari et al., 2021; Sajjad, 2021; Queiroz et al., 2020). Zekhnini et al., (2020) used adaptive fuzzy-neuro approach which is a machine learning technique to choose the best supplier in the digital supply chain in disruption as results they emphasized on the significance of "resilience," "sustainability," and "smartness" when choosing suppliers. For the simulation study, the Taguchi experimental design framework was utilized in the paper of Dev et al., (2021) to discuss the extent resiliency is effective on managing ripple effect caused by the disruption in the diffusion of green products.

In category 1, Structural Equation Modeling (SEM) approach was the most common, in category 2 and 3 Multi-Criteria Decision Making (MCDM) Algorithms was the most used approaches while in the target category Review Study, Conceptual Framework and models and Case Study are the most popular technique for examining how digital transformation affects supply chain sustainability and resilience.

Digitalization, Sustainability and Resiliency. As we discussed before, in the first category, BDA and AI have significant effect on increasing resiliency. Among resiliency enablers Visibility, Resilience Capacity, Flexibility, Collaboration, Agility, Transparency are most critical enablers respectively. In the second category, while most of the scholars analyzed all three bottom-lines of sustainability, it is proven that effect of digital transformation is lower on social dimension in comparison with economic and environmental dimensions, and economical dimension in the most imprisoned. In third category, the relationship between sustainability and resiliency in supply chain is analyzed, it was clarified that there is links between them, while a factor which is effective on resiliency is not necessarily effective on sustainability and vice versa. Finally, we want to exploit the interaction among digitalization, sustainability and resiliency.

Which is summarized in Table 3, some articles only focused on definition and theory building but did not clarify the interaction therefore in the table we just mentioned latter groups. As it is illustrated many scholars believe the digital transformation of supply chain affects both sustainability and resiliency of SC. While the magnitude of the effect is controversial, Ivanov et al., (2019) discussed the role of digitalization in SC grounded on SCOR model, and proved that

Table 3. Most prominent papers concentrated on digitalization, sustainability, supply chain simultaneously

Digitalization Focus	Resiliency Focus	Sustainability Focus	Summary of Results	References
Mobile apps, Artificial intelligence, Big data, Machine learning	Resilience	Product quality, Production costs, Visibility, Delivery time, Customer service, Inventory availability, CO2 emissions, employees' wages, Sales	The results proved only digital apps improved resiliency during COVID-19, business sustainability in terms of ROI, sales, and SC visibility increases the firms' probability to be resilient.	Trabucco et al., 2021
Blockchain, IoT, Big data analytics, AI, ICT	Traceability, Visibility, Transparency, Real-time-tracking	Competitive advantage, Predict food perishability, Manage food waste, Reduced costs, Higher efficiency, Good customer relationships, Marketability, Increase food safety	Digitalization positively affects sustainability and resilience.	Amentae and Gebresenbet, 2021
Industry 4.0, digital manufacturing, business analytics	Resilience (real-time visibility and robust decisions holding inventory or safety stock)	Sustainability (economic, environmental, social,)	After COVID-19 disruption companies increase applying digital technologies to achieve resilient and sustainable supply chain.	Alhawari et al, 2021
RFID, Machine Learning, Blockchain, Internet of thinks , Cloud Computing , Cybersecurity, Simulation, Self-driving vehicles, Additive manufacturing, Tracking and tracing system, Big data	Resilience, Flexibility, Agility	Sustainability	Describe how SC performance increase by integrating I4.0 enabling technologies, and lean, agile, sustainable, robust, and flexible paradigms.	Reyes et al., 2021
Digital logistics and technology infrastructure, Smart farming	Transparency, Traceability, Trust and collaboration	Social sustainability performance, Economic sustainability performance, Sustainable food security decisions, Standardization of sustainable practices	Digital Technologies, Logistics and infrastructure enhance sustainability and resiliency	Joshi and Sharma, 2021
Advanced digital technologies	Visibility, Collaboration	Social sustainability (employee protection schemes)	By implementing measures like employee protection programs, cutting-edge digital technology, diversification, localization and regionalization, and stakeholder participation, businesses will be better able to adapt to shocks and upheavals in the future.	Sajjad, 2021

Table 3. Most prominent papers concentrated on digitalization, sustainability, supply chain simultaneously

Digitalization Focus	Resiliency Focus	Sustainability Focus	Summary of Results	References
Engineering technology (collaborative robots, additive manufacturing, AGV, and mobile robots, drones, augmented and virtual reality); Data analytics technology (big data analytics and artificial intelligence); Infrastructure technology (cyber-physical systems and internet-of-things); Communication technology (M2M, cloud services, sensors, Blockchain).	Stress-testing, Proactive protection against disruptions, Disruption preparedness, Recovery planning, Contingency plans, Early warning procedures, Redundancy optimization	Nature and environment, Society, Resource efficiency, Human factors, Secure global food supply, Environmental footprint	Proposed a framework named X-network and conclude that "digitalization, resilience, sustainability and leagility can be positioned self-contained in their singularity and mutually enhanced by each other in their integrity within the Reconfigurable Supply Chain"	Dolgui et al., 2020
Suppliers' technological capability	Ambidexterity, Viability Vulnerability, Collaboration, Risk awareness,	Sustainability (economic, social, environmental) competencies	Discussed important criteria for choosing a supplier as resilience, sustainability, and smartness through technological capability	Zekhnini et al., 2020
Digital value chain (digital collaboration, digital innovation); Digital supply network (design process and product optimization, interoperability, advance analytics, synchronized planning and fulfillment, Intelligence supply)	Supplier competency (responsiveness, and resilience); Supplier competency (flexibility, and agility); Information and its usage (Information sharing and handling, Information visibility)	Supplier competency (social responsibility), Strategic orientation (quality of services, financial stability), Cost optimization	Using decision-making methods, to provide an algorithm for digital supply chains (DSCs) and digital supplier selection (DSS) to enhance quality management systems (QMS)	Sharma and Joshi, 2020
Digitalization	Ripple effect, Adaptation, and Recovery focus	Sustainability (economic, environmental, social,)	Suggesting a framework comprised of six perspectives including digitalization, recovery, ripple effect, and sustainability based on the structured literature review	Queiroz et al., 2020
Relying on technology (using AI and deep learning-based to improve decision making, applying scenario-based supply chain models using technologies such as digital twin)	Dynamic response, Developing a culture of collaboration, Diversification and dynamic adoption	Focus on sustainable supply chain	Analyzing the impact of COVID-19 on supply chain decisions and providing strategic recommendations for firms to overcome future supply chain challenges	Sharma et al., 2020
Big Data	Resilience in SC networks (Infrastructure, resource, Information sharing, public-private partnership, swift trust)	Sustainability	The current study provides direction to managers working throughout the disruption recovery period by clarifying the role of big data	Papadopoulos et al., 2017

although it has positive effects it also increases SC coordination complexity for example, as the results of applying industry 4.0 technologies and BDA, information disruption risk and data security issues as the results of increasing visibility, transparency and coordination, and increasing relying on single source supplier as a result of applying technologies such as additive manufacturing/ 3D printing. On the other hand, SCR efforts are in line with increasing redundancy and flexibility which is not in line with lean and sustainable practices and therefore mostly focused on effectiveness (Rice and Caniato, 2003). There are still ambiguities on digitalization practices that can improve both sustainability and resiliency, for example sustainable resource usage also effects on resiliency in positive way, but still need more research (Edgeman and Wu, 2016). Therefore, one solution can be using decision making techniques while considering synergies and trade-offs. Digitalization also is effective on improving quality of decision making, hence it is in line with the two concepts. Before COVID-19 epidemic, rather than focusing on sustainability and resilience, many studies discussed sustainability and risk (Shahin et al., 2019). While COVID_19 outbreak shocked global supply chain and shed lights on the importance of resiliency.

6. CONCLUSION AND DISCUSSION

6.1. Implications

This research presents a systematic literature review of recent scientific works concerning the industry 4.0 technologies that enhance sustainability and resiliency throughout the supply chain. To this end, 193 journal articles in Business and Management, Accounting, Engineering, Computer Science, Decision Sciences, Economics, Econometrics, and Finance areas are reviewed. Due to the size of the subject under review, the corpus is divided into three main categories: (1) Digital Resilient Supply Chain, (2) Digital Sustainable Supply Chain, and (3) Sustainable Resilient Supply Chain. The results of reviewing these three categories are then compared to the Target category “Digital Sustainable Resilient Supply Chain”. The first two categories of articles are concerned with the impact of digital transformation on achieving a sustainable and resilient supply chain and clarifying the undeniable role of technology. The various key technologies are identified as Big Data and DBA, AI, CPS, sensor, RFID, IoT, blockchain, additive manufacturing, AGV, and machine learning. Technologies that are more crucial in the context of sustainability than resiliency are recognized and the differences and similarities in the impact of digitalization in the two categories are analyzed. In the third category, the linkages between sustainability and resiliency are investigated in order to better comprehend the interactions, similarities, and differences between the two concepts. Resiliency is analyzed based on the resilience capacity theory, which considers three main capacities for the resilient supply chain namely, absorptive capacity, adaptive capacity, and restorative capacity (Hosseini et al., 2022). The concept of resiliency has been applied in two different phases in general. Some articles consider it in the pre-disruption phase (proactive) while others regard it in after disruption phase (reactive). Additionally, numerous resilience drivers and the role that digitalization plays in enhancing them are extracted from the corpus, including visibility, flexibility, agility, redundancy, transparency, responsiveness, collaboration, etc. This makes it possible for practitioners to effectively select the technology they should concentrate on in order to raise a particular resiliency enabler. Regarding sustainability, we considered three main domains named economic, environmental, and social

while some articles also consider human, aspects as well. The economical domain itself includes cost sustainability, energy sustainability, and revenue sustainability. In the literature, which we investigated, the relationship between industry 4.0 technology and sustainability is not clearly established, thus an attempt is made to shed light on the linkages between the two concepts to be used in future studies. The study identifies the potential of establishing a superior supply chain by combining the different 4.0 technologies, sustainability practices, and resilience factors. Future supply chain research is likely to be heavily influenced by themes of digitization, sustainability, and resilience and future technological advancements might lead to the proposed conceptual research framework being created. In addition, this research will provide a deeper insight into the effective implication of digital technologies in the supply chain which leads to a superior supply chain by considering both resiliency enablers and sustainability parameters, and it will help the supply chain managers (SCM) to build an integrated, efficient supply chain that is less vulnerable to severe disruptions.

The main objective of this study is to extract the theoretical foundation that clarifies the relationship between digital transformation on two important SC concepts, sustainability and resiliency. In order to address research questions, 193 peer-reviewed scholarly publications were analyzed in this study. In this section the research questions are answered based on the analysis:

RQ1: What is the magnitude and sign of the effect of digitalization on sustainable-resilient SC?

Most of the articles mentioned in category 1 and 2 and target category, using different scientific techniques proved that there is digitalization and Industry 4.0 technologies have positive influence on SC overall especially on sustainability and resiliency. As a result of the lesson that CVID-19 situation gave practitioners and scholars the focus on digital transformation is even more highlighted in the papers published after 2019. Awan et al., (2021) considered Industry 4.0 technologies which used in SC as disruptive including CPS, IoT, Big Data Analytics (BDA), Cloud Computing (CC) and Cyber Security Systems (CSS). Also, many scholars Frederico et al., (2021) such as proved that digitalization improve SC performance and ultimately profitability. Hence, digitalization is considered as positive factor in most of the articles but looking at the other side of the coin, it may have negative effects too, for example by insisting on integration, information sharing and coordination the information security will become a new concern. Additionally, implementing industry 4.0 enhances automation and therefore decrease dependency on human forces while at the same time increase safety for human forces in many conditions by handling hazards manufacturing process autonomously.

RQ2: What are the main technologies that have the most effects on sustainability and SCR?

We answered this question by dividing articles regarding sustainability and resiliency into different categories to answer more precisely, basically the main purpose of the sustainability practices and resiliency practice are not necessarily in correspondent. In the first category, most of the articles argued about the role of BDA and AI in increasing resilience effectively. While the AI and BDa itself are representative of many other technologies. In other words, technologies such as Machine-learning, Cyber Physical Systems (CPSs), Automated Guided Vehicles (AGV), and etc., are under the umbrella of AI and technologies such as simulation, predictive analysis, modeling, data

visualization techniques (digital twin), and etc., use data analytics as a core concept (Mittal et al., 2019). In the second category, Blockchain, IoT and BDA are respectively the most important technologies. By increasing transparency, blockchain technology give the producers the chance to track their products in all stages of SC to reduce inefficiency and waste**,** and therefore to increase sustainability. BT brough many benefits for manufacturers including real-time communication, ensuring trust among partners, developing secure relationships, speeding up payment processing with lower transaction fees, lowering product costs, shortening lead times, reducing bottlenecks, and resource conservation and recycling (Casado-Vara et al., 2018; Saberi et al., 2019).

RQ3: In which way digitalization, sustainability, and supply chain resiliency can be linked?

Based on the results extracted from reviewing articles in category 3 and target category, digitalization, significantly impacts on the drivers of sustainability and resiliency, some aspects although are not correspondent and are in contrast. For example, additive manufacturing positively affects SC sustainability since it significantly reduces the material waste and increase flexibility and ultimately efficiency, and it can increase resiliency by enabling the use of 3D printed components to replace materials that are in shortage, but on the other side it decreases redundancy by insisting on single resource, reducing inventory level and SC layers. Hence it has both negative and positive effects on SC concepts. The links and interactions between these three concepts are clarified in Table 3, among all drivers visibility, traceability and transparency are among the most important impacts of digitalization on both resiliency and sustainability aspect of SC.

6.2. Limitations

This study has certain limitations, despite the scientific methodology of SLR and the implications and consequences discussed in the previous section. First, it is exploratory study and based on the peer-reviewed articles over the past 10 years that are available in SCOPUS database, limited to only English language and limited area hence the study is not exhaustive. Second, this turdy tries to from a holistic perspective regarding the effects of digitalization on sustainable-resilience supply chain while it would be practical to look into the issue in more detailed view such as analyzing the effect of digitalization on each section in supply chain separately. Finally due to the recent sever impacts of COVID-19 on SC and the nature of this research, which is affected by the pandemic, the studies may overemphasize the importance of the subject automatically.

6.3. Future Research Opportunities

As mentioned previously, this article is developed based on considerable number of papers, therefore revealed many directions for further study to develop this subject. First, since the nature of our study we explanatory we have not mentioned any moderating, mediating and control variables, but it can be useful for example to consider the industry specific supply chain, such as food supply chain or agri-food supply chain, which were core of the concentration of numerous articles in the category 2 and 3. Hence one important future direction can be analyzing the same topic under supply chain specific context to realize similarities and differences and ultimately extract more accurate holistic perspective. Second, regarding the articles in the target category fewer empirical studies exist than nonempirical studies in this context. While this might be due to the fact that this issue is still immature.

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