



HAL
open science

Impacts of Digital Transformation on Supply Chain Sustainability: A Systematic Literature Review and Expert Assessment

Martha Orellano, Sanaa Tiss

► **To cite this version:**

Martha Orellano, Sanaa Tiss. Impacts of Digital Transformation on Supply Chain Sustainability: A Systematic Literature Review and Expert Assessment. 23th Working Conference on Virtual Enterprises (PRO-VE), Sep 2022, Lisbon, Portugal. pp.390-405, <10.1007/978-3-031-14844-6_32>. <hal-04642030>

HAL Id: hal-04642030

<https://inria.hal.science/hal-04642030v1>

Submitted on 9 Jul 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons CC BY 4.0 - Attribution - International License



This document is the original author manuscript of a paper submitted to an IFIP conference proceedings or other IFIP publication by Springer Nature. As such, there may be some differences in the official published version of the paper. Such differences, if any, are usually due to reformatting during preparation for publication or minor corrections made by the author(s) during final proofreading of the publication manuscript.

Impacts of Digital Transformation on Supply Chain Sustainability: A Systematic Literature Review and Expert Assessment

Martha Orellano*, Sanaa Tiss

Capgemini Engineering, Direction Recherche & Innovation, Blagnac 31700, France
{martha-stefany.orellano-carrasquilla, sanaa.tiss}@capgemini.com

Abstract. The current industrial context is characterized by the integration of digital technologies to improve process efficiency and Supply Chain agility to better respond to market volatility and customer needs. Digital transformation could contribute to the transparency, integration, connectivity, and flexibility of Supply Chains, enabling autonomous management and decision-making decentralization. Nevertheless, in addition to efficiency and agility, current and future Supply Chains should be sustainable, regarding the economic, environmental, and social pillars. In this paper, we analyzed the positive and negative impacts carried out by digitalization on the sustainability performance of Supply Chain activities, using the SWOT matrix method and the SCOR model. From a methodological point of view, a systematic literature review of 35 publications was performed and complemented by the expert consultation approach, involving a panel of experts in the fields of Supply Chain Management, digitalization, and sustainability.

Keywords: Digital transformation; Industry 4.0; Sustainable Supply Chain; Supply Chain Management; Systematic literature review.

1 Introduction

In the last few years, national and international standards and policies have been implemented to guide and incite companies to integrate sustainable development considerations into their activities. Also, the health crisis triggered by Covid 19 has accentuated the need to design flexible, resilient, and responsible logistics systems. Thus, the economic factors related to the increase of productivity within the Supply Chain (SC) are no longer the only concerns nor the only criteria ensuring the sustainability of SC activities. Rather, the integration of social and environmental considerations is becoming a key factor for SC sustainability and for gaining competitive advantage.

Furthermore, customers' needs become increasingly challenging, especially in terms of product customization. To keep up with the market dynamics and meet its new and growing standards, the adoption of digital transformation technologies is seen as a key

asset. The adoption of these technologies in logistics and Supply Chain Management activities has led to the emergence of Logistics 4.0 and Supply Chain 4.0.

The impacts of the adoption of these technologies in the SC have been considered positive regarding the pillars of sustainability, since it allows companies to improve their productivity, master their CO₂ emissions and improve their working conditions. However, the risks and negative impacts involved in the integration of these technologies are less emphasized in the literature.

In this paper, we study the impacts of new technologies on sustainable Supply Chain by relying on the state-of-the-art and expert opinions within the consulting firm Capgemini Engineering. First, we introduce the theoretical background on Supply Chain 4.0, and Sustainable Supply Chain. Then, we present our methodological approach, which combines a systematic literature review and expert consulting. After that, we present the main results of our work. Finally, we present the conclusions.

2 Theoretical Background

2.1 Logistics and Supply Chain 4.0

The notion of Industry 4.0 is generally used to characterize a system integrating digital technologies to autonomously collect, analyze, and evaluate data in real time and then decide and communicate with other systems, equipment, and humans [1, 2]. The application of Internet of Things (IoT)-based technologies is one of the key features of this industry phase (4.0) [3]. Industry 4.0 technologies allow the digital transformation of information, processes, and businesses to make information available anytime, anywhere, and in any context on different devices [4]. Different characteristics are used to describe the capabilities of digital transformation technologies. For instance, Junge [5] proposes the following characteristics to describe sustainable digital technologies: (1) elaborateness for more accurate and robust tools, (2) transparent structures for more technical openness, (3) comprehensive structure to be easily assimilated by humans and machines, (4) distributed location.

The adoption of industry 4.0 technologies in logistics and Supply Chain Management has led to the new concepts of logistics 4.0, Supply Chain 4.0, and Supply Chain Management (SCM) 4.0. Those technologies were adapted for logistics applications to better meet the volatility of today's market and respond more efficiently to individualized customers' demands [6, 7]. From an operational perspective, the use of intelligent et interconnected systems enhances the analytical and operational capabilities and thus optimizes Supply Chain activities [8–10]. The use of industry 4.0 technologies in Supply Chain Management allows accessing data in real time, promoting transparency between Supply Chain actors, and enhancing agility [4, 11].

2.2 Sustainable Logistics and Supply Chain Management

Nowadays, sustainability is one of the major concerns of manufacturers and SC managers. Ahi et C. Searcy [12] define Sustainable Supply Chain Management (SSCM) as “the creation of coordinated Supply Chains through the voluntary integration of economic, environmental, and social issues with inter-organizational business systems, to efficiently manage the material, information, and capital flows over the SC, to meet stakeholder requirements and improve the profitability, competitiveness, and resilience of the organization over the short and long-term”.

Besides, sustainable logistics is used as an interchangeable term for SSCM and can be defined as “the strategic and transparent integration and realization of social, environmental and economic objectives throughout the SC thanks to the systemic coordination of inter-organizational processes, enabling the economic performance of all the actors over the long term” [13]. Peng et al. [14] consider that sustainable Supply Chain Management is achieved through the following capabilities: sustainable strategy and governance, sustainable data collection and sharing, training and benchmarking, sustainable reporting, sustainable risk analysis, and sustainable innovation.

Particularly, environmental aspects in the logistic systems take a great extent in the contemporary debates and companies’ initiatives mostly related to transportation, warehousing, supplier selection, and product return management issues [15, 16]. In this line, Green Logistics is another notion that focuses on measuring and minimizing the impact of logistics activities from an ecological perspective [17].

Regarding the social aspects, the ISO 26000 standard [18] defines the main social categories as governance of organizations, working conditions, Human Rights, consumer protection, fair practices, and development of local communities. Yet, the social dimension of sustainability remains the most difficult to apprehend in sustainable SC, which is probably linked to the difficulty of measuring the intangible aspects related to the human factors [15]. Thus, new paradigms such as Society 5.0 and Industry 5.0 are emerging to emphasize the need to integrate social aspects by involving SC stakeholders benefiting from digital technologies, adapting and improving the SC organization, strengthening SC linkages, and capitalizing on the creativity of human experts in collaboration with intelligent machines [19, 20].

3 Research Methodology

3.1 Systematic Literature Review

We conducted a preliminary step concerning a bibliometric analysis, then we followed the steps of the PRISMA framework [21] (Fig. 1). The bibliometric analysis allows identifying the main trends, keywords and authors in the searched domain over time, to refine the research scope [22]. A systematic literature review is a well-structured and rigorous process that should be reliable and repeatable over time. It allows summarizing

and analyzing relevant literature about a subject and identifying the research gaps [23]. To conduct this research, we mobilized two bodies of literature, one concerning logistics 4.0 or Supply Chain 4.0, and the second one referring to sustainable Supply Chain. The following research questions guided this research: (1) What are the technologies involved in logistics 4.0 or Supply Chain 4.0? (2) How does the use of new technologies in Supply Chain activities impact positively and negatively the sustainability pillars?

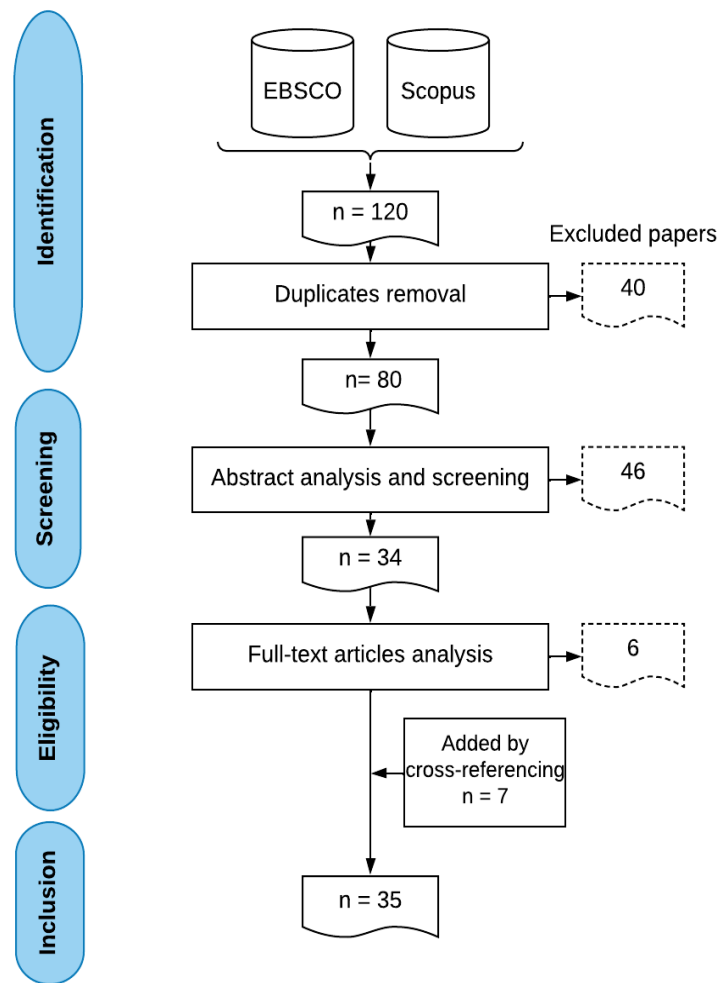


Fig. 1. Systematic literature review according to the PRISMA framework.

Preliminary Bibliometric Analysis. We applied the following keyword combination in Scopus database: (“logistics” OR “Supply Chain Management”) AND (“corporate social responsibility” OR “sustainability”) AND (“4.0 technolog*” OR “digital*” OR “smart”). The search was performed between 2000 and 2022. Three major periods

characterize the evolution of the academic literature that links Supply Chain Management, sustainability, and 4.0 technologies. First, the emergence of this research field coincides with the appearance of the Industry 4.0 notion in 2011 [7]. Then, between 2014 and 2018, the subject gained a slight interest, reaching an accelerated growth after 2018. We selected 2011-2022 as a representative time span to perform the successive steps of the systematic literature review process.

Source Identification. A set of keywords was defined based on the research questions, addressing two bodies of literature corresponding to logistics 4.0 and sustainable Supply Chain. Using Boolean operators, the keywords include the combination of (“logistics” OR “Supply Chain Management”) AND (“corporate social responsibility” OR “sustainability”) AND (“4.0 technolog*” OR “digital*” OR “smart”). We used Scopus and EBSCO databases and performed advanced research by “Title” and “Field”. Moreover, considering the bibliometric analysis, we defined a time span between 2011 and 2022. Peer-reviewed journals, conferences, and book chapters were considered. Only English-written articles were included. This step resulted in 80 papers.

Screening. An abstract analysis of the retained papers was performed throughout three screening criteria: i) the paper discusses at least one Supply Chain activity (i.e., SCOR model [24]: source, make, deliver, return, and plan); ii) the paper analyses the application of at least one technology 4.0 in Supply Chain activities; iii) the paper discusses either the environmental or the social pillar of sustainability. Two researchers performed an independent abstract analysis. Only the papers matching at least two out of the three criteria were included for full-text analysis. 34 papers were gathered at the end of this step.

Eligibility. Depth analysis of the screened papers was done considering the type of methodology implemented, the Supply Chain activity considered according to the SCOR model, and the pillar of sustainability addressed. Six articles were removed at this step because of their poor or no contribution to the research questions. Moreover, a cross-reference analysis was performed, from which seven papers were added to the sample. This step resulted in the consolidation of a relevant sample of 35 papers.

Included Papers. Most of the included publications take place between 2017 and 2021, and the sample is composed of 27 journal articles [3, 5, 7, 8, 10, 16, 17, 22, 25–43], six conferences [4, 5, 9, 14, 44, 45], and two book chapters [6, 46].

54% of the papers adopt a theoretical approach, 32% apply survey research, and 14% combine literature review and expert consulting.

3.2 Expert Assessment

The literature that crosses the applications of Industry 4.0 technologies in the Supply Chain and the dimensions of SC sustainability is very limited and particularly rare for those that deal with the negative impacts involved in the use of these technologies at the social and environmental level. We have relied on the experience of consultants within Capgemini Engineering to deal with these limits of the state-of-the-art. This

investigation was conducted using a brainstorming approach and semi-structured interviews with experts in logistics and digitalization.

4 Results and Discussion

4.1 Results of the Systematic Literature Review

A content analysis of the articles was performed according to the Supply Chain activities defined by the SCOR (Supply Chain Operations Reference) model [24]. This model is used by scientists and practitioners alike. This model classifies and describes the different levels of logistics processes as Source, Make, Deliver, Return, and Plan [24]. The articles were analyzed according to these SC processes while considering the use of new technologies and their sustainability impacts.

Sustainable Source 4.0. Gottge et al. [37] highlight the sourcing and purchasing challenges related to the management of an enormous mass of data, which is difficult to process using traditional methods. Big data analytics (BDA) enable an accurate analysis of a big volume of data at a high velocity [28]. Sun et al. [25] discuss the use of Artificial Intelligence (AI) for data analysis and risk anticipation, allowing companies to be more reactive in the face of threats. Furthermore, Sun et al. [25] evoke cloud computing as a useful technology to support buyer-supplier transactions and data sharing, since it enables centralized storage of data while providing autonomy and decentralized data access to each actor. Finally, Blockchain is evoked as a promising technology to assure data security in buyer-supplier transactions [27, 40, 41].

From an economic perspective, AI and BDA enable the analysis of market trends and suppliers' patterns, which favors the formulation of effective sourcing strategies [25, 28, 37]. Cloud computing and Blockchain facilitate data sharing and increase buyer-supplier trustworthiness. In particular, Blockchain can be used to create smart contracts, which eliminate the intermediation of transactions, reducing costs while improving data security [27, 40, 41]. Some economic shortcomings have been slightly discussed in the literature, concerning the high costs of system acquisition, management, and maintenance, and the risks of having technical problems [41].

From an environmental perspective, new technologies allow verifying suppliers' compliance with environmental regulations and tracking their environmental impacts [40]. It also promotes paperless operations [41]. In contrast, high energy consumption is needed for data storage and computation, and big amounts of electronic waste are generated from data centers [41]. Finally, considering the social issues, Blockchain improves data transparency, reducing the risk of corruption along the Supply Chain and contributes to tracing and tracking the ethical behavior of suppliers [27].

Sustainable Make 4.0. Junge [5] considers that real time, decentralization, and automation are the main capabilities of industry 4.0 technologies that allow for reducing

the cycle time and the efficient use of resources. Those capabilities can be provided by the combined use of autonomous robots and IoT which allows high connectivity and automation in smart production systems and thus more flow fluidity and real-time communication [25]. Using sensors for data acquisition in manufacturing systems allows for agility, better product quality, and thus better customer service rate [17, 38].

The use of Artificial Intelligent (AI) and cloud computing in connection with IoT-embedded systems is essential for effective planning and real-time work visualization and thus better process control [3, 25, 39]. Besides, Additive Manufacturing (AM) enables increasing customization capabilities and makes it easier to involve customers in product design and also the implementation of JIT [25, 33]. Blockchain allows the integration of information and material flow within the manufacturing system [25]. This integration facilitates information sharing, increases data security, reduces costs, and increases organizational efficiency [40]. Finally, simulation and Digital Twin (DT) can be used to handle emergency problems and enhance process efficiency [26, 35, 46].

Although there are various economic advantages of digitizing factories, it involves some business-related shortcomings. For instance, significant efforts and investments are needed for the implementation and integration of these technologies to ensure their interoperability and communication with the existing systems and equipment [17, 25].

Regarding the environmental pillar, using real-time data collection provides an opportunity for controlling energy usage and for efficient waste management [39]. Also, digitalization and automation of production systems allow waste minimization and paperless operations [38]. For example, AM makes it possible to use waste to make new value-added products [33]. Digital Twin can be used to detect and remove products or processes damaging environmental aspects [46]. However, the use and integration of these technologies imply different challenges and risks to the environment related to the lifecycle impact of the equipment [25]. For instance, Tran-Dang [17] highlight the significant energy consumption of IoT devices due to their permanent activity to fulfill real-time data collection requirements. Also, the use of AM can generate hazardous waste linked to the chemical consumables used in the transformation process [33].

From a social perspective, the features and services provided by Industry 4.0 technologies can lead to a better work environment by improving safety and reducing the work arduousness, while providing better visibility of accomplishments and progress to operators and managers [25, 38, 41]. Thanks to real-time monitoring, scraps and rework expenses and the associated workload can be reduced [39]. Furthermore, the application of Blockchain in manufacturing systems can be a useful tool for better assurance of human rights, especially those related to data privacy. Moreover, technologies like simulation can provide opportunities for operators' training in a safe environment. However, within digital and automated systems, the knowledge requirements will be higher, and this can cause job loss and anxiety [10, 25, 33].

Sustainable Deliver 4.0. Delivering-related technologies consist of IoT devices to track and trace products (e.g., RFID, scanning devices, intelligent goods), voice-guided picking systems, Intelligent Transport Systems (ITS), and Transport Management Systems (TMS), among others. The sustainability implications of those technologies have been discussed in recent literature, focusing on their positive aspects.

From an economic perspective, Nantee and Sureeyatanapas [10] and de Vass et al. [38] highlight the use of IoT devices in warehousing to facilitate order picking accuracy

throughout the implementation of RFID and scanning devices. In the same line, Barreto et al. [9] and Sajjad et al. [39] argue that IoT devices improve operational performance and traceability accuracy thanks to real-time data collection. Specifically, in transport operations, TMS and ITS enable interactions with the warehouse management system, the track and trace of freights, and improve routing optimization [9, 10]. As stated by Nantee and Sureeyatanapas [10], TMS and ITS contributes increasing customer satisfaction by reducing lead time and improving shipping and information accuracy, and better responsiveness. Nevertheless, the high costs of investment and use constitute a barrier to the broad adoption of these intelligent systems.

From the environmental perspective, ITS and TMS allow the reduction of CO₂ emissions thanks to routing optimization, provide eco-efficient driving support, and enable the planning of multimodal transport [9, 10, 42]. In complement, the use of sensors enables real-time monitoring of CO₂ emissions [38]. However, the use of these devices constitutes a source of electronic waste and requires a huge amount of energy.

Finally, concerning the social issues, digital technologies can improve the working experience. In the transport sector, it helps to increase the safety and comfort of drivers by facilitating traffic analysis, providing driving guidance, monitoring fatigue, and controlling security devices [10, 42]. In warehousing activities, IoT devices contribute to improving health and safety in the workplace through the use of sensors and fatigue analysis [38]. Furthermore, technology adoption in delivery operations can promote the acquisition of new IT skills [35]. However, some negative impacts can be indicated. Adopting new technologies can lead to the loss of manual jobs, and generate a feeling of work uncertainty among the employees [4, 10]. Moreover, human-machine excessive collaboration can provoke skills degradation. Finally, the data collection made throughout the delivery applications can lead to data privacy vulnerabilities.

Sustainable Return 4.0. The main technologies supporting return activities are tracking devices and Blockchain. For instance, Sajjad et al. [39] put forward the notion of a “recycling center”, which operates thanks to tracking technologies based on IoT, such as RFID and intelligent containers. The idea behind those recycling centers is to track the products until their end of life, identify the recycling products’ parts, and enable optimal inventory management of returned products. Besides, regulatory return policies can be defined within smart contracts enabled by the Blockchain.

From an economic perspective, the use of new technologies in return activities contributes to improving customer satisfaction and gaining a competitive advantage throughout business model innovation [33]. Concerning the environmental issues, these technologies enable close-loop Supply Chains, improving the efficient management of waste, defective products, maintenance flows, and excess Supply Chain products [41]. Furthermore, it allows for mastering the product's lifecycle information and the traceability of reusable containers [39]. From a social point of view, tracking technologies in reverse logistics allow information sharing transparency between the Supply Chain actors, including suppliers and customers [27].

Sustainable Supply Chain Management 4.0. The generalization of the use of IoT-based technologies throughout the Supply Chain, not only allows to improve traceability within this chain [37, 39], but also the agility thanks to an efficient process of risk management [14, 25, 31]. For instance, the use of cloud-based information

systems allows centralizing and facilitating the exchange of data between SC actors and thus reducing the synchronization cycle time, while respecting the autonomy of each actor [47]. This allows aligning the decisions of the SC actors and optimizing the flows through the SC [10, 39]. In this context of massive real-time data sharing, a primary concern is the quality and security of the shared data. Blockchain can help secure the data and improve cooperation between the various SC actors by eliminating intermediation [40], thus reducing the cost and time of transactions [27].

From an environmental perspective, tracking technologies and Blockchain can enable tracking products from their origin and along all their lifecycle and tracking their carbon footprint. This provides an opportunity for the development of effective eco-friendly products and thus avoid greenwashing issues [27]. As well, advanced information and communication systems help promote sustainability among SC actors (e.g., Social plastic or Recycle to Coin programs [27]) and align their visions toward a responsible logistics system. From a social perspective, Blockchain and smart contracts can improve reliability and contribute to developing sustainable and trustworthy relationships between SC actors [40][27]. This reduces the risk of corruption and opportunistic and unethical behavior within the SC [48].

4.2 Results of the Expert Assessment

Beyond the elements identified from the literature review, the brainstorming and interviews carried out with the experts at Capgemini Engineering led to relevant insights related to industrial applications of new technologies.

For instance, the voice picking system was identified as a new technology being implemented in the “Deliver” phase of the Supply Chain. This technology supports the operators to perform the picking operation through the voice instructions to indicate the right location, quantity, and reference of articles to perform the order preparation. Besides, related to the sustainability impacts of new technologies, most of the elements evoked by the experts correspond to economic and social aspects, whereas the environmental one was less addressed.

Among the economic impacts indicated by the experts, we count the costs of subcontracting IT and system adaptation for an IoT-based system. It was highlighted that this adaptation can aim even at a conception of new equipment to optimize the Process Cell for MES (Manufacturing Execution System). Furthermore, the technological interfacing cost, the management of special stock related to the use of new technologies (e.g., chemical consumables for additive manufacturing), and the reduction of the labor costs in manual operations were also evoked.

Concerning the social aspects, some threats such as the distrust in the algorithms, the gap between IT and real business practices, and the risk of losing autonomy in the case of IT outsourcing were indicated. Moreover, the imbalance in the technological maturity of the collaborators in the Supply Chain was indicated as a general feature in Supply Chains. Finally, “greenwashing” and “sustainability marketing” remain cross-cutting issues that threaten the integration of sustainability concerns in logistics systems, identified as major challenges according to the experts [16].

4.3 SWOT Analysis

The literature findings were summarized into a SWOT matrix, structured according to the activities of the SCOR model, the relevant technologies used in each of these activities, and their sustainability-related impacts. The sustainability impacts were summarized and categorized thanks to a thoughtful analysis of the literature. An initial SWOT matrix based on the literature insights was presented to the experts to have their validation and appreciation. Then, we completed the SWOT matrix with the experts' insights from their industrial experience (Table 1,

Table 2, and Table 3).

Table 1. Environmental impact analysis of 4.0 Technologies in Supply Chain activities.

	Sustainability Technologies	Environmental pillar	
		Negative impacts	Positive impacts
Source	AI Big data analytics Cloud computing Blockchain	<ul style="list-style-type: none"> Data center locations (Use of space) Energy consumption from the servers Electronic waste generation 	<ul style="list-style-type: none"> Supplier selection and purchasing strategy oriented towards eco-responsibility Reducing pollution thanks to paperless operations
Make	Autonomous robots IoT systems AI AM DT	<ul style="list-style-type: none"> Energy consumption Life cycle impacts of equipment Hazardous waste generation linked to the chemical consumables used in AM Electronic waste generation 	<ul style="list-style-type: none"> Equipment maintenance cycles Low raw material volume used in AM Waste reduction Reduction of remanufacturing, thus energy saving
Deliver	Tracking tech. ITS Voice picking	<ul style="list-style-type: none"> Electronic waste generation Energy consumption 	<ul style="list-style-type: none"> Mastering and reduction of CO₂ emissions thank to routing optimization and planning of multimodal transport
Return	Data-driven marketplace Tracking tech. Blockchain	<ul style="list-style-type: none"> Massive product labeling packaging Long-distance returns Electronic waste 	<ul style="list-style-type: none"> Product lifecycle information Increasing recycling efficiency closed-loop SC
SCM	Blockchain Cloud	<ul style="list-style-type: none"> Carbon footprint of information system technologies 	<ul style="list-style-type: none"> Tracking the entire product life cycle impacts

Table 2. Economic impact analysis of 4.0 Technologies in Supply Chain activities.

	Sustainability Technologies	Economic pillar	
		Negative impacts	Positive impacts
Source	Artificial Intelligence (AI) Big data analytics Cloud computing Blockchain	<ul style="list-style-type: none"> • Cost of system management and maintenance • Subcontracting cost and high dependency (If IT outsourcing) • Risk of sharing sensible data 	<ul style="list-style-type: none"> • Analysis of market trends and purchasing patterns • Effective planning • Reduction of errors linked to manual data entry and processing • Risk management
Make	Autonomous robots IoT systems AI Additive manufacturing (AM) Digital Twin (DT)	<ul style="list-style-type: none"> • Investment costs on equipment acquisition • Cost of system use • Cost of system maintenance • Cost of system interfacing • Management of stocks of chemical consumables for AM 	<ul style="list-style-type: none"> • Process performance improvement • Real-time process monitoring • Reduction of labor costs in manual operations • Increasing customization capabilities • Ease to involve customers in product design
Deliver	Tracking technologies Intelligent Transport Systems (ITS) Voice picking	<ul style="list-style-type: none"> • Cost of equipment acquisition • Cost of system management and maintenance • Cost of systems use • Recharging time of electrical equipment 	<ul style="list-style-type: none"> • Process performance improvement • Traceability accuracy • Process flexibility • Customer satisfaction • Reduction of manual labor costs • Stability of delivery costs
Return	Data-driven marketplace Tracking tech. Blockchain	<ul style="list-style-type: none"> • High investment cos • Cost of system management 	<ul style="list-style-type: none"> • Customer satisfaction • Competitive advantage throughout innovation • Traceability of reusable containers
SCM	IoT Blockchain Cloud	<ul style="list-style-type: none"> • Cost of enforcing technological adoption • Loss of collaborators (resistance to change) 	<ul style="list-style-type: none"> • Virtual currency transactions • Secure access to data • Improving marketing and strategic planning • Data-driven business

Table 3. Social impact analysis of 4.0 Technologies in Supply Chain activities.

	Sustainability Technologies	Social pillar	
		Negative impacts	Positive impacts
Source	Artificial Intelligence (AI) Big data analytics Cloud computing Blockchain	<ul style="list-style-type: none"> • Distrust in the algorithms • Gap between IT and real business practices • IT staffing shortage • If IT outsourcing, loss of skills and autonomy • Loss of purchasing jobs 	<ul style="list-style-type: none"> • Transformation of job profiles (IT and decision-oriented) • Autonomy given data decentralization • Buyer-supplier transparency
Make	Autonomous robots IoT systems AI Additive manufacturing (AM) Digital Twin (DT)	<ul style="list-style-type: none"> • Several applications and tools to master and handle • Layoff on manual jobs • Feeling of job uncertainty • Stress linked to high productivity exigence • Perception of autonomy loss • Reduction of human relationships • Hazardous waste generation 	<ul style="list-style-type: none"> • Reduction of work arduousness • Transformation of job profiles (from manual/technique to engineering/decision profiles) • Creation of new job profiles (IT and decision-oriented)
Deliver	Tracking tech. ITS Voice picking	<ul style="list-style-type: none"> • Layoff on manual-related jobs • Feeling of job uncertainty • Increasing stress linked to high productivity exigence • Competences and skills degradation • Data privacy vulnerability 	<ul style="list-style-type: none"> • Improvement of delivery working experience • Adaptable equipment/ vehicles (ergonomics) • Improvement of work safety (e.g., fatigue analysis)
Return	Data-driven marketplace Tracking tech. Blockchain	<ul style="list-style-type: none"> • Customer data privacy vulnerability 	<ul style="list-style-type: none"> • Improvement of flow transparency
SCM	IoT Blockchain Cloud	<ul style="list-style-type: none"> • Data privacy vulnerability • Interest conflicts 	<ul style="list-style-type: none"> • Trustworthy business environment

5 Conclusion

In this article we address the impacts of the adoption of industry 4.0 technologies in Supply Chains. We answered two research questions: What are the technologies involved in logistics 4.0 or Supply Chain 4.0? How does the use of new technologies in Supply Chain activities impact positively and negatively the sustainability pillars?

To answer those questions, we confronted the applications of different technologies in each of Supply Chain activities and studied their positive and negative impacts simultaneously on each of the pillars of sustainability (economic, environmental, social) within a SC. We relied on an analysis of the state-of-the-art, then we validated and completed this analysis with a panel of experts in the fields of digitalization and logistics. Finally, we summarized the results of this analysis using a SWOT matrix that crosses the different studied dimensions of SC activities using the SCOR model.

Based on the literature, we have detailed the applications of the different technologies in each of the SC activities according to the SCOR model. Data analytics and cloud computing technologies are significantly addressed at the level of purchasing and procurement activities of companies to improve the accuracy of forecasts and to assist the decision-making process. Additive manufacturing technologies and autonomous systems are also being used extensively in manufacturing systems to improve productivity and reduce production cycle times for customizable products. IoT devices and TMS (Transport Management Systems) are used in delivery and distribution activities to improve reactivity thanks to real-time data, and to control and optimize CO₂ emissions. These technologies are used to manage return flows, which enables closed-loop supply chains. Lastly, the management of transactions and data sharing using blockchain and IoT-based technologies enable a secure and efficient exchange of data between SC actors in an agile and trusted collaborative environment.

The collection of experts' opinions mainly contributed to identifying and analyzing practically the observed negative effects of 4.0 technologies according to their experience as implementers or users of these technologies. This allowed us to complete our analysis of the positive and negative impacts of 4.0 technologies on the SC sustainability, that are not well covered in the literature. The experts agreed with the fact that social factors are crucial to ensuring the effective integration and use of technologies to improve the efficiency and productivity of SC activities. They identified the necessary adaptation of usual processes for the integration of new technologies as the most constraining factor impacting the acceptability by users. Also, operators might feel a loss of autonomy in their interactions with these new technologies. On the economic pillar, the cost of integration is very high and mainly constrained by the significant efforts required to adapt existing tools and information systems. Furthermore, regarding the use of IoT-based technologies for the collection and analysis of real-time data, we stress that quantitative analyses are required to estimate the contribution of these technologies in comparison to the associated energy consumption due to their permanent running.

Finally, in the obtained SWOT matrix, we observe potential compensations between positive and negative impacts (e.g., new job profiles versus the loss of manual jobs). It will be possible to tackle this effect by assigning weights to the impacts using multicriteria analysis.

References

1. Thoben, K.-D., Wiesner, S., & Wuest, T. (2017). "Industrie 4.0" and Smart Manufacturing - A Review of Research Issues and Application Examples. *International Journal of Automation Technology*, 11(1), 4–16.

2. Ghobakhloo, M. (2020). Industry 4.0, digitization, and opportunities for sustainability. *Journal of Cleaner Production*, 252, 119869.
3. Çınar, Z. M., Zeeshan, Q., & Korhan, O. (2021). A Framework for Industry 4.0 Readiness and Maturity of Smart Manufacturing Enterprises: A Case Study. *Sustainability (2071-1050)*, 13(12), 6659.
4. Kayikci, Y. (2018). Sustainability impact of digitization in logistics. *Procedia Manufacturing*, 21, 782–789.
5. Anna Lisa Junge. (2019). Prospects of Digital Transformation Technologies (DTT) for Sustainable Logistics and Supply Chain Processes in Manufacturing. *Operations Management for Social Good : 2018 POMS International Conference in Rio*, 713.
6. Demir, S., Yilmaz, I., & Paksoy, T. (2020). Augmented Reality in Supply Chain Management. In *Logistics 4.0*. CRC Press.
7. Winkelhaus, S., & Grosse, E. H. (2020). Logistics 4.0: a systematic review towards a new logistics system. *International Journal of Production Research*, 58(1), 18–43.
8. Strandhagen, J. O., Vallandingham, L. R., Fragapane, G., Strandhagen, J. W., Stangeland, A. B. H., & Sharma, N. (2017). Logistics 4.0 and emerging sustainable business models. *Advances in Manufacturing*, 5(4), 359–369.
9. Barreto, L., Amaral, A., & Pereira, T. (2017). Industry 4.0 implications in logistics: an overview. *Procedia Manufacturing*, 13, 1245–1252.
10. Nantee, N., & Sureeyatanapas, P. (2021). The impact of Logistics 4.0 on corporate sustainability: a performance assessment of automated warehouse operations. *Benchmarking: An International Journal*, 28(10), 2865–2895.
11. Oleskow-Szlapka, J., & Stachowiak, A. (2019). The Framework of Logistics 4.0 Maturity Model. In *Springer, Cham* (pp. 771–781).
12. Ahi, P., & Searcy, C. (2013). A comparative literature analysis of definitions for green and sustainable supply chain management. *Journal of Cleaner Production*, 52, 329–341.
13. Carter, C. R., & Rogers, D. S. (2008). A framework of sustainable supply chain management: moving toward new theory. *International Journal of Physical Distribution & Logistics Management*, 38(5), 360–387.
14. Peng, X., Kurnia, S., & Cui, T. (2021). IT-Enabled Sustainable Supply Chain Management Capability Maturity. In *Proceedings of the 54th Hawaii International Conference on System Sciences*.
15. Roussat, C., & Fabbe-Costes, N. (2014). Logistique durable du futur : Etat des lieux en France et pistes de recherche. *Logistique & Management*, 22(1), 19–34.
16. Schiffer, M., & Dörr, D. M. (2020). Development of the Supply Chain Management 2040 – Opportunities and challenges. *Proceedings of the Conference on Production Systems and Logistics: CPSL 2020*.
17. Tran-Dang, H., Krommenacker, N., Charpentier, P., & Kim, D.-S. (2020). The Internet of Things for logistics: Perspectives, application review, and challenges. *IETE Technical Review*, 39(1), 93–121.
18. ISO 26000. (2010). *Guidance on social responsibility* (1st ed., Vol. 22).
19. Fornasiero, R., & Zangiacomini, A. (2021). Reshaping the Supply Chain for Society 5.0. *IFIP Advances in Information and Communication Technology*, 632 IFIP, 663–670.
20. Maddikunta, P. K. R., Pham, Q.-V., B, P., Deepa, N., Dev, K., Gadekallu, T. R., ... Liyanage, M. (2022). Industry 5.0: A survey on enabling technologies and potential applications. *Journal of Industrial Information Integration*, 26.
21. Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., ... PRISMA-P Group. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic Reviews*, 4(1), 1.
22. Frazzon, E. M., Taboada Rodriguez, C. M., Meireles Pereira, M., Cardoso Pires, M., & Uhlmann, I. (2019). Towards Supply Chain Management 4.0. *Brazilian Journal of Operations & Production Management*, 16(2), 180–191.

23. Xiao, Y., & Watson, M. (2017). Guidance on Conducting a Systematic Literature Review. *Journal of Planning Education and Research*, 39.
24. Stadler, H., & Kilger, C. (Eds.). (2008). *Supply Chain Management and Advanced Planning*. Berlin, Heidelberg: Springer Berlin Heidelberg.
25. Sun, X., Yu, H., Solvang, W. D., Wang, Y., & Wang, K. (2022). The application of Industry 4.0 technologies in sustainable logistics: a systematic literature review (2012–2020) to explore future research opportunities. *Environmental Science and Pollution Research*, 29(7).
26. Zhong, R. Y., Xu, X., Klotz, E., & Newman, S. T. (2017). Intelligent Manufacturing in the Context of Industry 4.0: A Review. *Engineering*, 3(5), 616–630.
27. Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research*, 57(7), 2117–2135.
28. Wang, G., Gunasekaran, A., Ngai, E. W. T., & Papadopoulos, T. (2016). Big data analytics in logistics and supply chain management: Certain investigations for research and applications. *International Journal of Production Economics*, 176, 98–110.
29. Beske, P., & Seuring, S. (2014). Putting sustainability into supply chain management. *Supply Chain Management: An International Journal*, 19(3), 322–331.
30. Montreuil, B. (2011). Toward a Physical Internet: meeting the global logistics sustainability grand challenge. *Logistics Research*, 3(2–3), 71.
31. Giannakis, M., & Papadopoulos, T. (2016). Supply chain sustainability: A risk management approach. *International Journal of Production Economics*, 171, 455–470.
32. Rajeev, A., Pati, R. K., Padhi, S. S., & Govindan, K. (2017). Evolution of sustainability in supply chain management: A literature review. *Journal of Cleaner Production*, 162.
33. Nascimento, D. L. M., Alencastro, V., Quelhas, O. L. G., Caiado, R. G. G., Garza-Reyes, J. A., Rocha-Lona, L., & Tortorella, G. (2019). Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal. *Journal of Manufacturing Technology Management*, 30(3), 607–627.
34. Marshall, D., McCarthy, L., Heavey, C., & McGrath, P. (2015). Environmental and social supply chain management sustainability practices: construct development and measurement. *Production Planning & Control*, 26(8), 673–690.
35. Bag, S., Telukdarie, A., Pretorius, J. H. C., & Gupta, S. (2021). Industry 4.0 and supply chain sustainability: framework and future research directions. *Benchmarking: An International Journal*, 28(5), 1410–1450.
36. Kumar, G., Subramanian, N., & Maria Arputham, R. (2018). Missing link between sustainability collaborative strategy and supply chain performance: Role of dynamic capability. *International Journal of Production Economics*, 203, 96–109.
37. Gottge, S., Menzel, T., & Forslund, H. (2020). Industry 4.0 technologies in the purchasing process. *Industrial Management & Data Systems*, 120(4), 730–748.
38. de Vass, T., Shee, H., & Miah, S. J. (2021). Iot in supply chain management: a narrative on retail sector sustainability. *International Journal of Logistics: Research & Applications*, 24(6), 605–624.
39. Sajjad Shokouhyar, Neda Pahlevani, & Farhang Mir Mohammad Sadeghi. (2019). Scenario analysis of smart, sustainable supply chain on the basis of a fuzzy cognitive map. *Management Research Review*, 43(4), 463–496.
40. Khanfar, A. A. A., Iranmanesh, M., Ghobakhloo, M., Senali, M. G., & Fathi, M. (2021). Applications of Blockchain Technology in Sustainable Manufacturing and Supply Chain Management: A Systematic Review. *Sustainability*, 13(14), 1–20.
41. Wolfram Groschopf, Mario Dobrovnik, & Christian Herneth. (2021). Smart Contracts for Sustainable Supply Chain Management: Conceptual Frameworks for Supply Chain Maturity Evaluation and Smart Contract Sustainability Assessment. *Frontiers in Blockchain*, 4.

42. Lorena Reyes-Rubiano, Adrian Serrano-Hernandez, Jairo R. Montoya-Torres, & Javier Faulin. (2021). The Sustainability Dimensions in Intelligent Urban Transportation: A Paradigm for Smart Cities. *Sustainability*, 13(10653), 10653–10653.
43. Govindan, K., Kilic, M., Uyar, A., & Karaman, A. S. (2021). Drivers and value-relevance of CSR performance in the logistics sector: A cross-country firm-level investigation. *International Journal of Production Economics*, 231, 107835.
44. Kusters, A. C. (2022). Relating digitization, digitalization and digital transformation : a maturity model and roadmap for Dutch logistics companies. University of Twente.
45. Ethirajan, M., Kandasamy, J., Dhinakaran, V., Kumaresan, G., & Raju, R. (2020). Assessment of sustainability in supply chain management for industry 4.0 requirements. *AIP Conference Proceedings*, 2283(1), 1–7.
46. Kim, G.-Y., Flores-García, E., Wiktorsson, M., 1971, & Noh, S. D. (2021). Exploring Economic, Environmental, and Social Sustainability Impact of Digital Twin-Based Services for Smart Production Logistics. *C-PALs IFIP Advances in Information and Communication Technology*.
47. Paksoy, T., Kochan, C. G., & Ali, S. S. (2020). *Logistics 4.0: Digital Transformation of Supply Chain Management*. CRC Press.
48. Bag, S., Telukdarie, A., Pretorius, J.-H., & Gupta, S. (2018). Industry 4.0 and Supply Chain Sustainability: Framework and Future Research Directions. *Benchmarking An International Journal*.