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Exploring the drivers and barriers to digital transformation adoption for sustainable supply chains: a comprehensive overview

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Abstract: In today's manufacturing industry, digital transformation has become a focal point for academia and practitioners due to its potential to drive supply chain management and sustainability outcomes. This transformation provides numerous opportunities to improve strategic, tactical, and operational capabilities to meet sustainability goals. However, the high level of uncertainty associated with digital transformation programs has created doubts among many manufacturing companies about the successful adoption of digital transformation in their supply chain processes. While previous studies have examined digital transformation technologies and their implementations in supply chains, little attention has been given to the drivers and barriers associated with adopting digital technologies for sustainable supply chains, especially in the context of manufacturing. Therefore, this study aims to fill this gap by providing a comprehensive overview of digital transformation adoption in manufacturing supply chains and identifying the critical drivers and barriers to successful digital transformation implementation. A total of six barriers and eleven drivers have been selected from the literature. Finally, this study provides insights for decision-makers to overcome the main barriers that hinder the successful implementation of digital technologies in supply chain functions, which can lead to a higher ethical supply chain level from a sustainability and operational efficiency perspective.

1 Introduction

Over the past few years, the term "digital transformation" (DT) has gained significant importance in the business world [1]. This is due to the impact of digital technologies on manufacturing processes, which has led to a change in the way businesses operate. This change is often referred to as the second machine age. Due to the competitive and volatile nature of the trading environment, organizations must develop capabilities to handle technological and operational mutations [2]. Thus, DT has become a buzzword concept. For example, in Germany, the transformation of manufacturing companies into digital entities is called "Industry 4.0" [3], whereas in the United States, the term "industrial internet" is commonly used [4]. However, DT is broadly characterized as leveraging digital technologies to devise novel business models and opportunities that align with the rapidly changing business landscape, which puts intense pressure on supply chain managers [5]. As a result, many organizations have adopted DT to improve systems integrations [6]. The significant transformation in supply chain management (SCM) is due to the emergence of disruptive technologies under digital transformation, such as the internet of things (IoT), cyber-physical systems (CPS), big data analytics (BDA), machine learning (ML), cloud computing (CC), radio frequency identification (RFID), and business-to-business (B2B) networks. These technologies have the potential to revolutionize the way SC processes are executed by making them more efficient, transparent, and secure [3,7]. In addition, they help manufacturing companies enhance flexibility, transparency, and productivity, generate innovation and optimize SC operations. Therefore, integrating digital transformation technologies into business models and SC operations leads to more efficient and sustainable operations [2]. DT involves the entire business and needs to be integrated into corporate strategy. It allows firms to achieve more satisfactory customer service, enhanced relationships with suppliers, creating real-time visibility on their internal and external operations, and thus, a more potent competitive edge [8,9]. Reaching well-balanced sustainable supply chain performance levels depends on tracking current technological trends and being aware of digital transformation while focusing on operational excellence. In this context, DT represents a strategic decision that can result in improved supply chain performance and competitive advantage [10,11].

Despite the potential advantages and benefits of DT in SC operations, its adoption is subject to high levels of uncertainty, leading many manufacturing companies to doubt its adoption. This uncertainty arises from the various operational, environmental, social, and financial factors that affect the long-term performance of companies [12,13]. However, DT adoption in sustainable supply chains (SSCs) is not free from barriers. Few scientific studies have been conducted on the barriers to DT adoption. Some have developed a conceptual framework to address these barriers in the manufacturing context [12], while others have focused on analyzing the barriers to DT adoption in the supply chain context [9], High-Technology Manufacturing [14], and logistics service providers [15]. Some research has even looked into barriers specific to micro, small, and medium-sized enterprises (MSMEs) [16]. However, there are only a few studies on the drivers and advantages of DT adoption in the supply chain context [15,17,18].

However, current research has not tackled the taxonomy of DT drivers and barriers in SSCs from a manufacturing context. To fill this gap, the authors have conducted a comprehensive overview of DT adoption drivers and barriers in the sustainable supply chain context. The novelty of the proposed paper includes the selection of the DT adoption drivers and barriers in SSCs from a manufacturing perspective based on current literature. Therefore, the main objective of the proposed study was translated into the following research questions:

- **RQ1.** What barriers hinder DT adoption in SSCs from the manufacturing context?
- **RQ2.** What are the drivers of DT adoption in SSCs from the manufacturing context?
- **RQ3.** What insights can be provided to practitioners and policy-makers to overcome the identified DT adoption barriers?

The paper is structured as follows: Section 2 describes the methodology used to conduct the study. Section 3 provides a comprehensive review of the relevant literature. In Section 4, the study focuses on identifying the drivers and barriers to DT adoption in SSCs. The main findings and related discussion are presented in Section 5. Section 6 discusses the study's implications. Finally, the conclusions and recommendations for future research are outlined in Section 7.

2 Research methodology

The first objective of this study is to conduct a literature review focused on DT technologies and their adoption in SSCs, with the aim of identifying the key drivers and barriers associated with DT adoption in SSCs. To achieve this, the authors have used online databases such as SCOPUS and ISI WEB OF KNOWLEDGE to select relevant peer-reviewed journal papers and book chapters. These databases are widely recognized as two of the most comprehensive and reputable academic research tools globally [11]. In addition, a total of eleven drivers and six barriers to DT adoption in SSCs have been selected through an extensive literature review.

Figure 1 provides an overview of the step-by-step research methodology followed in this study.

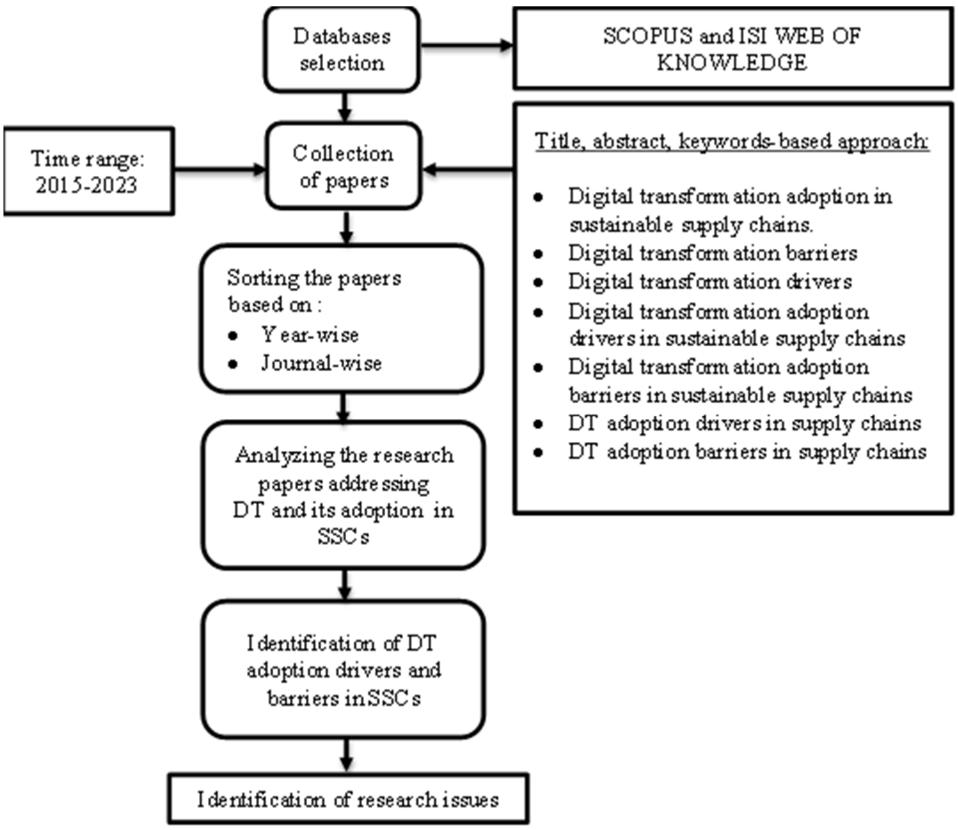

Figure 1 Step-by-step research methodology

3 Literature review

3.1 Digital transformation

DT has become widely recognized as a driving force for academicians across various disciplines, as well as practitioners and decision-makers [15]. DT involves digital platforms, high-level asset management, and inter-organizational and intra-organizational interactions induced by digital technologies [2,19]. Over the 21st century, the digital policy has evolved from a decentralized hierarchical functional structure to a globally connected IT-enabled network structure [20]. DT enables new business workflows and extends the trading environment by utilizing digital technologies [21]. At a high level, DT leverages digitally integrated technologies to develop more intelligent manufacturing processes. Innovative technologies under digital transformation, such as IoT, CPS, BDA, ML, CC, and RFID, lead to smarter production processes as they are the prerequisites for a smarter cross-linkage of systems [22,23]. According to Nayal et al. [13], DT is the process by which organizations transform their business models and eco-system by engaging digital capabilities. Also, digital technologies provide numerous socio-managerial and strategic opportunities for organizations. They generate opportunities to create more flexible, responsive, and integrated business models by networking with a broad range of partners, including customers and suppliers [24]. Due to these disruptive technologies, companies could generate additional customers, revenues, and business value [25]. Thus, DT features a new way of using and connecting digital technologies, blurring corporate boundaries [26] and allowing new market behaviours and transactions [27]. Despite being risky, DT drives long-term organizational performance by reshaping the overall financial value-creation process [28], particularly internal processes and customer and supplier relationships [29,30]. Therefore, decision-making has shifted from the asset level to the fleet one [31].

Despite the numerous benefits of DT, the adoption of DT is challenging for incumbent organizations. As they seek to break new ground in their digital business model, they frequently face trade-offs between traditional and new working methods [32,33]. In short, Digital transformation leads to three fundamental changes within companies, namely digitally-enabled and interconnected operations, digitally-enabled communication, and new value creation patterns through digital innovation or acquired digital data. These changes are evident across all industries worldwide. Organizations could initiate minor changes, such as disconnected digitization efforts, to progressively shift their traditional business model into a digital one. However, DT can require a significant deviation from the status quo and make existing business models obsolete [34,35]. As a result, DT forces companies to reconsider their managerial practices [27,36]. So, manufacturing companies need to develop their digital capabilities to reshape how they create and deliver value to their customers [37].

3.2 Digital transformation for sustainable supply chains

Digital technologies arising under the DT umbrella have created numerous opportunities and positive expectations for reducing the environmental impact of expanding supply chains and conserving resources [2,38]. DT technologies across the SC network help achieve SDGs by creating more visibility into the system concerning emissions [39]. This highlights the need to move from a classical supply chain to a sustainable and digitally enabled one [26,40]. This transformation includes product development, procurement, manufacturing, logistics, suppliers, customers, and services [41]. In addition, DT technologies provide crucial advantages for SCs, such as improving information availability and creating real-time transparency, agility, and flexibility, which leads to improved profitability and efficiency, optimized SCM practices, and reduced cost and delivery times, thus, contributing to sustainable development [2,42].

For example, blockchain technology (BT) is a decentralized technology that guarantees information transparency, traceability, and security. BT differs greatly from other information systems (IS), such as enterprise resource planning systems (ERP), by having four key features in its design: non-localization (decentralization), security, verifiability, and intelligent execution [43]. During the last years, companies adopted ERP systems for their SC processes [44]. However, they lacked an overall view of their SC, as they were unable to track their products' status beyond their SC network [45]. Moreover, ERP, as a centralized system, saves all information in a single central location/server, which makes it easy to be attacked, corrupted, and hacked [46]. BT is a solution for this issue as it improves SC processes and makes the SC system energy efficient, thus increasing customers' trust and further enhancing SC performance [47,48]. Furthermore, BT plays a crucial role in achieving SC sustainability, addressing sustainability challenges through the use of immutable and decentralized data, transparency, and smart contractual relationships to solve growing sustainability concerns [49,50]. Aside from the above, BT could decrease the environmental and social issues related to SC by reducing and controlling the recall and rework [51].

Likewise, IoT meets the requirements of the sustainability pillars [52]. It involves a set of devices interconnected with each other to exchange data that require minimal or no human intervention by using sensor-based technology. IoT technology could contribute to operational efficiency and revenue growth, providing a competitive advantage for companies that can implement it [53]. However, IoT also poses security risks and struggles to manage and control information shared among stakeholders [52,54]. To address this issue, IoT can be integrated with BT to enable effective stakeholder data exchange and enhance SC profitability [54,55].

Furthermore, big data analytics (BDA) is characterized by the collection, extraction, and storage of massive datasets, commonly known as the "6Vs" (Volume, velocity, variety, value, veracity, and variability) [56]. It associates with analyzing and examining extensive amounts of data with variable types to identify hidden patterns, trends, and correlations using advanced technologies to enhance operational efficiency and further explore new markets and opportunities [57]. BDA has become vital for organizations and society [58]. Indeed, the complexity of supply chains makes monitoring SC functions difficult, especially when following a sustainability agenda, since some SC players might not be transparent [59]. However, BDA helps to analyze data from each SC player at different decision-making levels, which can help in SC planning and visibility decisions [60]. From the sustainability perspective, BDA could minimize delivery time by integrating numerous customers, which can be achieved through real-time information sharing, thus reducing energy consumption [61,62]. Also, BDA allows SC members within each SC function to uncover unsustainable and unethical activities or other negative environmental conduct, as well as it could measure carbon emissions and air pollutants [63,64]. BDA applications are also likely to support SSCs from the social dimension by minimizing SC risks related to the procurement of goods/services [65]. Additionally, BDA can minimize supply chain risks related to procurement and support social sustainability. By comparing past performance with present and predicting future social problems, BDA capabilities align with the Triple Bottom Line and contribute to enhancing sustainability performance [56,60,65].

4 Identification of digital transformation adoption drivers and barriers for sustainable supply chains

As previously stated, despite the strengths and advantages of DT technologies in SC operations and sustainability concerns, research on DT adoption in SSCs has been unexplored in the extant literature review. Manufacturing firms strive to reach the global competitive advantage of products and services while achieving sustainable development goals. This comes by creating more visibility and transparency in SC operations. Therefore, designing digital and sustainable supply chain systems is needed to enhance SC profitability and effectiveness and achieve SDGs. However, DT adoption is not free from barriers. For this paper, barriers are related to factors that hinder and prevent the implementation of DT in the sustainable supply chain context. These factors affect manufacturing companies' efforts to adopt DT technologies from a sustainability perspective. However, the drivers of digital transformation adoption in SCs refer to the factors that motivate organizations to adopt digital technologies and strategies to improve SC operations.

Tables 1 and 2 summarize the literature related to drivers and barriers to digital technologies adoption in supply chains.

Table 1 Summary of studies investigating drivers of DT adoption in different supply chains

References	Analytical methods	Key features
Gupta et al. [7]	Literature review and Best-Worst Method (BWM) based on experts' opinions.	Identification and ranking of digitization enablers for supply chain performance improvement.
Yang et al. [25]	Literature review	Identification of the main drivers behind manufacturing firms' adoption of digital technologies
Queiroz et al. [32]	Conceptual analysis	Exploring the enablers and capabilities of digital supply chains.
Agrawal and Narain [35]	Literature review, expert interviews, and Interpretive Structural Modeling (ISM).	Identification and Analysis of the key enablers for digital transformation implementation in supply chains
Alzarooni et al. [36]	Literature review, Decision-making trial and evaluation laboratory (DEMATEL), and Interpretive Structural Modeling (ISM).	Identification and analysis of the main enablers for digital supply chain transformation in the service industry
Yadav and Singh [48]	Principal Component Analysis (PCA) and Fuzzy-Decision-making trial and evaluation laboratory (DEMATEL).	Identification and analysis of blockchain critical success factors for sustainable supply chains.
Attaran [66]	Literature review	Exploring digital technology enablers and their implications for supply chain management.

Table 2 Summary of studies investigating barriers to DT adoption in different supply chains

References	Analytical methods	Key features
Kumar Dadsena and Pant [6]	Literature review and Fuzzy Analytic Hierarchy Process (FAHP) based on experts' opinions.	Identification and ranking of supply chain digitalization barriers in the light of sustainable development goals.
Agrawal et al. [9]	Literature review, experts' interviews, and Interpretive Structural Modeling (ISM).	Identification and analysis of the major barriers to digital transformation implementation in supply chains.
Jones et al. [12]	Literature review and research agenda.	Description of DT in manufacturing and the main barriers to adopting it before, during, and after the COVID-19 pandemic.
Kouhizadeh et al. [49]	Literature review and Decision-Making Trial and Evaluation Laboratory (DEMATEL) based on experts' opinions.	Analysis of the main barriers to Blockchain technology (BT) adoption in sustainable supply chains.
Chaouni Benabdellah et al. [50]	Literature review, Analytical Hierarchy Process (AHP) method, and Decision-Making Trial and Evaluation Laboratory (DEMATEL) based on experts' opinions.	Identification and ranking of the barriers to Blockchain technology (BT) adoption in viable circular digital supply chains (VCDSCs).
Kusi-Sarpong et al. [57]	Literature review and Best-Worst Method (BWM) based on experts' opinions.	Selection and analysis of the main risks associated with the implementation of big data analytics (BDA) in sustainable supply chains.
Moktadir et al. [61]	Literature review, Delphi technique based on Analytic Hierarchy Process (AHP).	Analyzing the major barriers to the implementation of Big Data Analytics (BDA) in supply chains within the manufacturing industry in Bangladesh.
Selçuk Perçin [67]	Literature review, Delphi method, and Pythagorean fuzzy analytic hierarchy process (PFAHP) based on experts' opinions.	Identification of barriers to big data analytics (BDA) adoption in circular agri-food supply chains in Turkey.
Bag et al. [68]	Literature review and Fuzzy Total Interpretive Structural Modeling (TISM).	Exploring the main barriers and their interactions with BDA in sustainable humanitarian supply chains
Raut et al. [69]	Literature review, DEMATEL, Interpretive Structural Modeling (ISM), and fuzzy MICMAC.	Identification and analysis of BDA implementation challenges in Indian manufacturing supply chains.

Through literature review, both drivers and barriers to DT adoption in SSCs have been identified. The most critical drivers and barriers have been selected considering the manufacturing and sustainability contexts. Indeed, the DT adoption drivers include process improvement, workplace improvement, cleaner production, vertical and horizontal integrations, visibility, information sharing, sustainable technology capabilities, cost savings, waste, and emissions reduction [1,66,70]. However, the DT barriers involve organizational barriers which are related to lack of top management support and strategic orientation and the lack of organizational readiness [9,61,68,69], technological barriers which refers to lack of digital skills and infrastructural facilities, privacy and security concerns, low maturity levels of DT technologies, and scability challenges [61,70], financial barriers which are related to high implementation and running cost, high sustainability cost, and return on investment (ROI) issues [68,69,71], external barriers which reflect the market competition and demand uncertainty, lack of stakeholder involvement in DT adoption, lack of industry commitment to ethical and safe practices, legal and regulatory uncertainties, and velocity of technological development [50,61,70,71], social and environmental barriers which are related to low environmental regulations, wasted resources, lack of qualified human resources, lack of information sharing quality, lack of understanding of the interplay between technology and human beings, lack of collaboration between stakeholders and Lack of SC partners' awareness about social and environmental concerns and digital transformation technologies [9,39,50,68,70]. Figure 2 and 3 summarizes the DT adoption barriers and drivers in SSCs.

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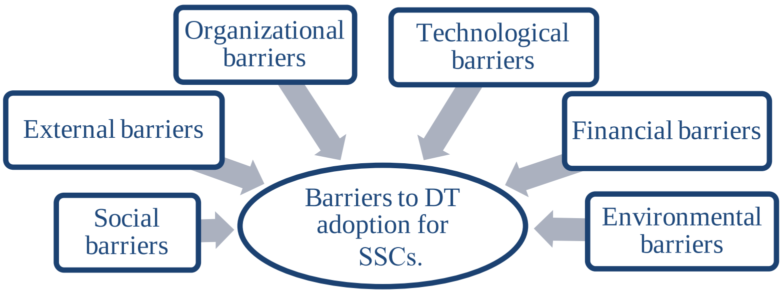

Figure 2 Barriers to DT adoption for sustainable supply chains

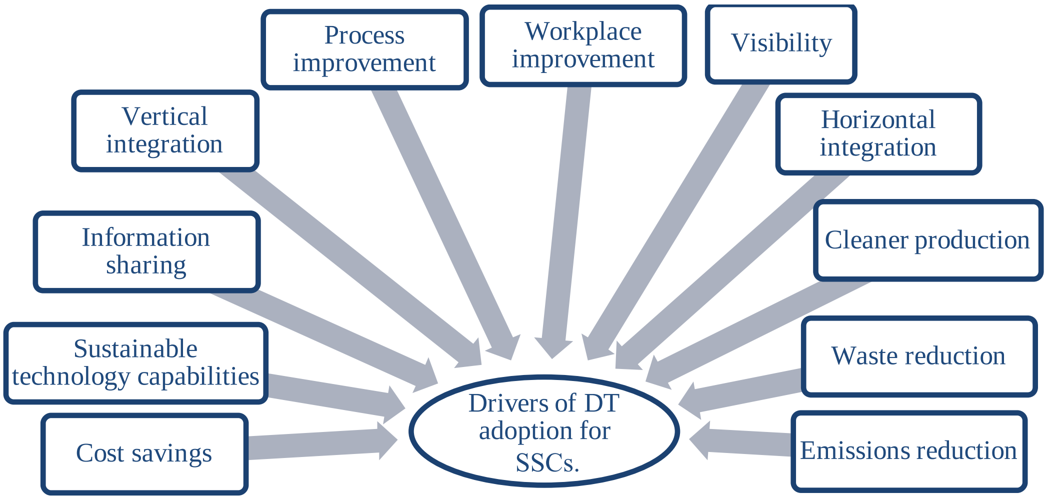

Figure 3 Drivers of DT adoption for sustainable supply chains

5 Findings and discussion

A total of six barriers and eleven drivers have been selected from the literature review. The barriers to DT adoption have been categorized into six dimensions: organizational, technological, financial, external, social, and environmental. Organizational barriers refer to the lack of management commitment, support, and strategic orientation. Indeed, SC managers need to make long-term commitments and support sustainable supply chain management practices using DT technologies. Hence, top management support is required for a sustainable and digitally enabled supply chain [9,70,72]. An organization needs to define various strategic orientations, such as customer and supplier orientations, technological orientation, and smart orientation, to create successful sustainable and digital transformation initiatives. Yet manufacturing companies worldwide need more management support, leadership, and relevant experience to take advantage of it. In addition, it provides a clear vision and strategy for digital transformation programs in companies. In fact, older employees are unfamiliar with the latest technology and their benefits, so without top management commitment, these employees will resist change. Moreover, organizational barriers also address the lack of organizational readiness. So, manufacturing companies need to create a cultural shift to cultivating a data-centric mindset [68,73]. Technological barriers refer to the lack of digital skills and infrastructural facilities. Most of the current technologies are still not able to meet the present infrastructure needs. For example, to run BDA programs, data collection, storage, and processing are challenging due to the lack of infrastructure readiness [70,73]. Also, digital skills include IT knowledge, machine learning, data mining, and optimization [59,66,70]. However, these skills are lacking in the manufacturing context, especially in under-developing countries. Privacy and security concerns can discourage SC managers from implementing DT technologies. Data security and privacy are critical barriers to manufacturing companies that are worried about hacker attacks. This could be possible due to the increasing exchange of information between suppliers and customers. Data security is needed for companies to compete in the global market [61]. Furthermore, low maturity levels of DT technologies and scalability challenges are also affecting DT implementation in supply chain systems. These technologies may lack stability and consistency regarding standards, and the increasing number of partially tested devices may lead to uncertainty [73,74]. Financial barriers refer to high implementation and running costs, high sustainability costs, and ROI issues. Indeed, data collection across the supply chain network and conversion to a digital system are costly for companies. Similarly, sustainability practices adoption impose costs. Furthermore, the ambiguity and lack of clarity on ROI benefits make stakeholders reluctant to implement DT technologies. The fear of a failed DT implementation leads to a loss of confidence in recovering the investment made. Otherwise, high investment needs to guarantee the readiness of new digital technologies, resources, skilled workforce, and new organizational capabilities. Manufacturing companies need to provide digital technologies training, such as IT systems training to their workforce to achieve a positive return on their digital transformation efforts [41]. External barriers reflect the market competition and demand uncertainty, lack of stakeholder involvement in DT adoption, lack of industry commitment to ethical and safe practices, legal and regulatory uncertainties, and velocity of technological development. In fact, the adoption of sustainable practices and digital technologies into SC operations is time-consuming [67]. This could affect the organization's market competitiveness and ultimately provide competitive risks, including uncertainty regarding the market demand for sustainable products, customer behavior, and future sales [49,75,76]. External pressures and support from external stakeholders to adopt sustainability practices and DT technologies could push manufacturing companies to integrate them into their SC operations and activities. However, the inappropriate government and industry policies and commitment to drive and support sustainable and safe practices act as a roadblock to achieving sustainability and advanced technologies in business processes [43,49]. Finally, social and environmental barriers refer to DT technologies and their relationships with the two pillars of sustainability. These barriers include low environmental regulations, wasted resources, lack of qualified human resources, lack of information sharing quality, lack of understanding of the interplay between technology and human beings, lack of collaboration between stakeholders, and lack of SC partners' awareness about social and environmental concerns and DT technologies.

Furthermore, the proposed study has also identified the DT adoption drivers, which are as follows: process improvement, workplace improvement, cleaner production, vertical and horizontal integrations, visibility, information sharing, sustainable technology capabilities, cost savings, waste and emissions reduction. Drivers can be viewed as external or internal enablers of why organizations embrace digital transformation [17,71]. Auto-adaptive systems handle the planning, control, and execution of production. Hence, the expected benefits include higher efficiency and reduced error rates. In addition, the use of disruptive technologies can ensure ergonomic work since robots perform complex and dangerous activities [71]. DT adoption can also improve manufacturing processes while minimizing breakdowns and setup times. This leads to reducing costs. Sensor technology collects data directly at the operational level and processes it for integration at the management level. The associated control information is returned through the hierarchy to the production systems [75,76]. With this information exchange, production-level planning can be more accurate, leading to running a wide range of products and production in smaller lots. Otherwise, the integration of various IT systems used in different SC functions and activities allows better exchange of materials, energy, and information within the supply chain system. Digital transformation serves the environmental pillar of sustainability, as it fundamentally involves optimizing resource consumption, energy efficiency, and waste and emissions reduction, thus enhancing SC profitability and effectiveness.

Tables 3 and 4 classify and rank key drivers and barriers to DT adoption for SSCs.

Table 3 Key drivers associated with DT adoption for SSCs

Rank	Drivers	Number of citations	Source
1	Information sharing	9	[1,2,25,32,36,40,48,66,76]
2	Visibility	8	[1,2,35,40,48,65,66,76]
3	Emissions reduction	7	[2,25,30,35,40,70,76]
4	Cost savings	6	[32,35,40,48,66,70]
	Waste reduction	6	[2,12,30,40,66,70]
5	Process improvement	5	[25,38,48,52,70]
	Cleaner production	5	[2,30,36,38,70]
	Sustainable technology capabilities	5	[1,30,40,70,76]
6	Workplace improvement	4	[15,25,38,52]
	Vertical integration	4	[12,25,34,36]
	Horizontal integration	4	[12,25,32,34]

Table 4 Key barriers to DT adoption for SSCs

Rank	Barriers	Number of citations	Source
1	Organizational barriers	14	[6,9,12,14,16,49,50,57,61,67,68,69,71,73]
	Technological barriers	14	[6,9,12,14,16,49,50,57,61,67,68,69,71,73]
2	Financial barriers	13	[6,9,12,14,16,49,50,61,67,68,69,71,73]
3	Social barriers	8	[6,12,50,57,67,68,69,71]
4	Environmental barriers	6	[6,9,12,49,50,67]
5	External barriers	4	[6,50,67,71]

6 Study implications

This study contributes to digital transformation and sustainable supply chain management research. Nonetheless, quantitative and qualitative studies on drivers and barriers to DT implementation for SSCs still need to be included. Firstly, both drivers and barriers have been selected from the current literature. The selected drivers and barriers may provide a roadmap for academia and policy-makers to comprehensively overview digital transformation implementation in the supply chain context. Manufacturing companies need to introduce suitable strategies to achieve a high level of success in the implementation. Findings reveal that decision-makers should consider the organizational, technological, financial, external, social, and environmental barriers before the DT implementation. However, manufacturing companies need to create and retain a sense of urgency as a first step in the digital transformation process, as many firms have already started implementing digital technologies in their business activities. Also, organizations should create a suitable environment that focuses on innovation, a culture of commitment, and a digital mindset at all decision-making levels. The results also argued that manufacturing companies require data scientists and analysts, as they can collect, refine and analyze data. In addition, digital transformation programs could only be successful with these skills. Digital security skills, mobile technology skills, blockchain, IoT, and cloud computing skills are also required for the digital transformation of firms. Therefore, manufacturing companies need to invest in specific training and hiring programs to enhance workforce skills and allow them to cope with new technologies and smart digital solutions. Otherwise, SC managers should promote the benefits of digital technologies and improve collaboration by improving the quality of information sharing among SC partners, focusing on organizational, technological, financial, external, social, and environmental barriers. IT units and organizations must jointly formulate sustainable and digital strategic plans to address all the opportunities to cope with all selected barriers and further achieve sustainability goals. This study is the first to identify the drivers and barriers to DT implementation in SSCs from a manufacturing context.

From the above discussion, a clear overview of drivers and barriers will allow manufacturing companies to realize the importance of addressing them. Therefore, they could start to take the abovementioned initiatives sequentially to fully develop the required capabilities for a sustainable and digitally enabled supply chain.

7 Conclusions

The present work aims to identify and discuss the key drivers and barriers to digital transformation adoption for sustainable supply chains from a manufacturing context. The adoption of DT is the main agenda for both developed and developing countries in the context of manufacturing. Current research has not tackled the taxonomy of DT drivers and barriers in SSCs from a manufacturing context. Therefore, this study was conducted in two stages to fill this gap. First, the authors have analyzed the past and current literature on DT and SSCs. This step was important for understanding the current status of digital technologies implementation in manufacturing supply chains. The second step was to select the critical drivers and barriers from previous studies. A total of six barriers and eleven drivers have been selected. A comprehensive grasp of DT dimensions is needed to shift to sustainable and digital supply chain systems successfully. The selected drivers can motivate manufacturing companies to shift supply chains from a classical level to a sustainable and digitally enabled one. Digital transformation program allows manufacturing companies to process improvement, workplace improvement, cleaner production, vertical and horizontal integrations, enhanced visibility, high level of information sharing, enhanced sustainable technology capabilities, cost savings, and waste and emissions reduction. A better understanding of the drivers allows manufacturing companies to proactively and positively shape the digital adoption process. However, DT barriers have been explored to mitigate the risk of implementation failure. These barriers have six dimensions: organizational, technological, financial, external, social, and environmental. Overcoming these roadblocks will increase the successful adoption of DT and, subsequently, the effectiveness and efficiency of supply chain systems.

However, this study had limitations that paved the way for future research directions. Firstly, this research could not be generalized, as it was devoted to the manufacturing sector. In addition, the selected barriers and drivers need to be checked by experts. Their insights and feedback can help to ensure the relevance and accuracy of the identified drivers and barriers, thereby enhancing the overall quality and reliability of the study. This makes it challenging to generalize the obtained results. Future research could apply other potential unique techniques to select the key barriers and drivers, such as qualitative studies and direct interviews. Although the proposed paper is the first to identify the barriers and drivers of DT implementation in sustainable supply chains from the literature, quantitative studies are needed to prioritize key barriers, sub-barriers, and drivers and evaluate their cause-effect relationships. Thus, multi-criteria decision-making (MCDM) methods could be considered for this analysis. Moreover, a systematic approach is needed to identify key drivers and barriers, allocate available resources wisely, and create the environment necessary for sustainable and digital supply chain systems. Empirical evidence on ranking DT drivers and barriers and assessing their relationship should be carried out for both developed and developing countries. However, future studies need to be directed toward different sectors. In the future, DT adoption strategies for sustainable supply chains can be pinpointed and assessed using empirical research models such as small sample sizes using structural equation modeling (SEM). Furthermore, future conceptual frameworks and empirical evidence about the impact of digital transformation adoption and sustainable supply chain performance may be investigated to evaluate to what extent manufacturing firms could involve digital transformation technologies to improve their sustainable supply chain performance.

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Review process

Single-blind peer review process.