

An Exploratory Impact Studies of Digitalisation on Global Supply Chain Sustainability Practices

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Abstract: - In recent years, the realm of decision management research focused on supply chain sustainability has grown significantly and emerged as a highly active and productive area. The foundation of sustainability relies on the concept of innovation. Traditional business practices and environmental responsibility are being transformed by the incorporation of digitalization in supply chain sustainability. The scope of digitalization within supply chains has expanded to cover digital goods and services, alongside the management of supply chain operations within companies that are undergoing these swift transformations. The research proposes a conceptual framework to analyze supply chain sustainability through digitalization. The study aims to examine the interactions of digital technologies and sustainable supply chain management (SSCM) benefits and challenges. The integration of digital and supply chain proposes a transformative approach for firms aiming to achieve sustainable development goals (SDGs). Finally, the study provides a comprehensive insight into future studies on the impact and integration of digitalization to achieve supply chain sustainability through academic and industry research studies in this field.

Key-Words: - Digital, Sustainable Transformation, Global Supply Chains, Digitalisation, Sustainable Development Goals (SDGs), Intelligent Technologies, Circular Economy, Reverse Logistics, Sustainable Supply Chain Management (SSCM), Digital Supply Chain Management (DSCM).

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1 Introduction

Studies have defined supply chains as a network of activities linking different parties (*i.e. internal and external stakeholders*) together and the links associated with each party's undertaking those activities. Supply chain is a combination of activities involved within the conversion and transportation of services and goods through the interaction of information and finance from material sources to end users [1]. The 4th Industrial Revolution (I4.0 or Industry 4.0) outlines the proposed framework within future production and operations systems. It transformed entire business procedures and paradigms. The key area of I4.0 focuses on the facilitation of automation for easy integration of systems across the entire manufacturing sector while working to achieve the goals of sustainability. Although technological advances drive much of this transformation, they are also looked by firms positive approach towards adaption and sustaining through the customer preferences and demands. Some of these approaches focus on the rise in customer demands for flexible

and customised products, while addressing the purchasing methods and blending the products with wider business processes and services. In contrast to the previous approach of manufacturing goods according to production schedules tied to market demands, these endeavours now stem from the digitalization of operations facilitated by the exchange of up-to-the-minute data via digital networks. This is referred to as digital transformation (DT), as per earlier studies [2], [3]. There is lack of research on the importance of sustainability within traditional business firms. However, with the advancement of global economies and the growing importance of environmental and social issues, integrating sustainable practices has now become of paramount importance for firms to survive while balancing their brand reputation and positive contribution to society. Firms usually operate in complex connections and thus the choices they adopt towards sustainability tend to affect their approaches towards economic, social and environmental dimensions [4]. In the modern era, a diverse range of parties have

engaged to achieve and fulfil sustainable practices within firms.

Alongside various other stakeholders, companies have found themselves obligated to expand their focus beyond mere economic responsibilities towards shareholders, encompassing a commitment to sustainable performance that benefits all stakeholders. Sustainability has permeated every stage, from product design to the management of post-consumer products, across numerous global sectors. However, the integration of sustainability into supply chain management (SCM) has been lacking. While prioritising sustainability is essential for the enhancement of firms' internal processes along with the optimising of the overall performance of supply chains (SC). Several factors contribute to enhancing the importance of sustainable supply chain management (SSCM) through a range of stakeholder involvement. An example of SC impact framework on sustainability shown in Figure 1.

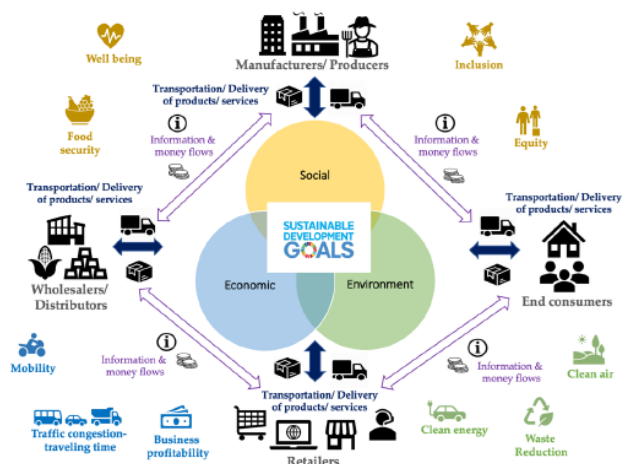


Fig. 1: SC & Sustainability Framework
Source: [5]

Within the automotive and wider electronics sectors, the integration of S-SCM has gained importance, especially with the evolution of regulatory requirements. A more ideal approach and strategy for integrating sustainability within supply chains involves conducting environmental impact evaluation (EIA) assessment for life cycle assessments (LCA) of the products and services. These evaluations tend to adopt a perspective centred around firms or their respective products. Recognising the significance of sustainability extends through the product level to organisational considerations, while the concept of organisational life cycle assessment (O-LCA) has gained wider importance. O-LCA extends the focus beyond

products, through a comprehensive evaluation of various impacts within the firms and across the value chains [6]. The European Commission (EU) actively advances the development of the Organisation Environmental Footprint [7]. These underscores the requirements for a well-structured governance framework while highlighting the crucial role of data identification for information sharing towards sustainability practices. Studies have suggested the importance and vision of a complete system wide sustainability analysis [8]. Manufacturing firms have observed and overcome several challenges with the shift in digital technologies. While sustaining position within the competitive landscape, many businesses have examined the impact of the implementation of these technologies within their operations. This further ensures their position in the market, while addressing the competitive nature and the growing demand from consumers. Hence, SC have emerged as DSC through meticulous data and information sourcing and utilisation through analytics with the support of digital technologies to further improve overall processes within the SC.

As a result, this optimization contributes to elevated customer service standards and the sustainable operational prowess of the firm. Research has shown that digitalisation impacts significantly on SC sustainability. Through real time visibility, data-driven decision making, and collaboration across SC; digital technologies have assisted firms to reduce waste, emission controls, and costs, while improving overall efficiency and customer satisfaction. The concept of I4.0 has gained more momentum through the interactions of various dimensions of business operations. One such is 3D printing also referred to as additive manufacturing (AM) that uses cloud and big data computing through advanced analytics solutions for optimising and enhancing operations and processes shown in Figure 2.

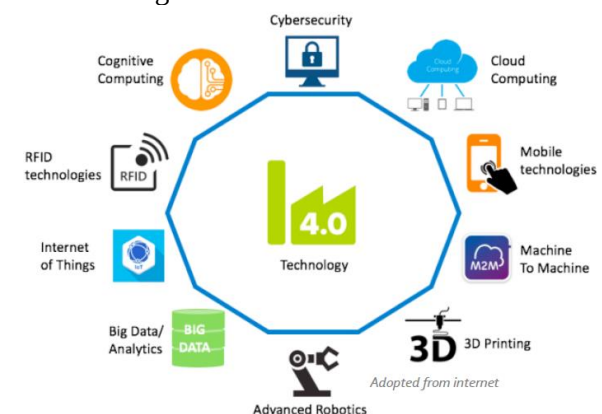


Fig. 2: Industry 4.0 Technologies Key Pillars
Source: [9]

Recent market demands and changes in global events have demanded the extensive use of digital tools towards addressing the gaps and shifts in market demands that has also impacted global SC. Concurrently, businesses are reevaluating their global SC networks considering these circumstances. Studies from industry reports [10], [11], [12] usually underscore the potential of digital transformation to amplify performance across multiple dimensions of SC operations that enhances by 5-10%, ideally within major services and inventory focussed sectors. This enables the opening of the digitalised SC or namely DSC (digital supply chains) for the integration and utilisation of advanced tools and technologies across all areas of firms operations [13], [14]. While these advancements favour the firm's position, there are several gaps on full scale utilisation such as network and data security and reliability. But the balance towards the usefulness on digital adoption to achieve and fulfil the sustainability parameters has enabled firms to contemplate the risks while benefiting from its advantages on long-term prospects.

1.1 Research Motivation

The key motivation of the research is to examine the impact of digitalisation on SC sustainability with the important element that the research has the capability in addressing the global challenges and enable positive changes across a wide range of industries. The key elements highlighting the importance are shown in Table 1.

Table 1. Key Research Elements

Key Research Element	Element Importance
Environmental Responsibility and Risk Mitigation	- The incorporation of eco-friendly methods aids firms in reducing the ecological influence; possibility of adverse impacts on ecosystems. - Businesses that place an emphasis on sustainability are more adept at handling limited resources, accommodating shifts in regulations, and alleviating potential legal ramifications. - Studies identifies sustainability integration within business empowers them to proactively confront ecological hurdles and augment their sustained viability [15]
Market Demand and Consumer Preferences	- In the present era, consumers are more attuned to their choices when making purchases and demonstrate a preference for businesses that align with their values. - The adoption of sustainable practices holds the promise of attracting committed customer base and consequently expanding market influence. - Today's environment, many consumers willing to pay extra for products and services offered by companies committed to sustainability [16].

Key Research Element	Element Importance
Enhanced Collaboration	- Digitalisation aims to elevate cooperation among distinct SC parties, thereby aiming to achieve sustainability targets. - Example: The utilization of cloud-based systems enables real-time data exchange between suppliers and clients, while leveraging social media can facilitate the cultivation of relationships and trust among various stakeholders [17].
New Business Models	- Digital advancements have the potential to facilitate novel sustainable business models. - To illustrate, the concept of a sharing economy could decrease the necessity for transportation and storage, while the principles of a circular economy could aid in diminishing both waste generation and emissions.

Source: Created by Authors

1.2 Research Background and Objectives

Digitalisation aims in SC sustainability focuses on leveraging technological advancements for the enhancement of efficiency, transparency, and traceability within supply chain operations while further reducing environmental impacts. The goal is to create a sustainable SC that is resilient, agile and responsive towards changing consumer preferences, market dynamics and regulatory requirements. Using digital technologies in the SC, stakeholders collect, analyses and share real-time data with the collaboration with partners, automating processes and tracking the sustainability performance of the SCs. This further enables firms to identify opportunities for improvement, mitigate any risks, optimise resources utilisation, while reducing waste and enhancing the social and environmental responsibility of the operations, and key research questions are as:

- RO1. To understand and evaluate the potential impacts of digital technologies on SC.
- RO2. How is digitalisation strengthening the integration and the agility of the SC?
- RO3. How do digital technologies control and coordinate the SC process and in supporting the industry 4.0?
- RO4. How to enhance the transparency using digitizing?
- RO5. How to reduce the risk associated with supply chain sustainability?

2 Literature Review

The integration of digitalisation will profoundly influence the execution of tasks in various industries and will also meld the forthcoming business approach along with its interconnected supply networks. Illustrations of the areas that will

experience an impact encompass the management of customer demand within the supply chain, the process of product development and design, customer interaction and cooperation with partners throughout the entire value chain, and more [18]. The continuous shift towards digitalisation in the context of I4.0 is still a developing trend, marked by its relatively unexplored nature and its coverage of a broad spectrum of research domains. The primary drivers of digital transformation often involve an increase in response speed and a boost in the adaptability of both industrial and supply chain systems. Figure 3 shows SC progression over 60 years. Through the early 1960s, manufacturing firms have prioritised higher production to lower unit costs as the key goal; while 1980s saw inventory and material management consolidation that progressed through to 1990s towards incorporating several cross-departmental activities, including production, warehousing, distribution and logistics. Over the years this has enabled a more seamless collaborative SC to improve and achieve efficient operations.

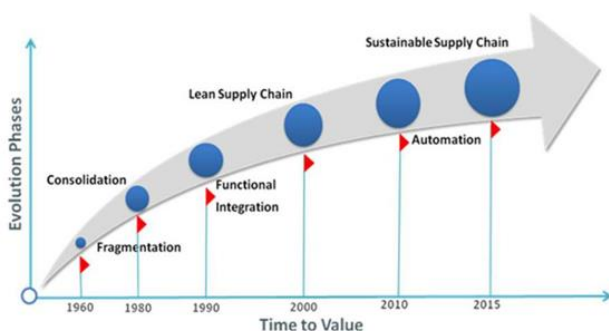


Fig. 3: Evolution of Supply Chain
Source: [19]

Through the aid of digital technologies and mobile devices, a seamless integration within the SC was achieved to connect different partners. This achievement empowered SCM to effectively oversee product data and financial streams. As the supply chain expanded continuously, it grew more intricate, featuring complex networks that required constant monitoring and control due to the numerous processes involved. Later, organizations recognized the global competition and shifted their focus towards waste reduction in terms of materials and machine running time. They also aimed to eliminate redundant processes, acknowledging the growing challenges within the SC [19].

Several studies suggest that **Sustainable Supply Chain Management (SSCM)** leads to enhanced efficiency, resulting in cost reduction. SSCM is a response to the transition from competition between

individual companies to competition between entire supply chains, potentially offering companies a competitive edge [20]. To achieve competitive edge enables trust and confidence amongst all the parties including suppliers and buyers as shown in studies [21], which increases complexities across SSCM. Factors such as reputation, trust, coordination, data, economic, social and geo-political complexities add further restrictions upon supply chain resource utilisation. Earlier studies have shown more positive aspects of stakeholder collaboration internally (i.e. suppliers, customers) and externally (i.e. external agencies) across SC through the firm's environmental, operations and reputational aspects [22]. Through the advancement in digitalisation and SC, sustainability has evolved and emerged as a key parameter within traditional business. In recent years, the rapid advancement of digital technologies has brought forth transformative opportunities for optimizing SC while concurrently addressing the imperative of sustainability as shown in Figure 4.



Fig. 4: Barriers in Implementing SSCM
Source: [23]

This literature review delves into the intricate interplay between digitalisation and SC sustainability through exploring the transparency, visibility, stakeholder enhancement and circular economy. By synthesizing a spectrum of scholarly works, this review aims to provide a comprehensive understanding of how digitalization is reshaping the landscape of sustainable supply chains and catalysing novel paradigms in the realm of business operations.

2.1 Intelligent Technologies as An Intermediary in Digital Supply Chain Sustainability

Digital transformation entails significant alterations in business processes, encompassing the conversion of various elements into digital formats. The primary aim of digital transformation is to promote improved cooperation among business processes by leveraging intelligent technologies. Intelligent systems and technologies have seen importance through the interaction of software and hardware, along with platforms, infrastructure and systems that share the key data and information. This further emphasises the role of advanced technologies in fully benefiting from the advantages and growth of digital transformation. Intelligent technologies expand web-based services by integrating features like mobile OS, which enable numerous service functions like organizational management, collaborative oversight, customer support, and service research and planning. Figure 5 shows the intelligent technologies framework. Through appropriate interactions with key stakeholders and exchanging crucial information and knowledge across organisational barriers, intelligent technologies have the potential to influence the advancement of procurement, supplier interaction and better customer service.

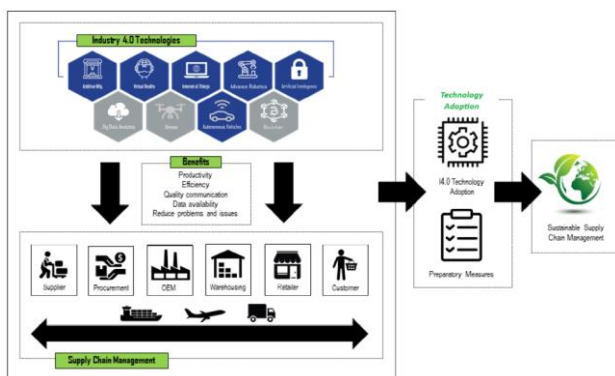


Fig. 5: Intelligent Technologies Framework
Source: [24]

Considering the points, it can be deduced that intelligent technologies are crucial for enhancing relationship performance and facilitating the digital evolution of businesses [25]. Business sectors have the option to utilize network or interoperable technologies to create links among their manufacturing procedures, suppliers, and clientele. This empowers them to rapidly adapt to shifts, reduce waste and excess production, and amplify energy and resource efficiency using intelligent management systems. These strides culminate in substantial progress concerning industrial

sustainability [26]. Studies highlighted that incremental sustainable innovation pertains to the step-by-step enhancement of conventional production systems via the adoption of novel technologies and the introduction of modifications to products and processes [27]. This strategy aims to progressively boost sustainability achievements. When analysing innovation on an organizational scale, it involves the investigation of individual companies and their capacity to create innovative technologies, along with the interactions between research and development (R&D), marketing, and production activities [27].

2.2 Visibility and Transparency

As evident through earlier studies, I4.0 tools allow the integration of digital technologies through a framework and network of advanced machines that allows sharing of data and information for enhanced decision making. The advent of I4.0 holds the promise of considerable progress in industrial development. Yet it also bears the capacity to disturb the sustainability of current industrial entities. Industry 4.0 furnishes resilient warehouse systems and dependable channels for information exchange and communication. It also enables the empowerment of decision makers and management to reduce expenses while improving customer experience [28]. Key technologies including IoT, Cloud, AI, BDA, Smart Sensors, Robotics and ML are involved within digital transformation of the business. This reshapes the traditional manufacturing plants into efficient and resourceful “smart factories” or “factories of the future”, thus playing an important part to carbon reduction [29]. Blockchain technology is employed to guarantee security, transparency, and visibility in supply chains. Through the utilisation of a distributed register that the firm manages a single record is thus reducing retrieval, and reconciliation processes with the help of automation. Technologies such as blockchain can transform SC operations through the enhancement of product traceability while streamlining processes within the business and improving overall security (Figure 6) towards the integration of information and material flow with the help of blockchain technology. Hence, with the use of blockchain, creation of collaborative platforms for management and sharing of product and service information is successfully achieved within the firm.

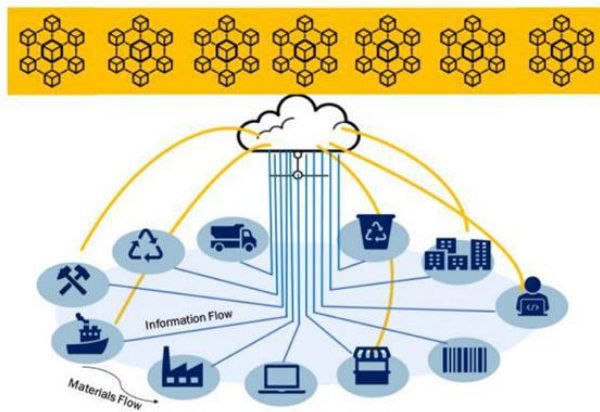


Fig. 6: Integration of Information and Material Flow through Block Chain Technology
Source: [30]

By facilitating efficient information sharing, blockchain enables the clear monitoring of materials and environmental data throughout the intricate, multi-tiered construction SC over its lifespan. Additionally, in terms of sustainability benefits in circular SC, blockchain can enable enhanced material traceability and transparency, lowered carbon and energy emissions, improved resource and energy efficiency, increased collaboration among stakeholders throughout a product's lifecycle, improved material quality, expedited delivery, heightened productivity, and reduced operational costs [31]. This is particularly beneficial for industries dealing with durable and capital goods, allowing various stakeholders to effectively leverage product lifecycle data [30].

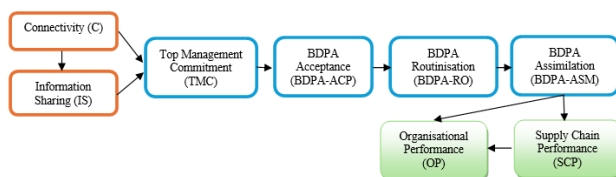


Fig. 7: Digitalisation Model
Source: Adapted from 32

Through digitization, the collection, analysis, and exchange of data within the SC network occur in real-time, promoting increased transparency and visibility. Studies shows digital technologies such as IoT and RFID supporting accurate, real-time tracking of goods and hence improving visibility across entire supply chains as shown in Figure 7 [32]. This increased visibility enables the identification of inefficiencies such as higher energy usage, transport emissions, and waste generation, thus allowing firms to optimise key operations while

reducing overall environmental impacts. Table 2 shows the operationalisation constructs.

Table 2. Construct Operationalization

Constructs	Measures
Connectivity	Current information systems satisfy communications requirements
	Information applications are highly integrated within the firm and supply chain
	Adequate information systems linkages exist with partners in supply chain network
Information sharing	Organization exchanges:
	Relevant information
	Timely information
	Accurate information
	Complete information
Top management commitment	Sensitive information
	Top management:
	expresses how supply chain partnering will provide significant business benefits to the firm
	expresses how supply chain partnering will create a significant competitive arena
	articulates vision for supply chain collaboration
Supply chain performance	formulates strategy for organizational information sharing
	establishes the metrics to monitor supply chain success through partnering
	Organization has full visibility of our supply chain
	Organization appropriately manages supply chain risk
	Organization's primary supply chain has the ability to minimize total product cost to final customers.
	Organization's primary supply chain has the ability to deliver product precisely on-time delivery to final customers.
	Organization's primary supply chain has the ability to deliver zero-defect products to final customers.
	Organization's primary supply chain has the ability to minimize all types of waste throughout the supply chain.
	Organization's primary supply chain has the ability to deliver right-sized lot sizes and shipping case sizes to final customers.
	Organization's primary supply chain has the ability to eliminate late, damaged and incomplete orders to final customers.
	Organization has the ability to minimize channel safety stock throughout the supply chain.
	Organization's primary supply chain has the ability to deliver value-added services to final customers.
	Organizations supply chain has the ability to respond faster than competitors to changing environments.

Source: [32]

This research explores how connectivity and information sharing, enabled by strong dedication from top leadership, play a role in integrating Big Data and Predictive Analytics (BDPA) capabilities. These capabilities then have an impact on Supply Chain Performance (SCP) and Organizational Performance (OP). Scholars underscore the significance of senior managers in building these abilities, ultimately aiding organizations in gaining a competitive advantage. The commitment of management plays a pivotal role in aligning resources and cultivating the development of these capabilities. Research studies explore how resources, including connectivity and information sharing, and capabilities—particularly the ability to incorporate big data—shape Supply Chain Performance (SCP) and Organizational Performance (OP) [32]. The study argues that the Resource-Based View (RBV) framework is relevant in understanding the integration of BDPA as a capability. This capability is built upon the combination of resources (C and IS) and positively influences both SCP and OP. Ultimately, it contributes to achieving a competitive advantage at both the organizational and SC levels. This research contends that the incorporation of BDPA demonstrates a favourable connection with OP. This

broadens the realm of investigation focused on the impact of IT, information exchange, and SC integration and change on both firm and SC performance [32].

2.3 Collaboration and Stakeholder Engagement

Digital tools enhance the collaboration and communication within SC stakeholders, while enabling the integration of key sustainability measures across the firm's supply chain. Through effective collaboration it enables diverse expertise and efforts supporting companies to strengthen their capabilities. By forming and creating more collaborative partnerships, firms can strengthen their internal capabilities while accessing advanced technologies and key resources both internally and throughout their SC. Through well integration and mutually beneficial partnerships, the exchange of knowledge and support towards the development of innovative capabilities, additional resources are generated thus enhancing value creation across SC. Blockchain technologies have gained huge attention due to its abilities to enhance traceability and transparency in sustainable SC. Studies have highlighted that blockchain provides a secure platform to record key sustainability metrics such as certifications, origin of product and fair-trade policies [33]. As a result, this technology enhances the level of trust and accountability among partners involved in the SC [32]. Apart from economic objectives, stakeholder entities exert influence on core companies to enhance the sustainability outcomes of their SCs. Governmental pressures and incentives usually stem from regulations formulated by national administrations or international regulatory entities across local, national, and global tiers. The competitive edge and image of a company are impacted by external stakeholder groups, who insist on transparent oversight and management of sustainable SC performance [27].

2.4 Circular Economy (CE) and Reverse Logistics

Currently, the manufacturing industry is placing significant importance on the notion of the circular economy (CE), a concept that has gained heightened significance in recent years for both corporate entities and academic researchers.

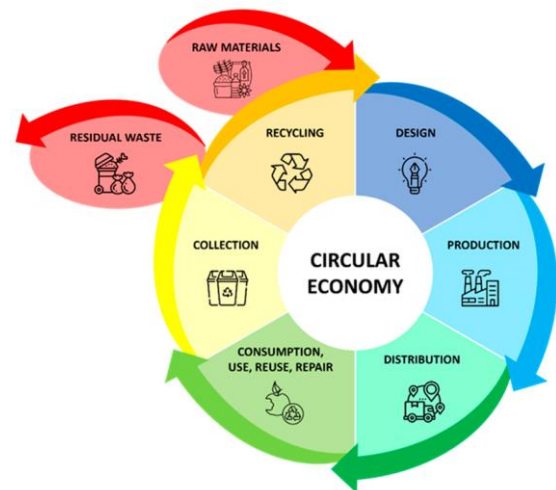


Fig. 8: Circular Economy Model

Source: [34]

This trend is evident in both advanced economies and emerging markets, as they actively promote the incorporation of CE principles into their operational structures (Figure 8). Digitization assumes a pivotal role in aiding the shift towards a CE by streamlining effective reverse logistics procedures. The incorporation of I4.0 functionalities has notably enhanced the exchange of information within SC, resulting in enhanced decision-making for sustainable operations management.

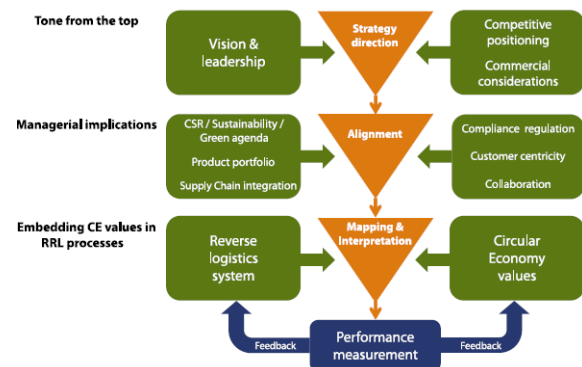


Fig. 9: Framework for Aligning CE with RL

Source: [35]

Consequently, the integration of I4.0 and CE principles can provide substantial benefits for managing sustainable operations. To adeptly manage a value chain centred around the CE, companies must ensure efficient oversight of recovery and remarketing processes, achievable through the implementation of a 'Reverse Logistics' (RL) initiative. The Circular principles and its alignment within I4.0 are shown in Table 3. Example framework aligning the CE with RL is shown in Figure 9 [35]. The authors introduced a **ReSOLVE framework**, outlining six strategies for

constructing business models grounded in CE and includes regenerate, share, optimise, loop, virtualise, and exchange [36].

Table 3. CE principles Aligned with I4.0

CE Principles	CE Principles [adapted from 38] Aligned with I4.0 Technologies [adapted from 39]
Regenerate	- Based on the conversion of waste into a source of energy for different operations along the value chain. - Aligns with I4.0 by making sustainable production decisions based on adapting data received via IoT
Share	- Based on sharing of resources to extend life cycle via recovery operations from the economic point of view. - Aligns with I4.0 using both cloud-based resources and IoT. The potential of this component of CE could be realized through sharing information related to inventory management, supply, and demand across the SC and the consumers as well. - These technologies can collect information concerning society's dynamic behaviour so that the organization can improve both operational parameters and resource utilization for environmental and economic performances
Optimize	- Based on technology-centred strategy, which requires the organization to use digital manufacturing technology such as principles of I4.0 to reduce waste in the operations system across the supply chains. - Aligns with I4.0 supported by CPS and IoT. These technologies can collect information in the form of data from processes and various resources to enable identifying work in process inventory, which helps in computing optimal order size.
Loop	- Based on the restoration of the value of products via recovery operations. - Aligns with I4.0 supported by IoT, CPS, and cloud services. It represents a broad aim of the circularity of materials and energy. The operations in RL such as tracking and tracing of products and transportation modes could be improved using sensors, RFID tags, etc.
Virtualize	- Based on the service-focus strategy that allows virtual and dematerialized products - Aligns with I4.0 supported by cloud manufacturing, IoT, and AM technologies. - These technologies enable the relationship between organizations, suppliers, and customers such that the physical world is replaced by the virtual world using simulation models by linking to sensor data. - AM enables customized products based on interactions among manufacturers, suppliers, and customers.
Exchange	- Based on introducing advanced and renewable goods instead of old and non-renewable goods. - Aligns with I4.0 by adopting additive manufacturing and IoT. AM enables sustainable production through reduced use of material and recovery operations

Source: [37], CE Principles adopted from [38], I4.0 Technologies adopted from [39]

3 Research Methodology

Numerous articles have been published in the domain of SC sustainability and digitalization, according to studies. There are also other articles on SC sustainability that examine the research. It should be highlighted, nonetheless, that there hasn't been much research done on how to analyse the operational and implementation aspects of digitalization in the context of SC sustainability,

combining theories and other factors that contribute to sustainability. In this research, a qualitative method is employed to examine academic works that discuss the implementation of digital technology within SCs. The rationale for selecting this method is rooted in the fact that prior investigations into the research queries have been individually developed through distinct instances. A qualitative analysis of these studies through a literature review allows for a comprehensive overview of the topic, recognition of trends in adoption trends, and the provision of scientific insights into the implications of this adoption. The literature review for the study is split in 4 states as defining research scope; selection of relevant studies; analysis of literature; and synthesis of the key findings. Each of these steps is further documented to ensure a transparent and replicable process [40], [41].

3.1 Qualitative Approach

Finding the scope of the research is the first stage. This study only focuses on newly developing digital technologies like IoT, big data, and sensor because of what these new technologies are and how they contribute to SC sustainability. This indicates that the literature review's purview is strictly limited to sustainability objectives. The generation, connection, and storage of real-time data is the primary purpose of digital technology, particularly IoT. IoT devices and other sources generate a lot of data, which is analysed using big data analytics. Through the application of learning algorithms, AI is used to perform predictive and preventive data analysis functions. Because the data gathered from IoT devices needs to be evaluated, IoT and AI are the two aspects of I4.0 that are most frequently linked to big data analytics. IoT has the potential to generate enormous amounts of data wherever it is used. For the data to be relevant for business, it must be examined effectively, and the usage of AI may help with both predictive and prescriptive functions.

The selection of studies is the second phase. The search was restricted to peer-reviewed English journal papers, as is typical in most review studies. The search strings include any combinations of "digitalization," OR "Internet of Things," OR "IoT," OR "Big data," OR "artificial intelligence," OR "AI," OR "industry 4.0," and "supply chain 4.0," or "Supply Chain sustainability," or "Sustainability" to find all potential articles related to digital technologies in supply chains and supply chain sustainability. All search results, including those for the keywords "digit", "digital", and "digitalization", are returned when the keyword "digit*" is used.

Time and journal limits are now in place for this stage to include all potential research in list as shown in Figure 10 for the paper selection. The next stage is to analyse the literature. After carefully reading all 189 papers, analysing the key points in each one, and selecting an additional 90 publications that were within the purview of the study.

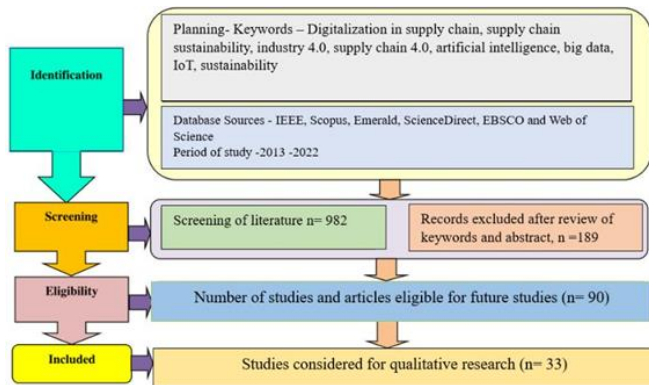


Fig. 10: Qualitative Research Selection Process
Source: [41]

The 90 publications were thoroughly reviewed, and the papers that addressed at least one of the five research questions were chosen. This phase was carried out by all authors to lessen the bias in the paper selection. Additionally, the articles' quality was considered to guarantee the validity of the review. Around thirty-three resources were chosen in the study, with the criteria and relevance to the five research topics being taken into consideration.

3.2 Thematic Findings

RQ1: Through a network of interconnected organisations, SCM encompasses the control, management, and improvement of the flows of goods and information between the initial suppliers and end users. Digital technologies are viewed as promising tools for enhancing supply chain operations like planning, scheduling, and logistics. Using BDA and AI, the real-time data gathered from IoT devices in combination with the data from other SC operations have the potential to produce significant commercial value. This supports firms to accurately predict customer demand, while identifying inventory patterns and thus optimising the use of resources and strengthen supplier relationships. The transformation of digital is not only limited to the products and processes, but also through the value chain, business model and the industrial ecosystem. Through enhancement of efficiency, resilience, reliability, visibility and robustness, and through the reduction of risks and uncertainties associated with the SC, digital

technologies can enable firms to improve their overall SC performance. Large amounts of data are generated because of the digitalization of SC, and this new type of resource is thought to have the potential to add value and boost competitiveness. This might have an impact on business models and alter how companies generate and capture value [40].

RQ2: Fundamental quality of SC that is required for survival in turbulent and volatile markets is agility.

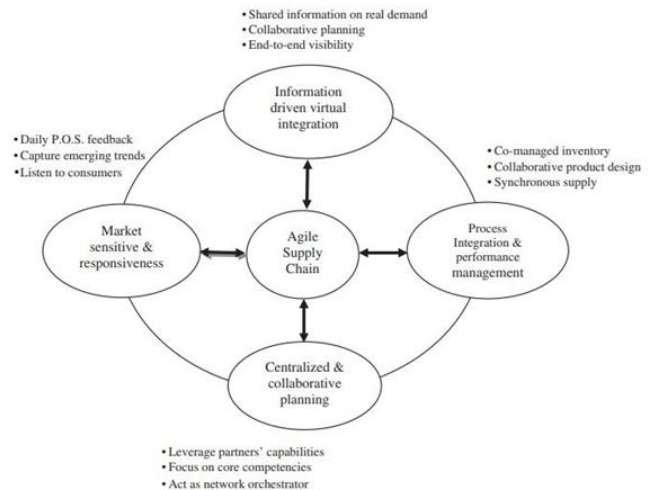


Fig. 11: Agile Supply Chains
Source: [42]

As product life cycles shorten and environmental variables contribute to the unpredictability, more risk in SCM becomes the norm. Similarly, agility enables the SC to deliver the right trilogy – right product to the right customer at the right time; thus, fulfilling the fundamental objective of any SC. By dismantling information silos, fostering collaboration, offering real-time insights, enabling quick modifications in reaction to shift market dynamics, digitalization enhances the integration and agility of SC. Operations in the SC become more responsive, effective, and customer-focused as a result in Figure 11 [42].

RQ3: I4.0, also commonly known to as smart production, smart manufacturing or smart factory involves the vertical-horizontal integration of product systems that are enabled through real-time data exchange and flexible manufacturing processes to support any bespoke production. The era is characterised through the use and adoption of digital technologies such as IoT, cloud computing, analytics and big data that are more widely used and accepted by practitioners and researchers. Businesses are integrating and connecting these

local solutions to improve their data-processing capabilities. BDA technologies are advantageous in many areas of operations and SCM in the context of I4.0, including analyses of SC, social and environmental sustainability, SC and organisational performance, and serviitization [43].

RQ4: Using blockchain to build a tamper-proof, decentralised, and auditable record of transactions includes utilising the technology's built-in capabilities. Blockchain operates through a decentralised network of computers, and once information is recorded on the ledger, it becomes immutable ensuring greater data integrity. All participants can instantly access the most updated version of this ledger as and when new transactions are added. This same understanding reduces differences and encourages transparency. Similarly, blockchain is also able to assist in tracking products' whereabouts through the supply chain, thus enabling the access to information through the process from start to end of the journey. This data is available to consumers, encouraging transparency and fostering confidence. Permissioned access is a feature that some blockchain implementations support, giving users varying levels of access depending on their position. This preserves privacy while guaranteeing accountability among important stakeholders. Blockchain secures data using cryptography to guarantee data integrity. Data cannot be changed once it has been input without network agreement, lowering the possibility of fraud or data manipulation.

RQ5: Strategic planning, teamwork, Risk Mapping, and preventative measures are required to reduce the risks connected to supply chain sustainability. The process of identifying and evaluating potential risks along the entire supply chain entails charting those associated with legal changes, labour practises, and more. To identify any potential SC risks through the implementation of supplier evaluation process and incorporating the social, ethical and environmental criteria. The real time monitoring of SC operations enables firms to track any sustainability-related performance metrics and indicators and take swift action to any emerging risks. Through leveraging advanced tools such as IoT, AI and blockchain that further enhance the traceability, efficiency and operational visibility across SC, thereby reducing overall risk exposure to the chain.

3.3 Discussions

Conceptual Framework for Digitalization in SC Sustainability - The concepts and technologies for

SC sustainability, thematic analysis, and creation of a theoretical digitalisation in the SC sustainability framework with an emphasis on the practical and operational aspects of SC sustainability as shown in Figure 12, and in Table 4 (Appendix) for key digitalisation.



Fig. 12: Conceptual Framework

Source: Created by authors

Data may be seamlessly integrated across many departments within the SC processes thanks to the digitization of the SC process. Information can be delivered in real-time through digital instruments, assisting in the practise of successfully managing knowledge. Modern digital innovations make it easier to share information instantly and support knowledge management techniques. The SC will undergo a transformation because of the desire to adopt new technology. By increasing revenue and value, using sophisticated technologies gives businesses a competitive edge.

Organisations will be able to remotely manage their supply chain operations thanks to the development of digitalization processes. It is clear from analysis that there is a lack of knowledge regarding the effective deployment of digital technology [41]. Following these rules encourages environmentally friendly behaviour. Legal and financial hazards related to non-compliance with regulations are addressed through regulatory compliance. Firms can lower the likelihood of legal consequences and fines, reputational damage by adhering to key regulatory requirements. Compliance activities typically include regular audits, performance reporting and the implementation of corrective measures. Several of these also align well with SDGs along with other global sustainability frameworks thus supporting wider global environmental initiatives. Upholding these standards enables effective promotion of stable and responsible business practices while

adjusting to ever evolving regulatory and economic conditions.

3.4 Implications and Key Limitations

Most manufacturing companies are currently in the initial phases of integrating advanced digital technologies. Managers face difficulties in determining which digital technologies to embrace, the methods of adoption, and comprehending the potential impact on both SC configuration and performance. The strategy could aid companies in strategically planning potential routes to transition between different stages, yet there are no predetermined, perfect trajectories of digitalization that guarantee achievement. It's essential for managers to evaluate their present situation, make suitable business choices across various tiers, and chart a course for their company's advancement.

The primary constraint of this study is its focus on examining the role of digitalization in enhancing SC sustainability, primarily delving into three specific technologies. Another limitation arises from the fact that the literature reviewed predominantly centres around the manufacturing sector. Service providers and other companies with distinct SC models were not accounted for in the literature. However, in a DSC, businesses are interconnected, and the boundaries between industrial sectors become less distinct. Consequently, this study does incorporate service providers, which could hold significant roles, and their digitalization might have substantial implications for SC.

4 Case Study Analysis

Supply chain social responsibility is a diverse concept that spans various fields such as procurement, SCM, logistics, and business ethics. The UK Govt. description of Corporate Social Responsibility (CSR) is centred on companies going beyond mere legal adherence and incorporating socially responsible actions into their fundamental principles. This is done with an awareness of the positive business advantages associated with such an approach [44].

4.1 Case - Waitrose

An example case is that of Waitrose and partners as major supermarket provider in UK operating more than 300 stores. The company maintains adherence to high environmental standards and supports the wellbeing of local communities where they operate and is integral in achieving long-term business objectives. The absence of traditional shareholders

provides Waitrose with a certain level of freedom to align its actions with its principles instead of being solely driven by the pursuit of increasing shareholder value. Given its historical commitment to ethical considerations, addressing social issues is not unfamiliar territory for Waitrose. The John Lewis Partnership, to which Waitrose belongs, formulates corporate policies and strategies for CSR in connection with areas such as the environment, responsible sourcing, community investment, and the well-being of its partners (*i.e. employees*) [45]. These concerns are approached through a risk assessment methodology. Annually, all potential CSR-related matters related to the key areas undergo evaluation to determine their significance to the business. This evaluation considers factors like legal requirements, costs, concerns of stakeholders (*including customers, partners, and suppliers*), and the organization's capacity to enact change and respond. A key factor towards ensuring fair and responsible SC at Waitrose is through the active involvement of the CSR head in overseeing the key sourcing practices. This is guided by both the strategic business objectives and ethical considerations. The firm's responsible sourcing committee supervises a comprehensive set of initiatives in ensuring the alignment with responsible sourcing standards. The following aims to outline key initiative types that are adopted by Waitrose under this committee's key objective and directive. Suppliers Ethical Data Interchange (SEDEX) was established in response to a collective realization among Waitrose and several other retailers [46]. They recognized that suppliers were burdened with the necessity of undergoing separate audits for each customer, resulting in resource constraints for suppliers and discrepancies between various codes of conduct.

To address this issue, SEDEX was formed as a platform to centralize the sharing of audit data concerning individual suppliers. Waitrose's supplier audit information is effectively managed through the SEDEX system. The Board overseeing SEDEX, which the Head of CSR at Waitrose was elected to lead in 2005, bears the responsibility of ensuring that SEDEX operates both as a commercially savvy entity and as a platform guided by ethical considerations. This primarily provides a detailed view of risk-related information of each supplier site, while enabling an in-depth assessment of individual sites through comprehensive reports, thus allowing the company to review SAQ responses, SMETA audit findings and any other non-compliance issues. Radar assists Waitrose in identifying sites they consider to be at a greater risk,

enabling them to concentrate their efforts on supplier engagement and enhancement in a more targeted manner. Essentially, Radar simplifies the process of overseeing ethical compliance among its suppliers, while also providing the opportunity to gain deeper insights into individual sites and their activities [37], [46].

4.2 Case - Wal-Mart

Traditional supply chains rely on manual processes, which considerable delays in learning the origins and travel routes of food products with safety issues. Over time, several foodborne illnesses have emerged due to the contamination of products entering SC. One of the notable examples involved Wal-Mart that faced significant food safety issues related to milk and infant formula in China, that affected more than 300k people [47]. Ensuring reliable traceability is hence essential, as it enables rapid identification of contaminated sources while supporting the integrity of SC operations. The sources of food must be located quickly and precisely for this endeavour. However, businesses engage with many suppliers and clients, which results in a glut of information on things like product specifications, costs, labour, and documents. According to Wal-Mart's experience, it can take several days to determine a product's provenance, underlining the urgent need to improve supply chains' traceability. Recognising this difficulty, Wal-Mart revealed a partnership with IBM's Food Trust programme in October 2016 to use blockchain technology to oversee the food delivery process [48]. This action was taken to simplify the procedures' customary complications.

With the main goal of improving food safety within the supply chains for pig products and mangoes, Wal-Mart launched two pilot initiatives. These initiatives make use of blockchain technology to create a traceable chain for pork products in China, from their farms of origin to Wal-Mart locations there. The objective of this implementation is to raise the bar on food safety. According to the 2017 Wal-Mart Global Responsibility Report, Wal-Mart also started a monitoring process for mangoes shipped from Latin American regions to the United States. Relevant information, such as origin details, batch numbers, factory details, processing data, and transportation characteristics, is instantly recorded on the blockchain at each stage of the journey of food items from suppliers to consumers [49].

Wal-Mart has seen outstanding success thanks to this real-time record-keeping system. Notably, a package of sliced mangoes experienced a noticeable

improvement because of the incorporation of a blockchain-based supply chain system. For mangoes from Mexico, it only took an outstanding 2.2 seconds to retrieve origin records. In contrast, the old paper-based record-keeping method required six days to accomplish the same task. Wal-Mart expanded the use of blockchain technology to help with the tracing of food origins for a wider range of items, including strawberries, poultry, yoghurt, and baby meals, after the successful deployment of pilot programmes for two products. This expansion serves as an example of how the blockchain-based SC system can effectively monitor a range of items. Notably, this technology is crucial in building trust with important parties like suppliers and clients. The blockchain technology promotes an environment of greater trust by offering precise and transparent information about the sources and manufacturing procedures of products. The ability of SCs to interact more effectively, especially in terms of information sharing, is a clear result of this strategy. The success of the technology depends on suppliers' involvement because they are obliged to enter data into the blockchain system. In the big picture, this emphasis on improved traceability has repercussions for the SC social, political, and environmental components. By utilising this technology, Wal-Mart can not only guarantee the quality of their items but also have a beneficial impact on these key tenets that direct entire supply chain activities. In 2005, Wal-Mart introduced waste-reduction initiative as "zero-waste" aimed at cutting store-generated waste by 25% by 2008.

This target covered wide range of materials, including cardboard, plastics, metals, food waste, glass, wood, tenant waste and residual waste [50]. According to the Wal-Mart Sustainability Report, even a 5% reduction could deliver significant environmental benefits, that is equivalent in removing 213,000 transport vehicles from roads each year, while aiming to conserve 323,800 tons of coal and overall saving 66.7million gallons of diesel fuel which otherwise would have been consumed within the process [51]. Wal-Mart has achieved measurable progress in waste reduction as reflected in their sustainability reporting. However, much of these improvements have been driven by reducing cardboard waste, while other waste streams especially food waste, have shown far less advancements. In 2014, the firm introduced targeted initiatives to address food waste, but the goals were not met. In response, Wal-Mart established a revised waste-reduction objective in 2016 as "zero waste future" that broadened the scope to include the complete food SC – right from agriculture sourcing

to production and manufacturing and to the end consumer consumption stages.

Simultaneously, improvements were made to the food waste tracking system, marked by the integration of the IBM Food Trust into Wal-Mart's food SC operations. The IBM Food Trust system functions as an intelligent solution for tracking waste across each stage of the food chain. The advanced system enabled Wal-Mart to accurately determine the remainder of product shelf life while supporting informed decisions to maintain freshness. The adoption of IBM's food trust platform enables the improvement of efficiency and effectiveness of waste management across the food SC while strengthening environmental sustainability efforts. This was achieved through enhanced monitoring and improved food packaging recycling that was considered a major contributor to the overall waste generation. At the end of 2016, Wal-Mart recorded 15.3% reduction in food waste that demonstrated the effectiveness of this updated strategy introduced under the "zero waste future".

This advanced approach enables consumers and SC partners to access reliable and transparent information on the origins of materials. This supports precise tracing of food products while identifying the areas they were cultivated and helping detect any potential cross-contamination or foodborne illness risks across the food SC. This information's accessibility has various advantageous effects. By giving consumers accurate information about the things they use, it first improves consumer welfare. Additionally, it helps to avoid additional expenditures for both supply chain participants and society at large. To establish accountability, Wal-Mart has taken concrete initiatives to work closely with its upstream partners. Effective communication among various SC nodes is crucial to the success of this initiative. For example, early in 2017 Wal-Mart partnered with IBM and Tsinghua University to implement a blockchain based traceability system in China aimed at enhancing food safety. In 2018, Wal-Mart US used blockchain technology in a comparable way to apply to leafy items.

The Wal-Mart Global Sustainability Report highlights the results of these projects and shows that after the adoption of these blockchain-based traceability solutions, food safety concerns significantly improved. These accomplishments highlight how effective these technological solutions are at enhancing food safety and establishing an open and transparent SC [51].

5 Challenges and Risks of Digitalisation on SCS

In the current dynamic and evolving landscape of the supply chain, organizations encounter numerous obstacles in the manufacturing realm. These challenges encompass global competitiveness, a deficiency in adaptability, and the speed of entering the market, as depicted in the provided Figure 13. Manufacturers frequently face the challenge of accurately forecasting demand relative to supply while also reducing production lead times. To address these issues, firms require appropriate resources and streamlined technology-supported processes that enable them to develop innovative products while delivering high-quality services. Uncertainty in SCM is often driven by factors such as global competition, limited adaptability, and delays in bringing products to the market [52]. With the adoption of IoT it helps mitigate any of these challenges, while contributing to a significant transformation within the SC.



Fig. 13: Key Challenges in Supply Chain

Source: [19]

For instance, this technology can be utilized to monitor the whereabouts and speed of vehicles carrying consignments, ensuring that users receive alerts in case of late deliveries [19]. While the potential advantages of incorporating digital technology into SC sustainability are apparent, there are also hurdles and potential hazards that must be dealt with. The primary concern related to DSC revolves around the unauthorized divulgence and unintended release of collaborative information among partners. This encompasses the revealing of business-related data exchanged with consultants and legal representatives, personally identifiable details about customers and staff, and proprietary knowledge exchanged with suppliers.

Any unauthorised divulgence refers to the accidental disclosure of sensitive or confidential information to individuals or entities without any proper authorisation. In contrast, data leakages involve the unintended transmission of or loss of information, that may result in its exposure to unauthorised parties. These risks further pose significant threats to the security of and

confidentiality of shared data and may lead to financial losses, reputational damage, legal repercussions and diminished competitive advantage. Given that the digitization of SC involves gathering and exchanging sensitive information among multiple stakeholders, concerns regarding data security and privacy bring about considerable risks [53] (Table 5). The primary challenges in establishing a DSC come in two main aspects. Firstly, there is the requirement to amass essential data from a variety of sources that exhibit unique and diverse characteristics. Moreover, ensuring the precision of this data presents a substantial hurdle. Secondly, it lies in the development of a software architecture and platform capable of effectively utilising data to manage and execute SC operations.

Table 5. Key Digitalisation Challenges

Key Challenge	Background
Inadequate planning	Shows lack of a comprehensive demand plan and deficiency of suitable instructions and resources to back it up, thus leading to unfavourable impacts throughout the SC.
Lack of Collaboration	- Resulting in wide range of consequences for SC operations - Due to lack of effective collaboration with external partners, (i.e., suppliers, distributors, logistics providers), it becomes difficult to establish smooth information sharing while coordinating actions and attaining common objectives.
Demand Forecasting Challenges	The provision of imprecise and excessively optimistic predictions for various elements like demand, inventory, production, and other pertinent information.
Insufficient data exchange	- The reluctance of firms to share crucial information and expertise with one another such as demand projections, production capabilities, stock levels making it difficult to achieve precise coordination and synchronization across SC. - This lack of transparency results in inefficiencies including surplus inventory, order fulfilment delays, or mismatches in production timetables [52].
Excessive Risk & Licensing Issues	- Firms fail to consistently assess their Digital Supply Chain to confirm that they are complying with appropriate usage permissions, contractual terms, and precautions against risks outlined in both new and existing agreements. - This leads to significant challenges such as licenses, crucial ownership rights, and contravening access or security protocols.

Source: Created by authors

Because SC involve both internal and external partners, their extended structure makes them vulnerable to delays and errors. In addition, existing inventory levels may be insufficient to meet demand, logistics infrastructure may be inadequate, and maintaining consistent product quality can be difficult. Several of these recognized difficulties are summarised in Table 5, with the regulatory and compliance challenges shown in Table 6. When shifting SC sustainability initiatives into the digital domain, it becomes essential to address the associated regulatory and compliance requirements. Adhering to relevant regulations and standards is critical for maintaining ethical, lawful and sustainable operational practices.

Through time the lack of openness in SC has obstructed the key development within the sector, with urgent issues in as shown in Figure 14.

Table 6. Regulatory & Compliance Obstacles

Key Obstacles	Background
Data Privacy Regulations	Through digital technologies implementation, SC generate and exchange large volumes of data, such as sensitive customers, suppliers, and partners information. Compliance with data privacy regulations such as General Data Protection Regulation (GDPR) in the EU and the California Consumer Privacy Act (CCPA) in the USA is crucial. Firms need to ensure that data is collected, processed, and stored in accordance with these regulations.
Intellectual Property and Licensing -	Implementing digital technologies may involve using software, algorithms, and other intellectual property owned by third parties. Ensuring that proper licensing agreements are in place to use these technologies legally is essential. Failure can result in legal disputes and potential disruptions to supply chain operations.
Cybersecurity Regulations	As supply chains undergo greater digitalization, the vulnerability to cyberattacks and data breaches escalates. Adhering to cybersecurity regulations and standards becomes of utmost importance to safeguard sensitive information and uphold the reliability of supply chain activities. Directives (NIST Cybersecurity Framework) offer instructions for bolstering cybersecurity protocols.
Environmental Impact of Technology -	While digitization can enhance supply chain sustainability, the production and disposal of digital devices and infrastructure can have their own environmental footprint. From the extraction of raw materials to the energy consumption during operation, the environmental impact of these technologies should be considered in the overall sustainability equation.
Product Compliance and Traceability	The process of digitization holds the potential to enhance the ability to track and reveal the journey of products within supply chains. This aspect gains significance in relation to adhering to regulations pertaining to the source, safety, and Caliber of products. Nonetheless, the task of creating precise and all-encompassing digital records that match regulatory prerequisites can be intricate, particularly in sectors characterized by rigorous product compliance criteria.
Industry-Specific Regulations	- Different industries have their own specific regulations and standards that govern SC operations. - For example, the pharmaceutical and food industries have regulations related to tracking and ensuring the quality of products. - Integrating digital technologies while complying with these industry-specific regulations requires careful planning and execution. Contemporary supply chain dynamics necessitate the deployment of inventive capacities and approaches to effectively navigate uncertainties, enhance adaptability, and establish comprehensive solutions that harmonize expenses, services, timeliness, and customer anticipations. - In complex businesses, SC executives face managing extensive worldwide supply networks. To protect both financial performance and revenue streams, they must be skilled at handling disruptions.

Source: Created by authors

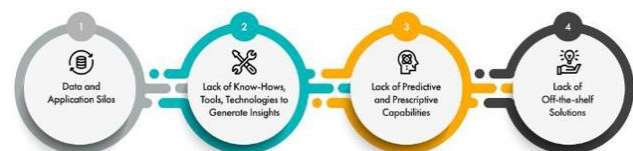


Fig. 14: Modern Supply Chain Challenges

Source: Created by authors

5.1 Data and Application Silos

Many companies adhere to a vertically integrated structure, employing various systems like ERP, TMS, WMS, and MRP to oversee their distinct functional divisions. These functions predominantly depend on plans formulated within these systems to guide the implementation, surveillance, and management of their operations. However, this approach has led to a compartmentalization of vital information such as customer demand, logistical aspects, supply hurdles specific to individual functions, and accumulated workloads. These insights remain isolated and concealed from other departments. While analysing information within specific functions demands considerable time, gaining a comprehensive understanding across

functions is even more intricate and demands sifting through substantial data volumes. Consequently, leaders at the business unit level lose sight of the broader strategic objectives of the entire supply chain. Only 6% of businesses believe they have achieved total SC visibility [54].

5.2 Know-Hows, Tools, Technologies to Generate Insights

In the era of digital data, the traits of volume, accessibility, and the potential to extract insights via analytics have become pivotal for establishing a resilient SC. However, despite the influx of data, its potential remains largely untapped due to the limited utilization of analytics. A significant number of SC are deficient in robust data engineering and analytical competencies. As a result, SC leaders often struggle to quickly access and utilise relevant data to support timely decision-making.

5.3 Predictive and Prescriptive Capabilities

Supply chain leaders must not only harness emerging capabilities to predict market sentiments, anomalies, and unforeseen geopolitical dynamics but also navigate the challenge that a significant portion of advanced analytics applications are tailored to address specific problems. The ability to address broader SC challenges and offer guidance through prescriptive approaches or simulate what-if scenarios remains significantly underdeveloped. In addition, the limited availability of high-quality AI and ML driven analytics solutions discourages executives from adopting ML technologies and restricts the potential for automating SC operations.

5.4 Off-the-shelf Solutions

Each use case or challenge demonstrates unique traits catered to certain consumers' needs. To satisfy the needs for customisation and personalisation, generic, ready-made solutions fall short. When considering the key performance indicators (KPIs) that businesses need to assess, the use cases vary greatly from one business to another, making off-the-shelf software ineffective for handling this variety. SC managers must format data in accordance with their specifications because these standardised solutions are inflexible. Value can frequently be lost because of excessive customisation and complex options [55].

6 Conclusions and Future Research

The purpose of this study was to examine why manufacturing companies adopt digital technology,

how they do so, and how the adoption affects the supply chain. Here, a conceptual framework for the sustainability of the supply chain through digitalization was constructed using a qualitative literature review of peer-reviewed journal publications. The academic and professional community of logistics and SCM sees the digitalization of the SC as a strategic issue. To ensure the successful implementation of digital supply chains, several strategic, operational, organisational and technological challenges must still be addressed.

As SC sustainability becomes increasingly dependent on digitalisation, advanced technologies play a crucial role. Through the provision of real-time visibility, enabling data-driven decision-making, and strengthening collaboration across SC, digital tools can support companies to reduce waste, optimise transportation and improving energy efficiency.



Fig. 15: UN SDGs within Research

Source: Created by Authors

By strategically leveraging digital technologies, SC can transform into a transparent, efficient and environmentally responsible system, thus aligning with UN SDGs as shown in Figure 15 and Table 7. The integration of digitalisation further enables the reduction in waste and carbon emissions, enhances transparency, and strengthens collaboration among diverse stakeholders, supporting the broader goal of developing sustainable and resilient supply chains. Finally, some key **future recommendations** are shown in Table 8.

Table 7. Key SDGs and Digitalisation Impact

SDG	Key Measures
Innovation and Infrastructure	- Digitalization serves as a catalyst for improved industrial efficiency and innovation by streamlining operations, enabling informed decision-making based on data, and promoting the integration of novel technologies, all of which play a pivotal role in fostering sustainable industrial progress. - Through digital tools, more effective route planning, real-time vehicle tracking, and optimized transportation strategies become attainable, leading to substantial reductions in carbon emissions linked to transportation.
2.Responsible Consumption	- Precision in demand forecasting is attainable, leading to diminished instances of overproduction and surplus inventory. - This, in turn, mitigates waste and the necessity for disposing of unsold goods. - Digital technologies play a crucial role in monitoring and orchestrating production processes, thereby curbing waste, optimizing the use of resources, and fostering more sustainable patterns of consumption.
3.Partnerships for Goals	- Digitalization serves as an enabler of collaboration among diverse stakeholders within the supply chain, fostering alliances aimed at advancing sustainable development goals. - This collaborative approach facilitates the exchange of resources, information, and optimal methodologies, consequently contributing to a more effective utilization of resources and a decrease in environmental footprints.
4.Sustainable Cities and Communities	- Digitalization aids in optimizing urban logistics and transportation, which in turn fosters sustainable urban progress and lessens both congestion and pollution. - The economic advancement driven by digitalization furnishes the necessary means to establish intelligent city infrastructure, including streamlined transportation networks, effective energy management, and improved public services.
5.Good Jobs and Economic Growth	- Digitalization process has the potential to result in heightened efficiency and productivity, thereby playing a role in fostering economic expansion and generating respectable employment prospects, including the establishment of chances for sustainable startups and enterprises. - This upswing in economic activity can bring about favourable effects on the advancement of intelligent urban centres and communities that prioritize sustainability.
6. No Hunger	Digital innovations enhance agricultural methodologies, facilitating more effective and environmentally sustainable food cultivation practices. This aspect is vital for addressing issues related to hunger and guaranteeing global food security.

Source: Created by Authors

Table 8. Key Research Recommendations

No	Key Focus Area	Observations and Recommendations
1	Future Trends and Predictions	✓ Future predictions are vital in forming and improving digital supply chains. ✓ SC managers can create strategic plans that are compatible with any changes through future trends prediction models. ✓ The ability to anticipate technology changes enables SC to keep on top of things. ✓ SC uses this data to gain competitive edge and grow strategically into new areas. ✓ Digital SC can maintain a competitive edge, agility, and resilience in a market that is continually changing by embracing future trends and predictions.
2	Environmental Impact Assessment	✓ Companies may proactively address environmental issues, optimize operations, and align with sustainability goals. ✓ Compare traditional SC carbon footprints and other environmental indicators to those using cutting-edge digital technologies.
3	Consumer Awareness and Demand	✓ DSC plans taking customer demand and awareness into account not only meet market expectations but also encourages innovation, resource efficiency, and competitive edge. ✓ Companies that proactively align their SC with these needs are better positioned for long-term success as customers continue to place a premium on sustainability. ✓ The rise in consumer awareness to environmental and societal matters has resulted in an elevated desire for products that are environmentally responsible. Businesses are presently crafting items using sustainable materials, less packaging, and extended lifespans to correspond with consumer principles.
4	Global Supply Chain Reshoring	✓ This trend developed in reaction to a range of factors and difficulties linked to offshoring. During offshoring, businesses aimed to gain cost benefits and access specialized skills by transferring their manufacturing to countries with cheaper labour and operational expenses. ✓ Local and regional sourcing will become more viable with the integration of digital technology, lowering the carbon footprint caused by long-distance travel.
5	Regulatory Compliance and Reporting	✓ The digital evolution of supply chain sustainability is propelled by regulatory adherence and reporting, necessitating precise data handling, automation, openness, traceability, and proficient communication. ✓ Consequently, companies can more effectively meet regulatory benchmarks while elevating their holistic sustainability endeavours. ✓ This streamlining facilitates businesses' alignment with evolving sustainability norms and reporting mandates, enabling them to demonstrate conformity, steer clear of penalties, and exhibit their commitment to responsible practices.
6	Resource Efficiency and Waste Reduction	✓ Reverse logistics facilitated by digitalization, making it simpler to recycle and return goods, further reducing waste generation and promoting circular economy principles. ✓ Digitalization's integration of resource efficiency and waste reduction reduces environmental impact thus improving cost effectiveness, advancing sustainability objectives, and addressing shifting consumer demands.
7	Risk Management and Resilience	✓ Businesses may lessen the effects of interruptions, assure smoother operations, increase customer satisfaction, aligned with sustainability goals by cutting waste and optimizing resources. ✓ Customer satisfaction is influenced by risk management and resilience as it reduces disruptions and retain consistency, with customer loyalty and brand reputation dependent on it. ✓ Digital supply chains can regularly assess and update strategies to stay ahead of emerging risks and challenges.

Source: Created by Authors

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the author(s) utilized artificial intelligence (AI) technologies solely for the purpose of linguistic refinement and grammatical correction. Following the application of these tools, the author(s) comprehensively reviewed, verified, and edited the resulting text. The author(s) maintain full accountability and responsibility for the accuracy, integrity, and final content of the publication.

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APPENDIX

Table 4. Key Digitalisation Discussions

Digital Technologies	- The use of digital technologies (<i>i.e. sensors, blockchain, IoTs</i>) significantly improves the sustainability of SC. - Sensors can gather and transmit data pertaining to their environment; sensors find utility in monitoring a range of attributes, encompassing temperature, humidity, geographical positioning, and the condition of goods during their transportation. This data across entire SC plays key role towards prevention of spoilage, waste reduction, and ensuring the calibre of products. - Blockchain technology produce a reliable and impenetrable record of each transaction and movement of commodities in supply networks; resulting in increased traceability and transparency, lowering the possibility of fraud, forgery, and unethical behaviour. - IoT devices possess the capability to monitor and convey information concerning various facets of the supply chain, encompassing inventory quantities, machinery functionality, and transit conditions. Leveraging this data leads to heightened effectiveness, decreased energy consumption, and optimization of travel paths.
SDG Goals	- Sustainable goals assure the long-term viability of supply networks, to protect SC against approaching disruptions and regulatory changes. - Sustainable objectives provide clear guidance on the areas in which firms may have the biggest positive impact. - By giving firms, the framework to align its efforts with broader environmental, societal, and ethical ambitions to play a crucial part in enhancing the sustainability of supply chains.
Information and Data Analytics	- Firms use data analytics to take informed decisions through examining historical and current data from various points within SC, thus assisting in locating inefficiencies, bottlenecks, and potential improvement areas. - Firms correctly plan inventory levels by anticipating changes in demand and supply using historical data and predictive algorithms, thus reducing waste, extra output, and inventory. - Data analytics enable firms to make decisions supported by facts, optimize operations that aligns with sustainability.
Connectivity	- Real-time communication across SC parties such as suppliers, manufacturers, distributors, and retailers, has been achieved through advanced connectivity tools, thus resolving problems quickly and reducing delays. - This allows to accurately track inventory levels across several locations and makes it easier for partners to share data, that reduces waste and extra stock and inventory levels. - Connectivity fosters ongoing progress by setting a feedback loop.
Traceability and Transparency	- With transparency and traceability, firms make better decisions, streamline processes, and align with sustainability goals, such as origin and path of raw materials and finished goods are clearly. - This supports firms in ensuring the suppliers fulfil ethical and environmentally friendly sourcing principles, avoiding products that may contribute to human rights abuses or environmental destruction. - Firms spot areas of inefficiency, resource waste, and excessive energy use by having visibility into the supply chain. - Businesses could initiate strategies to reduce and optimise resources and environmental effects by identifying these problems. By accurately disclosing information regarding product origins, production procedures, and sustainability initiatives, transparent supply chains increase consumer trust.
Collaboration	- When multiple stakeholders work together, they collectively contribute to the SC-SDGs, through collaboration across suppliers, manufacturers, distributors, retailers, and even customers. - This all-encompassing strategy covers the product lifecycle, from raw material sourcing to final disposal at the end of lifecycle. - To overcome obstacles while approaches to reducing waste, preserving resources, having smaller negative impact on the environment, collaborators engage in creative problem-solving. - The knowledge sharing & insights across partners makes it easier to measure progress towards SDGs, monitor practices, and spot inefficiencies. - Strong partnerships can encourage ongoing collaboration on both current and upcoming projects.
Risk Management	- SC Sustainability is protected by risk management (RM), which spots weaknesses and takes action to lessen their effects. - Potential dangers are identified with the aid of efficient risk management procedures before they develop into serious problems. - Companies maintain operations and reduce the impact on SDGs by predicting and preparing for probable disruptions such natural catastrophes, geopolitical crises, or supply chain outages. - Risk management considers dangers relating to morality and social responsibility, such as exploitation of workers, human rights abuse, unethical SC practices.
Regulatory	- Regulatory frameworks offer unambiguous rules and requirements that businesses must follow when operating their SC. Regulation adherence guarantees that SC operations adhere to moral norms. - This contributes to overall sustainability efforts and includes fair labour practices, anti-corruption measures, and responsible material sourcing.

Source: Created by authors