energies

Article

The Influence of Digital Transformation and Supply Chain Integration on Overall Sustainable Supply Chain Performance: An Empirical Analysis from Manufacturing Companies in Morocco

Imadeddine Oubrahim [1,*], Naoufal Sefiani [1] and Ari Happonen [2,*]

[1] Department of Mechanical Engineering, Research Laboratory in Engineering, Innovation, and Management of Industrial Systems, Faculty of Sciences and Techniques, Abdelmalek Essaadi University, Tangier 90000, Morocco
[2] Department of Software Engineering, LUT School of Engineering Science, LUT University, 53850 Lappeenranta, Finland
* Correspondence: imadeddine.oubrahim@etu.uae.ac.ma (I.O.); ari.happonen@lut.fi (A.H.); Tel.: +212-604227847 (I.O.)

Abstract: This study examined the association between digital transformation (DT), supply chain integration (SCI), and overall sustainable supply chain performance (OSSCP). The current literature has preliminarily explored the concepts of DT and SCI and their relationship with sustainable supply chain performance. However, real empirical evidence of the direct impact of DT and SCI on OSSCP has been missing so far. To fill this gap, data were collected from 134 professionals working in international manufacturing companies operating in Morocco through a questionnaire-based survey from August 2022 to November 2022. A conceptual framework was developed based on DT, SCI, and OSSCP and analyzed by partial least squares structural equation modeling (PLS-SEM) with the assistance of SmartPLS 4.0 software. The findings revealed that DT has a significant positive influence on SCI and OSSCP. Furthermore, SCI directly and positively impacts OSSCP with a partial mediation effect on the relationship between DT and OSSCP. Further, this research provides insights for practitioners into enhancing sustainable supply chain performance by adopting digital technologies and integrating SC functions. In particular, this study revealed that DT adoption drives a higher ethical supply chain level from the perspective of sustainability and efficiency in operations. This study is the first to analyze the influence of digital transformation and supply chain integration on sustainable supply chain performance in a manufacturing context.

Keywords: digital transformation; supply chain integration; sustainable supply chain performance; manufacturing sector

check for updates

Citation: Oubrahim, I.; Sefiani, N.; Happonen, A. The Influence of Digital Transformation and Supply Chain Integration on Overall Sustainable Supply Chain Performance: An Empirical Analysis from Manufacturing Companies in Morocco. *Energies* **2023**, *16*, 1004. https://doi.org/10.3390/en16021004

Academic Editor: Arunima Malik

Received: 19 December 2022
Revised: 6 January 2023
Accepted: 12 January 2023
Published: 16 January 2023

1. Introduction

Amid technological advances in many industries, supply chain management (SCM) has received substantial attention from organizations seeking supply chain efficiency [1]. Focusing on supply chains is a move toward the broader adoption and development of sustainability, as the supply chain considers products from procuring raw materials to delivery to customers. Supply chain sustainability has arisen from increasing public awareness of social and green aspects and strengthening environmental legislation and regulations in developed countries [2]. Moreover, with global climate change, both manufacturers and customers are increasingly aware of the pillar of sustainability, which is driving manufacturing activities throughout supply chains to be more eco-friendly and has shifted the transition from classic supply chains to sustainable ones [3,4]. Companies have pushed their suppliers to implement International Organization for Standardization (ISO) standards, such as ISO 14.0 0/14.0 01. Therefore, sustainable supply chain management (SSCM) seeks to integrate the issue of sustainability within overall supply chain management, focusing on economic, social, and environmental goals [5]. Both academia and practitioners have argued that improved sustainable supply chain performance comes from achieving sustainability in supply chains [6]. Sustainable supply chain performance (SSCP) can be seen as a measure of how well, e.g., a company's supply chain practices align with environmental, social, and economic sustainability goals. These practices include reducing waste and pollution, supporting local communities (societal sustainability), guaranteeing fair labor practices, aiming to reduce energy usage, looking for long-term operational and environmental feasibility, and so on. In other words, a sustainable supply chain benefits the environment and society and can improve a company's long-term financial performance by reducing costs and increasing efficiency. Generally, to achieve well-balanced sustainable supply chain performance levels, one has to follow the current technological trends, be aware of what is going on in the digital transformation front, and at the same time, focus appropriately on operational excellence [7]. This makes assessing and understanding overall sustainable supply chain performance critical from both the practical and the theoretical standpoints. By adopting sustainability practices into supply chains, businesses could focus on their customers, innovate, and better use their resources, capabilities, and productivity while maintaining certain environmental aspects [8]. The overarching objective of SSCM is to enhance supply chain performance (SCP), which is linked to sustainable development (SD) goals [9]. However, achieving such objectives is challenging given the complexity of decision-making processes and the incidence of trade-offs between indicators involved in decision-makers' choices.

Recently, two terms have widely been discussed in the context of SCs: digital transformation (DT) and supply chain integration (SCI) [8,10–14]. DT technologies support supply chains by increasing the accessibility of information, collecting real-time data, optimizing SCM practices, reducing production and transaction costs, improving the timely delivery of products to customers, and increasing both the efficiency and effectiveness of SC functions [15,16]. It is also highly likely that digital technologies will continue to play a central role in shaping the future of business and social activities through the exponential development speed of current technologies [17]. Therefore, companies could reach operational efficiency and minimize their bullwhip effect by making internal processes smarter using DT technologies [18]. DT refers to how businesses use digital competencies to transform their business development models and ecosystems. It includes the internet of things (IoT), cyber-physical systems (CPS), big data analytics (BDA), machine learning (ML), radio frequency identification (RFID), and business-to-business (B2B) networks [19,20]. On the other hand, SCI has received much attention from both industry and academia in the last two decades due to the increasing level of competition in today's marketplace that has made decision-makers look for partnership strategies to enhance SC performance and reduce costs and lead time [8,14,21,22]. From a supply chain perspective, integration is how a company can structure its organizational practices, activities, and strategies into collaborative, synchronized, and manageable processes to meet customer needs. Therefore, SCI is essential for an efficient SC [23–25].

Although the previous literature has explored the concepts of DT and SCI and their relationship with supply chain performance [8,10,15,24,26–28], empirical evidence and research models targeting the evaluation of the impact of DT and SCI on sustainable supply chain performance have not been investigated yet. More particularly, the role of DT in enhancing SCI and further sustainable supply chain performance has not been explored yet. Otherwise, Morocco is one of the emerging economies fully committed to sustainable development and has recently undergone a digital transformation in different sectors, particularly the manufacturing context [29,30]. This has motivated authors to examine whether a direct relationship exists between digital transformation, supply chain integration, and overall sustainable supply chain performance in international manufacturing companies located in Morocco. The proposed research realizes the importance of an empirical study to examine to what extent manufacturing firms could involve digital transformation technologies to improve their supply chain integration and further their sustainable supply chain performance. Thus, the main objective of this work is to empirically examine the relationship between DT, SCI, and OSSCP in a manufacturing context by suggesting a research model based on the literature review to address the above-mentioned knowledge gap. To the best of our knowledge, the proposed study is the first empirical study that includes and assesses all these constructs together in the context of the manufacturing sector.

The remainder of the proposed study is structured as follows. Section 2 goes into the literature review and theoretical background for digital transformation adoption, supply chain integration, and sustainable supply chain performance. Section 3 describes the conceptual model, including the hypotheses' development. Section 4 details the empirical research methodology and the data analysis approach. Findings, discussion, and study implications are presented in Sections 5–7, respectively. Finally, the paper concludes with a summary of the main conclusions, the research limitations, and recommendations for future research.

2. Literature Review and Theoretical Background

2.1. Digital Transformation

DT has emerged as an essential aspect that drives several academic fields and affects practice, yielding independent research streams [31]. DT includes digital platforms, infrastructures, high-level asset management, political and lexical will, as well as supporting and needed technologies [32,33]. DT-related technologies, such as sensors and tracking devices, can provide real-time data and insights to help companies to optimize their SC operations. For example, sensors on shipping containers can provide information on their location, temperature, and other factors, allowing companies to manage their inventory better and reduce the risk of spoilage or damage. On the other hand, anyone utilizing sensor technologies must be knowledgeable about their strengths and limitations [34]. Additionally, IoT technologies can automate and streamline operations such as scheduling and routing, improving efficiency and reducing costs. Overall, the integration of digitalization into current operations and the digital transformation of old ways to modern models leads to more efficient and sustainable operations. Here, DT uses digital technologies to generate new business processes and widens the available business landscape. Thus, with the utilization of DT, companies are undergoing digital transitions to enhance system integrations [31]. Supply chain digitalization enables firms to fulfill customers' dynamic needs on time and address the challenge of SCM and the expectations in the quest for a competitive edge [35,36]. This shows the need to shift from a classic supply chain to a digitally enhanced supply chain [37,38]. DT enables organizations to generate innovation and increase productivity, transparency, and flexibility. These disruptive technologies under DT, such as IoT, CPS, BDA, ML, RFID, and B2B networks are used to design robust, transparent, and secure supply chain management systems [39]. Moreover, they have made smart manufacturing possible and sped up innovation at a dizzying pace. For example, Industry 4.0 is a clear tool for sustainability improvement, and it can significantly impact SC behavior toward reaching intelligent and more flexible processes, helps it to be more circular, promotes resource efficiency, automation, and optimization measures, and increases employees' welfare [40–43]. Likewise, blockchain technology (BCT) has a tremendous potential to transform SC functions from procuring raw materials to delivery to customers. It also ensures the transparency, reliability, and authenticity of information, as well as smart contractual relationships for a secure environment [44–46]. Therefore, SCs are affected by DT with no exception.

Several studies have dealt with DT in the context of SCM. For example, Tavana et al. [31] have reviewed the most-used technologies in the context of DT and SCM. They have found that BDA and BCT are the widespread clusters that have been considered in recent years. Büyüközkan and Göçer [38] have proposed a framework for digital supply chains (DSCs), including advantages, drawbacks, and limits regarding the existing DSC literature, and have identified features, components, and technologies that enable the development of a

DSC framework. Furthermore, Stroumpoulis and Kopanaki [47] have analyzed the impact of DT technologies, including BDA, BCT, and IoT on SSCM. Findings revealed that DT plays a vital role in enhancing business performance and supporting sustainable strategies.

2.2. Supply Chain Integration

Over the last two decades, the focus from academia and practitioners on integration practices between SC partners has mainly grown due to the highest level of global competition and the increased customer demand patterns [48–50]. Consequently, SCI has been recognized as a pivotal issue in the SCM literature. SCI refers to the extent to which all processes within an organization, along with the operations of its suppliers, customers, and other SC partners, are incorporated [48,51]. Thus, companies have recognized that creating strategies and incorporating internal functions, suppliers, and customers is a suitable model for achieving competitive advantage. This has made SCI a useful practice widely adopted by firms focusing on improving their performance by establishing closer relationships between SC functions [52]. SCI is a multidimensional concept. Previous works have highlighted that considering SCI dimensions is crucial to understand how the individual dimensions affect performance and also how they interact [23,28,48,49].

SCI is devised into external and internal integration. Despite being directly linked, they both play separate roles in the context of SCI and thus are crucial SCI measurement concepts. External integration (EI) means linking a company's logistics operations with its customers and suppliers across boundaries [23,24,53]. EI involves the strategic alignment with suppliers and customers, where the business creates strategic cooperation with its suppliers and customers and jointly establishes strategies to address potential markets. Information sharing and synchronized planning are the most critical issues in external integration. Furthermore, EI enables organizations to develop collaborative relationships with trading partners and capitalize on their core capabilities while minimizing transaction costs [14,54]. Meanwhile, internal integration (II) is the coordination, collaboration, and integration of SC functions and logistics with other functional areas [48,49]. II mainly entails data and information systems integration using enterprise resources planning (ERP), real-time inventory and operating data searching, and activity integration across multiple functional areas. It also includes cross-functional cooperation and collaboration over multiple functions to improve processes or develop new products [55]. Generally, II refers to information sharing between internal SC functions, strategic cross-functional cooperation, and collaboration. Therefore, EI and II are essential for an efficient SC. The main objective of SCI is to make supply chains seamless with fully integrated information and material flows [50,52]. SCI is only achieved by proceeding across various phases, as II usually comes before EI. In practice, it is not sufficient to merely align the activities of various SC functions and internal structures within firms to enhance their performance. By connecting internal operations to external suppliers and customers along the SC network, tremendous outcomes can be reached [21,56]. Due to this, both upstream and downstream supplier and customer integration have become critical in business strategy.

Over the last couple of decades, many studies on SCI have been carried out. For instance, Bagchi et al. [57] have conducted a quantitative study to obtain an overall perspective of the supply chain integration state in European companies. The findings showed that SCI positively impacts operational performance, and efficiency and cost are influenced by the degree of integration. Wong et al. [58] have proved how both internal and external integrations separately and collectively improve product innovation. They have shown that external integration independently influences product innovation positively. In contrast, the relationship between internal integration and product innovation is not supported. However, they have found that the complementary integration of II and EI (not the balance between them) improves their capability to develop product innovation. Likewise, Zhao et al. [55] have studied the relationship between II, EI, and relationship commitment. Their study has clearly illustrated based on the literature and empirical evidence that II and relationship commitment positively impact EI. Particularly, II enables EI, as companies should firstly improve internal integration capabilities using data system integration before they can commit to significant external integration. Furthermore, organizations should be aware of incorporating trading partners, which is evidenced by their relationship commitment, before implementing external integration.

2.3. Sustainable Supply Chain Performance

Sustainable supply chain performance is indeed a concept that measures and assesses both the efficiency and effectiveness of SC processes in a dynamic environment by integrating financial, social, and environmental measures in SC operations [15,25,43,59]. It is considered a multidimensional criterion that should be conceptualized and understood consistently. Sustainability in SC operations has been considered a highly emerging issue for companies, as the lack of resources requires adopting sustainable development strategies (SDS) to achieve sustainable performance [60]. This has increased the focus on sustainable strategy from stakeholders that desire to protect the environment from pollution and maintain a balanced ecosystem [15,61–63]. Therefore, SSCP is crucial for companies to mitigate any negative effects on employees, suppliers, customers, the environment, and society.

Developing SSCP as a higher-order multidimensional construct has not only enhanced sustainable performance, it also provides an execution guideline that leads to competitive advantages. This concept enables organizations to integrate it into vision, strategy, and operations to achieve overall sustainable outcomes [64]. Every SCM strategy that desires to maintain a competitive advantage must incorporate all dimensions of SSCP (financial, social, and environmental aspects) into the businesses' strategy, with a powerful and more visible orientation [47,64].

Based on the triple bottom line (TBL) sustainability approach, three basic dimensions are considered to measure SSCP (economic, social, and environmental performance). They have been recognized as the triple-bottom-line pillar of sustainability [65,66]. Firstly, economic performance indicators include return on investment (ROI), SC overall cost (i.e., manufacturing cost, distribution cost, and transaction cost), along with environmental costs such as energy cost and profitability or sales revenue [6,67,68]. The economic pillar focuses on the financial performance and profitability of the organization. Social performance indicators include employees' wellness, work conditions, satisfaction, safety, health, and truthfulness [68–70]. The social pillar considers the organization's impact on people and communities, including issues such as human rights, labor practices, and social welfare. At the same time, environmental performance indicators involve energy and water consumption, asset utilization, and waste disposal [65,68,71]. The environmental pillar evaluates the organization's impact on the natural world, including issues such as greenhouse gas emissions, waste, and resource use [72]. Hence, organizations must align financial objectives with social and ecological objectives to conduct a comprehensive review of their sustainability performance and to be able to improve their overall business performance.

A rich body of literature has dealt with sustainable supply chain performance. For example, Shibin et al. [73] have developed a framework that explains SSCP and its enablers. They identified nine enablers for SSCP (i.e., coercive pressure, mimetic pressure, normative pressure, top management belief, logistics capability, top management participation, supply chain information-sharing, supply chain connectivity, and supply chain talent). In another work, Kumar and Goswami [64] attempted to develop a conceptual model of SSCP. They argued that SSCP is designed based on three dimensions (supply chain performance, supply chain environmental performance, and supply chain social performance). The findings revealed that social capital attracts more to achieve sustainable performance, while environmental issues are given priority.

3. Conceptual Framework and Hypothesis Development

3.1. Linking Digital Transformation Adoption with Overall Sustainable Supply Chain Performance

Adopting DT technologies across supply chains is a key prerequisite for organizations to fulfill the existing market's needs in the quest for a competitive edge [36]. This is reflected in the necessity to shift from a traditional supply chain to a sustainable, digitally enhanced supply chain [37]. This transformation is driven by shorter product life cycles, changing market dynamics, limited resources, and global competition challenges. DT tools offer crucial benefits for supply chains, such as the improved availability of information, real-time data collection, the optimization of SCM practices, reduced production and transaction costs, the timely delivery of products to the customers, and the increased efficiency and effectiveness of SC functions [16,25,74]. However, with the companies' increased carbon emissions and energy consumption, organizations must focus on a low-carbon and energy consumption strategy and follow green metrics [75]. To be able to reduce emissions, there is a need to develop digital SC networks to achieve sustainable and operational outcomes [76], including minimizing asset utilization and reducing emissions from manufacturing activities. Using digital technologies, companies could enhance operational efficiency and reduce their bullwhip effect by making internal processes smarter [18,25]. Moreover, DT adoption in the SC network significantly influences product development efficiency and adds long-term value for customers [10]. Therefore, DT provides a sustainable competitive advantage, enhancing overall SC performance.

In the existing literature review, various studies have shown the crucial role of DT on sustainable supply chain performance. For example, Gupta et al. [27] found that big data analytics (BDA) and Industry 4.0 are the most suitable tools for enhancing SC performance among other DT tools, such as the internet of things (IoT) and blockchain technology. In another work, Lee et al. [77] investigated the relationship between digital supply chains (DSCs), SC performance, and organizational performance in the Malaysian manufacturing industry. They found a direct impact of digitalization on SC performance. However, findings revealed a mediating role of SCP in the relationship between digitalization and organizational performance. Similarly, Dudukalov et al. [10] found statistical evidence of a relationship between digital transformation and supply chain performance. Nayal et al. [78] investigated the relationship between flexibility, AI–IoT adoption, and SC firm performance under the circular economy (CE) environment. In addition, they pointed out the direct impact of AI–IoT adoption on SC firms' performance. However, Nayal et al. [15,45] have conducted two other research studies. Firstly, they investigated the impact of supply chain collaboration and coordination (SCC), collaborative advantages (COA), DT, and sustainable development strategy (SDS) on sustainable supply chain firm performance (SSCFP). The findings revealed that DT positively impacts SSCFP and fully mediates the link between SCC and COA. Thus, in their second research work, they studied the mediating role of BCT to enhance SSCP. The outcomes revealed that BCT adoption is influenced by numerous factors such as green and lean practices, supply chain integration, supply chain risk, performance expectancy, top management support, internal and external environmental conditions, regulatory support, costs, and innovation capability. Moreover, BCT adoption positively impacts sustainable supply chain performance in the agriculture sector. Furthermore, according to Kim and Lee [79], digitalization positively affects the formation of social capital, which in turn has a positive effect on supply chain performance. This means that the direct effect of healthcare digitalization on supply chain performance is small, and relatively large parts are mediated and influenced by social capital. Thus, Sharma et al. [76] examined whether digital supply chain networks can shape sustainability performance in the manufacturing sector. Additionally, through a quantitative study, Raut et al. [60] have shown that BDA directly impacts sustainable supply chain business performance and fully mediates the relationship between environmental practices and sustainable supply chain business performance. Their conceptual model includes numerous variables such as BDA, lean practices, environmental practices, social practices, financial practices, organizational practices, supply chain practices, and total quality management and sustainable supply chain business performance. Based on their outcomes, Kamble et al. [80] have supported the hypothesis by arguing that BCT technologies positively influence SSCP. However, this relationship is fully mediated by SCI.

From the above literature review, it is argued that digital transformation benefits organizations and supply chain performance. However, the current literature fails to deal with sustainability performance across supply chains and its relationship with DT technologies. In other words, there is a shortage of academic research on the direct relationship between digital transformation and sustainable supply chain performance [81,82]. As a result, the following hypothesis is proposed:

Hypothesis 1 (**H1**)**.** *There is a positive and significant relationship between digital transformation and overall sustainable supply chain performance.*

3.2. Linking Digital Transformation Adoption with Supply Chain Integration

Although the role of DT technologies is to improve both the efficiency and effectiveness of organizations' processes, they also have the potential to achieve information sharing, coordination, and organizational linkages, which are the main focus of SCI [45,77]. DT includes inter-organizational and intra-organizational transactions driven by digital technologies. Valuable data-driven decisions could only be reached with accurate information provided by digital technologies and involved SC partners along the overall SC network. For example, blockchain technology has the potential to make information stable and unchangeable, so it cannot be edited without the authorization of approved stakeholders, thereby preventing corruption [47]. This leads to enhancing both internal and external integration, which are the two key types of SC integration. Internal integration involves integrating data and information systems using ERP, retrieving real-time inventory and operational data, and integrating activities across multiple functional areas using blockchain technology. At the same time, external integration means strategic alignment with suppliers and customers to create strategies that address potential markets. So, information sharing and synchronized planning are the most critical issues in external integration. However, they can only be strengthened by utilizing DT technologies [26,36,58,83].

With the emergence of disruptive technologies such as Industry 4.0, DT has streamlined complex structures and boosted supply chain integration through the use of various advanced technologies, including cloud computing, big data, and blockchain [20,38,84]. Thus, various studies have covered that digital transformation technologies could be a key factor in developing integration within organizations [26,28,44]. For example, Nayal et al. [78] have argued that the deployment of digital technologies such as artificial intelligence (AI) and the internet of things (IoT) would enable accurate and real-time information sharing, production, planning, and functional alignment, and therefore improve SC performance. Wang et al. [85] have explored a conceptual framework that reflects the significant role of BCT in improving SC integration capabilities, which are supply chain visibility, supply chain flexibility, and supply chain agility. Thus, supply chain visibility refers to collaboration, trust, and information sharing between SC partners without boundaries along the supply chain network. Supply chain agility is defined by an organization's capability to react to internal and external changes and disruptions quickly. Otherwise, it is needed to handle issues in the strategic decision-making process and enhance companies' responsiveness against environmental challenges. Additionally, supply chain flexibility is a firm's ability to allow flexible operations management to fulfill customer needs and economic targets, reconfigure assets to reduce cost and time further, and mitigate supply chain risks. Furthermore, Li et al. [86] have shown through their empirical study that IT implementation cannot directly impact SCP without the mediating role of SCI. However, the hypothesis that links IT implementation and SCI is supported. In another work, Shi et al. [87] highlighted digitalization's positive impact on improving SCI. However, their study was limited to the Chinese manufacturing industry.

Following the above discussion, this study expects that DT technologies' adoption enhances internal and external integration, which are the two types of SCI. However, there is no empirical evidence of the direct link between DT and SCI [80]. Therefore, the following hypothesis is suggested:

Hypothesis 2 (H2). *There is a positive and significant relationship between digital transformation and supply chain integration.*

3.3. Linking Supply Chain Integration with Overall Sustainable Supply Chain Performance

As market demand has become more volatile, supply chain uncertainty management is crucial [2,47]. Therefore, organizations have recognized that creating strategies along with incorporating internal functions, suppliers, and customers is a suitable alternative for achieving competitive advantage. This made SC integration a useful practice widely adopted by firms focusing on improving their sustainable performance by establishing closer relationships between SC functions [48,56]. SC integration is an SCM approach in which contribution from SC partners is needed. By coordinating intra- and inter-organizational processes, it has been considered a strategic collaboration and partnership between supply chain firms to manage the environmental and operational impacts [28,48]. Thus, SCI can potentially have a positive influence on cooperative environmental activities [56,77]. This explains the SCI practices' capability to minimize environmental externalities [48]. At the same time, SCI is a practical approach that simplifies both internal and external business operations while improving the performance of an organization's customers and suppliers [14]. Internal operations and external suppliers and customers must be aligned along with the SC network to reach sustainable performance outcomes [21,56].

Previous papers have tried to report a positive relationship between SCI and SSCP. For example, Ahmed Khamis al Naqbi et al. [88] have suggested a conceptual model that includes internal integration, supplier integration, customer integration, and SSCP. They found that internal integration is a strong predictor to achieve firms' sustainable performance. Prajogo and Olhager [89] have investigated the impact of logistics integration on operational performance and the relationship between information and material flow integration and SCI using data from Australian firms. The findings showed that SCI significantly affects performance and that long-term supplier relationships have both direct and indirect positive effects on performance. Abdallah et al. [90] have explored the effect of SCI in terms of suppliers, customers, and internal integration on SCP and export performance. Their results showed that internal and customer integration positively affect SCP, while supplier integration does not. However, both customer integration and internal integration indirectly influence export performance through SCP. In another work, Mackelprang et al. [91] studied the relationship between strategic SCI and performance by conducting a meta-analysis. They found that the relationship between integration and performance is complicated and nuanced, such that integration should not be universally considered as improving performance. Kumar et al. [49] investigated the association between SCI metrics and SC performance in the UK food sector. The findings showed that SCI provides advantages and benefits such as reductions in total logistics costs, which would ultimately lead to enhanced profitability for companies and improve the flexibility of organizations to meet the external changes in the market. Therefore, it positively impacts SC performance. Furthermore, Junaid et al. [8] have proposed a framework relating sustainable SCI, green innovation, and firm performance. The results showed that sustainable SCI fosters firm green innovations, which enhance a firm's financial performance. However, they have not highlighted a direct relationship between SCI and SC performance. Subsequently, Han and Huo [92] have explored the impact of green SCI on sustainable performance, particularly on environmental, social, and economic performance. They have argued that Green internal integration plays a major role in green customer integration (GCI) and green supplier integration (GSI), and is linked to both environmental and social performance. GSI positively impacts economic performance. However, GCI positively influences social performance. Mofokeng and Chinomona [93] examined the impact of collaboration, partnership, and integration on supply chain performance, particularly within the small and medium enterprise (SME) sector. The findings revealed that SCI strongly influenced SME supply chain performance, but supply chain partnership and supply chain collaboration have a weaker relationship with supply chain performance. Additionally, Erboz et al. [94] examined the influence of Industry 4.0 on supply chain integration (SCI) and supply chain performance (SCP). The outcomes showed that Industry 4.0 positively influences SCI and SCP. However, SCP is positively impacted by SCI. In addition, SCI partially mediates the association between Industry 4.0 and SCP.

Further to the previous discussion, there is a shortage of research focusing on the direct link between SCI and SSCP. However, they have only dealt with the relationship between dimensions of SCI and SCP or firms' performance, neglecting the concept of sustainability [23,26,90,94]. Therefore, the following hypothesis is suggested:

Hypothesis 3 (H3). *There is a positive and significant relationship between supply chain integration and overall sustainable supply chain performance.*

3.4. Conceptual Framework

The proposed conceptual framework is based on an in-depth literature review and experts' opinions. The model in Figure 1 clearly reveals the expected links between DT, SCI, and OSSCP. The proposed model hypothesizes that adopting DT in manufacturing companies in Morocco will increase the level of integration of SCs and enhance overall sustainable supply chain performance. Thus, SCI is expected to influence OSSCP.

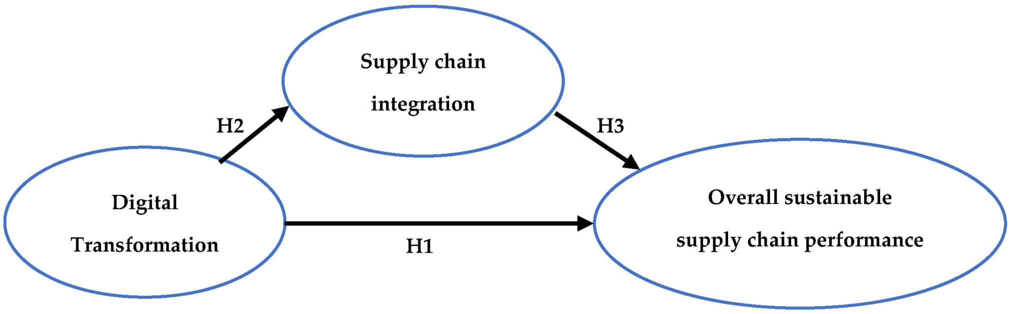

Figure 1. Conceptual framework.

4. Empirical Research Methodology and Data Analysis

4.1. Survey Design and Data Collection

This study uses a questionnaire survey to evaluate the interrelationships among variables [71,78,90]. The questionnaire was constructed using a five-point Likert scale, where 1 denotes strongly disagree, and 5 signifies strongly agree. This scale achieves an appropriate balance between the responses' complexity and the data analysis's simplicity [5]. Firstly, the questionnaire was pre-tested by a panel of experts from academia and industry for the relevance of the items and variables. The panel included fifteen experts: three full professors in the field of supply chain management, two associate professors, two postdoctoral researchers, four Ph.D. students in the area of sustainability, two supply chain managers with more than six years of experience, and two IT managers with an excess of five years' experience in supporting firms in their digital transformation. Based on their opinions, the instrument was modified to ensure that the participants understood the questions clearly. The questionnaire includes four sections: (a) general information about the participants and their companies, (b) DT, (c) SCI, and (d) OSSCP. The constructs and items were developed based on the academic literature (see Appendix A).

After adjusting the required corrections, the questionnaire survey was sent to 580 professionals working in international manufacturing companies located in Morocco from August 2022 to November 2022. A total of 134 professionals answered the survey, corresponding to a response rate of 23.10%, which is considered suitable for the partial least squares structural equation modeling (PLS-SEM) analysis, with a minimum sample size of 50 respondents [95,96]. In addition, the response rate can be considered acceptable relative to previous works (e.g., Delic and Eyers [95], Lee et al. [77], and Marodin et al. [97]).

The sample characterization of the participants is shown in Table 1. As seen in Table 1, out of 134 participants, 51 participants are engineers/operational employees (38.1%), 39 participants are middle managers (29.1%), 23 participants hold top management positions (17.2%), 8 participants are assistant managers (6%), and 6 participants are team leaders (4.5%). Males represent 58.2% of the total respondents and respondents with working experience of more than 5 years were the most common (57.5%). Moreover, 73.1% of participants have a master's degree. In this work, Excel was used to analyze records from the respondents. The data entry of participants' demographics was performed with Excel.

Table 1. Sample characterization of the respondents.

Characteristics	Sub-Characteristics	Frequency	Percentage
Gender	Male	78	58.2%
	Female	56	41.8%
Job position	Top-level/executive manager	23	17.2%
	Middle manager	39	29.1%
	Assistant manager	8	6%
	Team leader	6	4.5%
	Engineer/operational employee	51	38.1%
	Others	7	5.2%
Academic degree	High school	8	6%
	Bachelor	10	7.5%
	Master	98	73.1%
	P.h.D.	9	6.7%
	Executive/MBA	9	6.7%
Experience	<5 years	77	57.5%
	5–10 years	27	20.1%
	10–20 years	22	16.4%
	>20 years	8	6%
Number of employees in the firm	<100	24	17.9%
	101–500	34	25.4%
	501–1000	19	14.2%
	>1000	57	42.5%
Sector activity	Operations/manufacturing	78	58.2%
	Financial services	2	1.5%
	Logistics or other service provider	40	29.9%
	Others	14	10.4%

4.2. Data Analysis Approach

For data analysis, the partial least square structural equation modeling (PLS-SEM) has been used with the assistance of SmartPLS 4.0 software. However, PLS-SEM has been widely applied in the quantitative research approach. This tool differs from the SPSS technique as it is considered a variance-based approach and not covariance-based utilized in SPSS [48]. In addition, prediction rather than confirmation is more the purpose of PLS-SEM models [98]. Indeed, it achieves a high level of complex model prediction with small sample sizes and develops the relationship between constructs [99,100]. According to Hair et al. [98] and Iqbal et al. [101], SEM has been considered a suitable technique to measure direct and indirect paths, as it analyzes unobservable latent constructs that are difficult to evaluate. Furthermore, it includes inner and outer model analyses, assessing the links between independent and dependent variables and between latent variables and their estimated items. Therefore, the estimation of our model was performed in two stages: first, the measurement model, where validity and reliability statistics were detected, and second, the analysis of the structural model, where the proposed hypotheses were identified [48,98]. Thus, using SmartPLS 4.0 software, both the measurement and structural models were tested, estimating parameters with the bootstrap procedure [77,98].

4.3. Measurement Model

The reliability and validity of the collected data were evaluated by Confirmatory Factor Analysis (CFA). According to the CFA, all items with factor loading (FL) less than 0.5 were dropped [48,77,102,103]. In this study, the lowest FL value among items was 0.61. Therefore, all items were retained. The measurement model aims to measure the reliability of each item along with the internal consistency of variables' reliability, convergent validity, and discriminant validity (see Figure 2) [98,103]. Cronbach's alpha (CA) and composite reliability (CR) were used to evaluate the internal consistency of the reliability. According to Hair et al. [98,103], the threshold values of both CA and CR are 0.7. Therefore, the proposed study revealed CA values ranging between 0.948 and 0.973, whereas the CR values ranged between 0.95 and 0.974. According to Lee et al. [77], CR values above 0.80 are considered suitable for confirmatory research, whereas values greater than 0.90 represent high reliability. Furthermore, the average variance extracted (AVE) was calculated to check all constructs' convergent validity [48,104]. AVE values should exceed 0.50 so that a satisfactory model has been reached [104,105]. In this study, the AVE values varied between 0.525 and 0.69, all of which are higher than the recommended cut-off value of 0.50. In aggregate, all variables have met the requirement of reaching the satisfaction level of convergent validity. Table 2 provides the results of the constructs' reliability and validity for the main study.

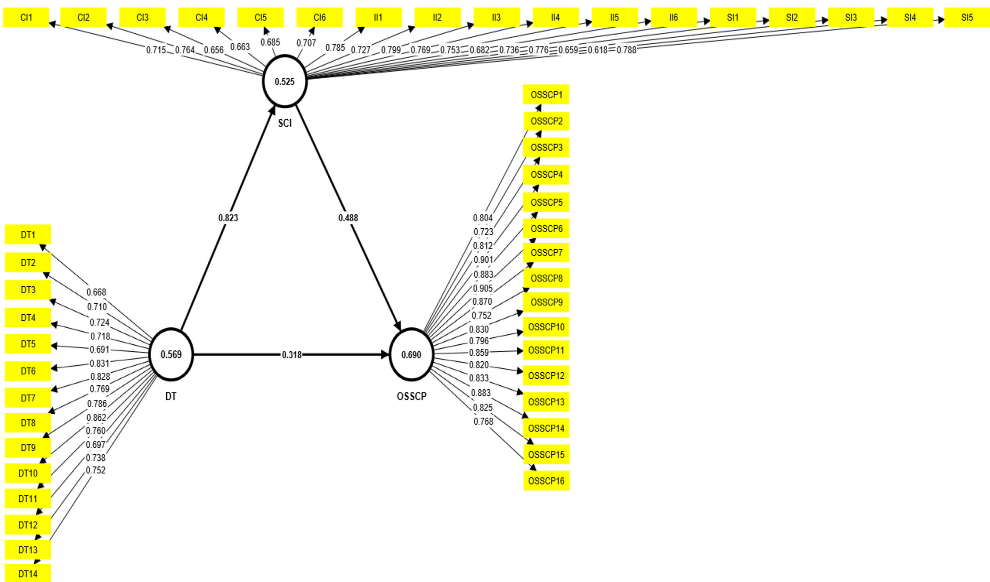

Figure 2. The measurement model.

Once convergent validity was established, the discriminant validity was tested to measure the mean correlation of items throughout the model. In other words, it reveals the ability of items to clearly identify different variables. The discriminant validity was evaluated using the Fornell and Larcker criterion [104]. The square root of the AVE was calculated and compared against all variable correlations. Indeed, if the square root of the AVE of any variable is higher than the correlation between that variable and all other variables, discriminant validity is ascertained [104]. Table 3 shows Fornell and Larcker's tests which reveal no discriminant validity issues in the proposed study. However, the heterotrait–monotrait (HTMT) ratio has emerged as a new method to detect discriminant validity, which was developed by Henseler et al. [105]. This method has currently gained preference over Fornell and Larcker as it estimates the real correlation between two constructs if they were measured perfectly [5,100,106,107]. According to Henseley et al. [105], the HTMT value should be at most 0.9. In this study, the HTMT ratio ranges between 0.715 and 0.823. Table 4 reveals the existence of discriminant validity since all the obtained values are less than 0.9.

Table 2. Construct reliability and validity.

Construct	Total Number of Items	Item Code	FL	CA	CR	AVE
Digital Transformation (DT)	14	DT1	0.668	0.948	0.950	0.569
		DT2	0.710			
		DT3	0.724			
		DT4	0.718			
		DT5	0.691			
		DT6	0.831			
		DT7	0.828			
		DT8	0.769			
		DT9	0.786			
		DT10	0.862			
		DT11	0.760			
		DT12	0.697			
		DT13	0.738			
		DT14	0.752			
Supply Chain Integration (SCI)	17	SI1	0.736	0.949	0.951	0.525
		SI2	0.776			
		SI3	0.659			
		SI4	0.618			
		SI5	0.788			
		CI1	0.715			
		CI2	0.764			
		CI3	0.656			
		CI4	0.663			
		CI5	0.685			
		CI6	0.707			
		II1	0.785			
		II2	0.727			
		II3	0.799			
		II4	0.769			
		II5	0.753			
		II6	0.682			
Overall Sustainable Supply Chain Performance (OSSCP)	16	OSSCP1	0.804	0.973	0.974	0.690
		OSSCP2	0.723			
		OSSCP3	0.812			
		OSSCP4	0.901			
		OSSCP5	0.883			
		OSSCP6	0.905			
		OSSCP7	0.870			
		OSSCP8	0.752			
		OSSCP9	0.830			
		OSSCP10	0.796			
		OSSCP11	0.859			
		OSSCP12	0.820			
		OSSCP13	0.833			
		OSSCP14	0.883			
		OSSCP15	0.825			
		OSSCP16	0.768			

Note: SI, CI, and II refer to supplier integration, customer integration, and internal integration, respectively.

Table 3. Fornell–Larcker criterion.

Construct	DT	OSSCP	SCI
DT	0.755		
OSSCP	0.719	0.831	
SCI	0.823	0.749	0.725

Table 4. Heterotrait–monotrait (HTMT) discriminant validity of the main study.

Construct	DT	OSSCP	SCI
DT			
OSSCP	0.715		
SCI	0.823	0.749	

5. Findings

Structural Model and Hypothesis Testing

The structural model was designed to analyze the interrelationships between the latent variables of the main study. Due to the model criteria and the sample, PLS-SEM is suitable for analysis [98]. This study qualified for the consistent PLS algorithm, as all the research constructs were reflective [107,108]. Hence, the significance of the constructs path analysis was checked through consistent bootstrapping in SmartPLS 4.0. The R^2 value was used in the dependent constructs to examine the model's predictive power. It indicates the degree of variance in the dependent variables that the independent variables can explain. Chin [109] suggested a cut-off value of 0.4 for R^2. For SCI and OSSCP, the determination coefficient R^2 values were 0.594 and 0.677, respectively, confirming the prediction validity. Furthermore, the effect size f^2 was analyzed to evaluate the impact of independent variables on the dependent ones. According to Henseler et al. [105], cut-off values of 0.02, 0.15, and 0.35 were proposed to categorize the effect sizes into small, medium, and large. The findings show that DT has a substantial impact on the endogenous variable SCI (f^2 = 2.093). In addition, the predictive relevance Q^2 of the corresponding independent variable (DIT) for the dependent variables, SCI (Q^2 = 0.601) and OSSCP (Q^2 = 0.469), are higher than zero [107]. This means that the proposed model has predictive capacity. Moreover, the variance inflation factor (VIF) was analyzed to evaluate the collinearity between independent and dependent variables. The VIF values of the inner model are less than 3.3 [110]. This depicts no issue of multi-collinearity in the model. Therefore, the proposed research variables have met the pre-determined requirements, allowing the hypotheses to be evaluated. Table 5 summarizes the outcomes from the structural model.

Table 5. Structural model results.

Construct	R^2	Q^2	f^2 in Relation to		VIF
			OSSCP	SCI	
DT	-	-	0.080	2.093	1.000
OSSCP	0.594	0.469			3.093
SCI	0.677	0.601	0.190		3.093

The proposed study analyzed the causal relationship between the variables by the path coefficient β, t-statistic value, and *p*-value. In this study, the directional hypotheses were tested by a one-tailed test with a significance level of 0.05 (5%) [77,111]. Thus, a hypothesis is supported when the t-value of the path coefficient is greater than 1.96. At the same time, the *p*-value must be less than 0.05. The bootstrapping results for the structural model analysis are presented in Table 6. The findings confirm that DT has a statistically significant positive influence on OSSCP (β = 0.318, t-statistics = 2.339, p = <0.05), and so H1 is supported. H2, which predicts DT positively impacts SCI, is also found to be statistically significant (β = 0.823, t-statistics = 17.015, p = <0.05). Furthermore, H3, between

SCI and OSSCP, is supported (β = 0.488, t-statistics = 3.581, p = <0.05), which hints that SCI positively impacts OSSCP. Therefore, the evidence shows that all the research hypotheses are supported.

Table 6. Hypothesis testing.

Hypothesis	Path	β	Standard Deviation (SD)	T-Statistics	p-Values	Decision
H1	DT -> OSSCP	0.318	0.136	2.339	0.010	Supported
H2	DT -> SCI	0.823	0.048	17.015	0.000	Supported
H3	SCI -> OSSCP	0.488	0.136	3.581	0.000	Supported

Regarding the mediating effect of SCI, the findings show strong associations between DT and OSSCP with SCI (β = 0.402, t-statistics = 3.462, p = <0.05). Moreover, Table 5 shows that the coefficient β of H1 (β = 0.318) is both significant and less important than others. This reflected the mediation effect of SCI. According to Lowry and Gaskin [112], there are three mediation effects: no mediation, partial mediation, and full mediation. No indirect effect between variables means no mediation effect. Partial mediation reflects the significance of both direct and indirect effects between variables. However, full mediation signifies only indirect effects. This strengthens the partial mediation effect of SCI on the relationship between DT and OSSCP since both the direct and indirect effects of DT on OSSCP are significant. Table 7 summarizes the results of the mediating effect of SCI.

Table 7. Mediating effects.

Relationship	β	Standard Deviation (SD)	T-Statistics	p-Values	Decision
DT -> SCI -> OSSCP	0.402	0.116	3.462	0.000	Partial mediation

6. Discussion

This study has made it possible to empirically explain the impact of digital transformation (DT) and supply chain integration (SCI) on overall sustainable supply chain performance (OSSCP). The findings unveiled a significant effect of DT on OSSCP (H1). Previous works are missing the ability to highlight the importance of digital transformation as a construct in enhancing sustainable supply chain performance. What has been previously present in the academic literature are explorations of the association between sustainable supply chain performance and digital transformation technologies such as blockchain technology [80,113], RFID [114], warehouse automation [115], big data analytics [27,60], the internet of things [78], and management practices [116]. Economically, DT in connection to new technology adoption [117], can favor companies and their sustainability performance from the operational to the strategic level, positively impacting their economic performance. For example, by reducing the amount of generated waste and emissions from operational manufacturing activities, a company can enhance its sustainability performance outcomes such as reduced raw material and water consumption and energy efficiency [118]. Subsequently, digital technologies can help to reduce and limit human errors and reduce delays and the time needed for transactions while improving employees' wellness, work conditions, and job satisfaction. In addition, the hypothesis testing results also showed the mediation effect of SCI on the relationship between DT and OSSCP. This means that DT adoption enhances OSSCP under the partial mediation effect of SCI. Hence the three dimensions of SCI, namely, supplier integration, customer integration, and internal integration, promote the successful adoption of DT intending to enhance OSSCP.

Furthermore, DT positively affects SCI in manufacturing companies (H2). Companies conducted internal integration to share information between internal supply chain functions, cooperating and collaborating strategically and cross-functionally using digital transformation technologies such as enterprise resources planning (ERP) and the internet of things. At the same time, external integration enables companies to develop collaborative relationships with suppliers and customers. Hence, information sharing and synchronized planning using digital technologies are the most critical issues in external integration, not just from a purely technical point of view, but also as they provide changes for better open-book practices, visibility to collaborators' actions, and add to the level of shared trust, which is a crucial element in successful collaboration relationships [119,120]. Moreover, despite no previous empirical studies investigating the direct impact of DT on SCI statistically, this empirical study was found to be in line with the current DT-related literature that states that the three dimensions of supply chain integration are highly impacted by digital transformation adoption [36,58,83,94].

SCI positively impacts OSSCP in the manufacturing company context (H3). Companies have recognized that integrating internal functions, suppliers, and customers is a suitable alternative for the better coordination of activities to improve supply chain performance and sustainability. In addition, integrating internal and external activities is practically helpful for corporations to reach their internally set or externally forced sustainability performance outcomes, especially when aligned with the SC network operations [21,56]. Furthermore, strategic collaboration and partnership between supply chain firms enable the management of environmental and operational impacts, so SCI practices can potentially have a high effect on cooperative environmental activities and further reduce environmental externalities [48,56]. Still, academic studies have yet to pinpoint a direct relationship between SCI dimensions (internal, supplier, and customer integration) and overall sustainable supply chain performance. In other words, previous studies have been missing a positive link between supplier integration and sustainable supply chain performance [88,90], and they found a weak association between supply chain partnership and collaboration with supply chain performance [93]. The proposed study filled this gap compared to earlier studies by examining the direct relationship between SCI and OSSCP.

In this way, the main findings have many significant theoretical and managerial implications, as reported below.

7. Study Implications

7.1. Theoretical Implications

The outcomes of this study provide several valuable insights into the current literature on DT, SCI, and OSSCP. The proposed research has confirmed that DT has a significant positive influence on SCI and OSSCP. On the other hand, prior research could not highlight the importance of DT adoption in improving SCI and further enhancing OSSCP. Therefore, this study is the first to design a conceptual framework that links these constructs. The findings showed that the application of digital technologies such as enterprise resources planning and the internet of things improves supply chain integration, as it strategically and cross-functionally supports shared information between internal supply chain functions, cooperation, and collaboration. Additionally, the analysis results have shown that DT adoption can support manufacturing companies in Morocco and their sustainability performance from various levels impacting their economic performance.

Furthermore, the results have revealed that sustainability performance outcomes such as reduced raw material and water consumption and energy efficiency could be enhanced by reducing waste production and emissions from manufacturing activities. Subsequently, the mediating effect of SCI on the association between DT and OSSCP reveals that DT adoption enhances OSSCP under the partial mediation effect of SCI. As a result, the three dimensions of SCI, namely, supplier integration, customer integration, and internal integration, promote the successful adoption of DT intending to enhance OSSCP. Otherwise, the empirical results showed that SCI positively impacts OSSCP. This shows that SCI is a valuable practice adopted by manufacturing firms in Morocco to improve sustainability performance by establishing closer associations between SC functions. In addition, strategic collaboration and partnership among manufacturing companies and their suppliers and customers help to manage environmental and social impacts, so SCI practices potentially have a high influence on enhancing sustainability performance outcomes.

Finally, this research is valuable as it focuses on the association between digital transformation adoption, supply chain integration, and overall sustainable supply chain performance in the Moroccan manufacturing sector, which is not considered in the literature. In such a sector, the process is heavily digitalized; consequently, manufacturing companies in Morocco could gain the most from applying digital technologies.

7.2. Practical Implications

This research contributed to the theory by providing empirical evidence on the impact of digital transformation adoption and supply chain integration practices on overall sustainable supply chain performance for practitioners in manufacturing companies located in Morocco. The analysis results provide new factual support for decision-makers about the need to embrace digital technologies to efficiently improve the achievable level of integration in supply chain networks. This is imperative for practitioners, as their companies' capabilities to achieve trustable information sharing, coordination, and organizational linkages among SC partners are directly related to the level of integration, the trust that the SC partners share, and the quality of data and information they share between each other. Indeed, DT adoption in manufacturing companies can strengthen the reliability, trust, and collaboration between trading partners, including suppliers and customers [26,80]. Therefore, DT is found to have a direct and positive influence on SCI dimensions (internal, supplier, and customer integration). This shows that digital technologies have a dynamic capability to improve both internal and external integration. So, SC managers in manufacturing companies can utilize this knowledge to improve SC efficiency by integrating digital technologies.

Furthermore, manufacturing companies in Morocco still need to continue implementing front-line digital technologies in their production, operations, and value-adding services to keep enhancing sustainability performance outcomes, as quickly developing DT is constantly offering new ways to influence overall sustainable supply chain performance positively. DT adoption provides crucial advantages for supply chain networks, as it improves the availability of information, collects real-time data, optimizes SCM practices, reduces production and transaction costs, and further increases both the efficiency and effectiveness of SC functions. In addition, DT enables companies to enhance SC flexibility and visibility and reduce SC risks [27,121]. However, manufacturing companies in Morocco must focus on a low-carbon and energy consumption strategy due to increasing carbon emissions and high energy consumption. So, digital technologies need to be integrated into SC networks to achieve sustainable and operational outcomes [76], including reducing carbon emissions from manufacturing activities and minimizing asset utilization. In addition, manufacturing companies should be more aware of the strategies developed for the integration of internal functions, suppliers, and customers, as, currently, it does not seem to be embraced as much as it should be, given the gains it offers on the competitive advantage front. This reflects the role of SCI practices in manufacturing firms to improve their sustainable performance by building deeper associations between SC functions [48,56]. Indeed, supply chain manufacturing firms must collaborate and cooperate with each other to manage the environmental and social impacts, as SCI practices can potentially have a high effect on cooperative environmental activities and further reduce environmental externalities [48].

8. Conclusions

The study extends the current knowledge space on the association between digital transformation, supply chain integration, and overall sustainable supply chain performance. First, this study developed a conceptual framework with three hypotheses to empirically assess the impact of DT and SCI on OSSCP in manufacturing companies located in Morocco. Using sample data from manufacturing companies' senior executives and managers, the analysis results reported that the proposed conceptual framework is valid since all three hypotheses are supported in this study. The supported hypotheses are:

- Digital transformation directly and positively influences overall sustainable supply chain performance (H1).
- Digital transformation directly and significantly impacts supply chain integration (H2).
- Supply chain integration positively affects overall sustainable supply chain performance (H3).

Furthermore, the hypothesis testing findings also showed the partial mediation effect of SCI on the association between DT and OSSCP.

The proposed study and its findings provided new targeted theoretical development and empirical research on what manufacturing companies in Morocco need to adopt digital technologies and integrate their SC functions to enhance sustainability performance and successfully address the changing business and market requirements. This study is the first empirical study that includes and assesses all these constructs together in the context of the manufacturing sector.

However, this research contained limitations that pave the way for future research directions. Firstly, the study is based on a sample size of 134 respondents from a specific sector (the manufacturing sector), as the authors faced challenges in obtaining manufacturing-based companies' direct contacts. Hence, it can be challenging to generalize the findings. Secondly, this study is cross-sectional research in one specific country, with a sample size of 134 respondents. So, future empirical studies can duplicate this research by analyzing the hypotheses in other countries and sectors and designing longitudinal research based on mediation models to better capture the association between the constructs in the long term. Furthermore, the findings are likely to be different for under-developed countries whose organizational capacity and availability of information and communications technology resources are limited.

Further, the study measured the overall sustainable supply chain performance items from the respondents' perceptions. Thus, there is a need to conduct a suitable follow-up for this research to gather objective measures for the endogenous variable from the same representative firms and compare it with the perceptual responses to ensure that both measures are meaningfully interrelated. Indeed, the financial, social, and environmental components of OSSCP were considered in the main study. However, regarding the environmental pillar, future studies are recommended to consider energy consumption related to costs, as it has numerous effects on the overall cost of the supply chain [122]. Moreover, energy efficiency evaluation is also recommended, as it improves competitiveness, profitability, and quality, providing significant cost savings and improving the working environment [123]. Moreover, future studies need to examine how DT adoption can drive other sectors besides the manufacturing sector by improving and redefining their products and services through digital content in order to develop new revenue streams to sustain their survival.

Author Contributions: Conceptualization, I.O.; methodology, I.O.; validation, A.H.; formal analysis, I.O.; resources, I.O.; data curation, I.O.; writing—original draft, I.O.; writing—review and editing, I.O. and A.H.; supervision, N.S. and A.H.; funding acquisition, A.H. All authors have read and agreed to the published version of the manuscript.

Funding: LUT University international collaboration funding, granted for Ari Happonen.

Data Availability Statement: Data available upon request from corresponding author.

Acknowledgments: The authors would like to offer their deepest gratitude for the IIMSI research laboratory of Abdelmalek Essaadi University, LUT university, and the international collaboration funding granted to Ari Happonen, which has made the collaboration possible and supported the open-access publishing of this work.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Constructs and their measurement items.

Constructs		Items	Sources
Digital transformation (DT)		DT1. Your company always applies digital technologies in its operational activities.	[26,45,77,124]
		DT2. Your company pursues digital transformation strategies specifically in the supply chain.	
		DT3. Your smarter production makes value creation easier by reducing the cost of manufacturing.	
		DT4. Your smarter production makes value creation easier by producing better quality.	
		DT5. The activities and processes in your company's supply chain are automated as much as possible.	
		DT6. Digital technologies adoption allows your company to reduce SC risks.	
		DT7. Digital technologies adoption helps your company to enhance SCM flexibility.	
		DT8. Digital technologies adoption allows your company to reduce SC risks.	
		DT9. Your company always applies digital technologies to transact with suppliers.	
		DT10. Your company always applies digital technologies to transact with customers.	
		DT11. Information sharing between your company and your suppliers has been performed through digital technologies.	
		DT12. Digital transformation enables changes necessary to achieve your company's strategic vision.	
		DT13. Digital transformation technologies such as the use of internet communications channels enhance customer relationship management in your company.	
		DT14. Digital transformation technologies enable your company to design and manufacture new products and services in order to fulfill your customers.	
Supply chain integration (SCI)	Supplier integration (SI)	SI1. Your company shares information with your major suppliers through information networks.	[14,70,83,89,90,93,125]
		SI2. Your company ensures permanent procurement through networks with your major suppliers.	
		SI3. Your company shares the demand forecasts and production plans with your major suppliers.	
		SI4. Your company shares your inventory levels and production capacity with your major suppliers.	
		SI5. You have a high level of strategic partnership with your major suppliers.	
	Customer integration (CI)	CI1. Your company shares information with your major customers through information networks.	
		CI2. Your company uses multiple touchpoints and communication channels to interact with your customers.	
		CI3. Your company has a high level of communication with your customers.	
		CI4. Your customers share demand forecasts with your company.	
		CI5. Your company shares the inventory level and production plan with your customers.	
		CI6. Your company follows up with your major customers for feedback.	

Table A1. *Cont.*

Constructs	Items	Sources
Internal integration (II)	II1. Your company realizes data integration among all internal functions.	
	II2. Your company has integrative inventory management.	
	II3. Your supply chain functions such as planning, sourcing, production, delivery, and sales have real-time integration.	
	II4. In your company, enterprise resource applications are used to integrate the different functions.	
	II5. Your company analyzes real-time information about supply, production, and demand.	
	II6. Your company organizes periodic interdepartmental meetings among internal functions.	
Overall sustainable supply chain performance (OSSCP)	OSSCP1. After implementing DT, your company has increased its return on investment (ROI) from its product sales.	[15,71,77,79,80]
	OSSCP2. After implementing DT, your company has grown in market share and profitability.	
	OSSCP3. After implementing DT, your company has improved its order fill rate without running out of stock at any given time.	
	OSSCP4. After implementing DT, Your company has improved manufacturing lead time.	
	OSSCP5. After implementing DT, your company has improved its customer service level.	
	OSSCP6. After implementing DT, your company has improved the quality of products and services.	
	OSSCP7. After implementing DT, your company quickly adjusts the degree to which it increases or decreases production in immediate response to changes in customer demand.	
	OSSCP8. After implementing DT, your company has reduced the order delivery cycle time.	
	OSSCP9. After implementing DT, your company has reduced SC costs (transportation, manufacturing, and procurement)	
	OSSCP10. After implementing DT, your company has reduced energy consumption.	
	OSSCP11. After implementing DT, your company has improved employees' wellness, work conditions, and satisfaction.	
	OSSCP12. After implementing DT, your company has enhanced employees' safety and health.	
	OSSCP13. After implementing DT, your company has increased its efficiency by reducing the use of resources (e.g., water, raw materials).	
	OSSCP14. After implementing DT, your company has reduced its waste production from its manufacturing activities.	
	OSSCP15. After implementing DT, your company has reduced its carbon emissions from its manufacturing activities.	
	OSSCP16. After implementing DT, your company has improved the recycling of materials.	

References

1. Balfaqih, H.; Mohd, N.Z.; Saibani, N.; Al-Nory, M.T. Review of Supply Chain Performance Measurement Systems: 1998–2015. *Comput. Ind.* **2016**, *82*, 135–150. [CrossRef]
2. Oubrahim, I.; Sefiani, N.; Happonen, A. Supply Chain Performance Evaluation Models: A Literature Review. *Acta Logist.* **2022**, *9*, 207–221. [CrossRef]
3. Seuring, S.; Aman, S.; Hettiarachchi, B.D.; de Lima, F.A.; Schilling, L.; Sudusinghe, J.I. Reflecting on Theory Development in Sustainable Supply Chain Management. *Clean. Logist. Supply Chain.* **2022**, *3*, 100016. [CrossRef]
4. Wang, H.; Pan, C.; Wang, Q.; Zhou, P. Assessing Sustainability Performance of Global Supply Chains: An Input-Output Modeling Approach. *Eur. J. Oper. Res.* **2020**, *285*, 393–404. [CrossRef]

5. Rodríguez-González, R.M.; Maldonado-Guzman, G.; Madrid-Guijarro, A. The Effect of Green Strategies and Eco-innovation on Mexican Automotive Industry Sustainable and Financial Performance: Sustainable Supply Chains as a Mediating Variable. *Corp. Soc. Responsib. Environ. Manag.* **2022**, *29*, 779–794. [CrossRef]
6. Suhi, S.A.; Enayet, R.; Haque, T.; Ali, S.M.; Moktadir, A.; Paul, S.K. Environmental Sustainability Assessment in Supply Chain: An Emerging Economy Context. *Environ. Impact Assess. Rev.* **2019**, *79*, 106306. [CrossRef]
7. Mangla, S.K.; Kusi-Sarpong, S.; Luthra, S.; Bai, C.; Jakhar, S.K.; Khan, S.A. Operational Excellence for Improving Sustainable Supply Chain Performance. *Resour. Conserv. Recycl.* **2020**, *162*, 105025. [CrossRef]
8. Junaid, M.; Zhang, Q.; Syed, M.W. Effects of Sustainable Supply Chain Integration on Green Innovation and Firm Performance. *Sustain. Prod. Consum.* **2022**, *30*, 145–157. [CrossRef]
9. Fu, Q.; Abdul Rahman, A.A.; Jiang, H.; Abbas, J.; Comite, U. Sustainable Supply Chain and Business Performance: The Impact of Strategy, Network Design, Information Systems, and Organizational Structure. *Sustainability* **2022**, *14*, 1080. [CrossRef]
10. Dudukalov, E.V.; Terenina, I.V.; Perova, M.V.; Ushakov, D. Industry 4.0 Readiness: The Impact of Digital Transformation on Supply Chain Performance. *E3S Web Conf.* **2021**, *244*, 08020. [CrossRef]
11. Schniederjans, D.G.; Curado, C.; Khalajhedayati, M. Supply Chain Digitisation Trends: An Integration of Knowledge Management. *Int. J. Prod. Econ.* **2020**, *220*, 107439. [CrossRef]
12. Chen, C.; Feng, Y.; Shen, B. Managing Labor Sustainability in Digitalized Supply Chains: A Systematic Literature Review. *Sustainability* **2022**, *14*, 3895. [CrossRef]
13. Ataseven, C.; Nair, A. Assessment of Supply Chain Integration and Performance Relationships: A Meta-Analytic Investigation of the Literature. *Int. J. Prod. Econ.* **2017**, *185*, 252–265. [CrossRef]
14. Flynn, B.B.; Huo, B.; Zhao, X. The Impact of Supply Chain Integration on Performance: A Contingency and Configuration Approach. *J. Oper. Manag.* **2010**, *28*, 58–71. [CrossRef]
15. Nayal, K.; Raut, R.D.; Yadav, V.S.; Priyadarshinee, P.; Narkhede, B.E. The Impact of Sustainable Development Strategy on Sustainable Supply Chain Firm Performance in the Digital Transformation Era. *Bus. Strategy Environ.* **2022**, *31*, 845–859. [CrossRef]
16. Bigliardi, B.; Filippelli, S.; Petroni, A.; Tagliente, L. The Digitalization of Supply Chain: A Review. *Procedia Comput. Sci.* **2022**, *200*, 1806–1815. [CrossRef]
17. Mashelkar, R.A. Exponential Technology, Industry 4.0 and Future of Jobs in India. *Rev. Mark. Integr.* **2018**, *10*, 138–157. [CrossRef]
18. Queiroz, M.M.; Pereira, S.C.F.; Telles, R.; Machado, M.C. Industry 4.0 and Digital Supply Chain Capabilities: A Framework for Understanding Digitalisation Challenges and Opportunities. *Benchmarking Int. J.* **2021**, *28*, 1761–1782. [CrossRef]
19. Frederico, G.F.; Garza-Reyes, J.A.; Kumar, A.; Kumar, V. Performance Measurement for Supply Chains in the Industry 4.0 Era: A Balanced Scorecard Approach. *Int. J. Product. Perform. Manag.* **2020**, *70*, 789–807. [CrossRef]
20. Aryal, A.; Liao, Y.; Nattuthurai, P.; Li, B. The Emerging Big Data Analytics and IoT in Supply Chain Management: A Systematic Review. *Supply Chain. Manag.* **2018**, *25*, 141–156. [CrossRef]
21. Di Maria, E.; de Marchi, V.; Galeazzo, A. Industry 4.0 Technologies and Circular Economy: The Mediating Role of Supply Chain Integration. *Bus. Strategy Environ.* **2022**, *31*, 619–632. [CrossRef]
22. Qu, K.; Liu, Z. Green Innovations, Supply Chain Integration and Green Information System: A Model of Moderation. *J. Clean. Prod.* **2022**, *339*, 130557. [CrossRef]
23. Huo, B. The Impact of Supply Chain Integration on Company Performance: An Organizational Capability Perspective. *Supply Chain Manag.* **2012**, *17*, 596–610. [CrossRef]
24. Pakurár, M.; Haddad, H.; Nagy, J.; Popp, J.; Oláh, J. The Impact of Supply Chain Integration and Internal Control on Financial Performance in the Jordanian Banking Sector. *Sustainability* **2019**, *11*, 1248. [CrossRef]
25. Oubrahim, I.; Sefiani, N.; Quattrociocchi, B.; Savastano, M. Assessing the Relationships among Digitalization, Sustainability, SC Integration, and Overall Supply Chain Performance: A Research Agenda. In Proceedings of the 2022 14th International Colloquium of Logistics and Supply Chain Management (LOGISTIQUA), El Jadida, Morocco, 25 May 2022; pp. 1–6.
26. Liu, K.P.; Chiu, W. Supply Chain 4.0: The Impact of Supply Chain Digitalization and Integration on Firm Performance. *Asian J. Bus. Ethics* **2021**, *10*, 371–389. [CrossRef]
27. Gupta, H.; Kumar, S.; Kusi-Sarpong, S.; Jabbour, C.J.C.; Agyemang, M. Enablers to Supply Chain Performance on the Basis of Digitization Technologies. *Ind. Manag. Data Syst.* **2021**, *121*, 1915–1938. [CrossRef]
28. Tan, C.L.; Tei, Z.; Yeo, S.F.; Lai, K.H.; Kumar, A.; Chung, L. Nexus among Blockchain Visibility, Supply Chain Integration and Supply Chain Performance in the Digital Transformation Era. *Ind. Manag. Data Syst.* **2022**. *ahead of print*. [CrossRef]
29. El Hamdi, S.; Oudani, M.; Abouabdellah, A. Morocco's Readiness to Industry 4.0. In *Proceedings of the 8th International Conference on Sciences of Electronics, Technologies of Information and Telecommunications (SETIT'18), Volume 1*; Bouhlel, M.S., Rovetta, S., Eds.; Smart Innovation, Systems and Technologies; Springer International Publishing: Cham, Switzerland, 2020; Volume 146, pp. 463–472. ISBN 978-3-030-21004-5.
30. El Hilali, W.; El Manouar, A.; Janati Idrissi, M.A. Reaching Sustainability during a Digital Transformation: A PLS Approach. *Int. J. Innov. Sci.* **2020**, *12*, 52–79. [CrossRef]
31. Tavana, M.; Shaabani, A.; Raeesi Vanani, I.; Kumar Gangadhari, R. A Review of Digital Transformation on Supply Chain Process Management Using Text Mining. *Processes* **2022**, *10*, 842. [CrossRef]

32. Nambisan, S.; Wright, M.; Feldman, M. The Digital Transformation of Innovation and Entrepreneurship: Progress, Challenges and Key Themes. *Res. Policy* **2019**, *48*, 103773. [CrossRef]
33. Kortelainen, H.; Happonen, A.; Kinnunen, S.K. Fleet Service Generation—Challenges in Corporate Asset Management. In *Proceedings of the 10th World Congress on Engineering Asset Management (WCEAM 2015)*; Koskinen, K.T., Kortelainen, H., Aaltonen, J., Uusitalo, T., Komonen, K., Mathew, J., Laitinen, J., Eds.; Lecture Notes in Mechanical Engineering; Springer International Publishing: Cham, Switzerland, 2016; pp. 373–380. ISBN 978-3-319-27062-3.
34. Jahkola, O.; Happonen, A.; Knutas, A.; Ikonen, J. What Should Application Developers Understand about Mobile Phone Position Data. In Proceedings of the 18th International Conference on Computer Systems and Technologies, Ruse, Bulgaria, 23 June 2017; pp. 171–178.
35. Ivanov, D.; Dolgui, A. A Digital Supply Chain Twin for Managing the Disruption Risks and Resilience in the Era of Industry 4.0. *Prod. Plan. Control* **2021**, *32*, 775–788. [CrossRef]
36. Deepu, T.S.; Ravi, V. Supply Chain Digitalization: An Integrated MCDM Approach for Inter-Organizational Information Systems Selection in an Electronic Supply Chain. *Supply Chain Forum Int. J.* **2021**, *1*, 100038. [CrossRef]
37. Ageron, B.; Bentahar, O.; Gunasekaran, A. Digital Supply Chain: Challenges and Future Directions. *Supply Chain Forum Int. J.* **2020**, *21*, 133–138. [CrossRef]
38. Büyüközkan, G.; Göçer, F. Digital Supply Chain: Literature Review and a Proposed Framework for Future Research. *Comput. Ind.* **2018**, *97*, 157–177. [CrossRef]
39. Batista, L.; Dora, M.; Garza-Reyes, J.A.; Kumar, V. Improving the Sustainability of Food Supply Chains through Circular Economy Practices—A Qualitative Mapping Approach. *Manag. Environ. Qual.* **2021**, *32*, 752–767. [CrossRef]
40. Happonen, A.; Ghoreishi, M. A Mapping Study of the Current Literature on Digitalization and Industry 4.0 Technologies Utilization for Sustainability and Circular Economy in Textile Industries. In *Proceedings of Sixth International Congress on Information and Communication Technology*; Yang, X.S., Sherratt, S., Dey, N., Joshi, A., Eds.; Lecture Notes in Networks and Systems; Springer: Singapore, 2022; Volume 217, pp. 697–711. ISBN 9789811621017.
41. Ghoreishi, M.; Happonen, A.; Pynnönen, M. Exploring Industry 4.0 Technologies to Enhance Circularity in Textile Industry: Role of Internet of Things. *Int. Work. Semin. Prod. Econ.* **2020**, 3471421. [CrossRef]
42. Ghoreishi, M.; Happonen, A. The Case of Fabric and Textile Industry: The Emerging Role of Digitalization, Internet-of-Things and Industry 4.0 for Circularity. In *Proceedings of Sixth International Congress on Information and Communication Technology*; Yang, X.-S., Sherratt, S., Dey, N., Joshi, A., Eds.; Lecture Notes in Networks and Systems; Springer: Singapore, 2022; Volume 216, pp. 189–200, ISBN 9789811617805.
43. Fatorachian, H.; Kazemi, H. Impact of Industry 4.0 on Supply Chain Performance. *Prod. Plan. Control.* **2021**, *32*, 63–81. [CrossRef]
44. Dutta, P.; Choi, T.M.; Somani, S.; Butala, R. Blockchain Technology in Supply Chain Operations: Applications, Challenges and Research Opportunities. *Transp. Res. Part E Logist. Transp. Rev.* **2020**, *142*, 102067. [CrossRef]
45. Nayal, K.; Raut, R.D.; Narkhede, B.E.; Priyadarshinee, P.; Panchal, G.B.; Gedam, V.V. Antecedents for Blockchain Technology-Enabled Sustainable Agriculture Supply Chain. *Ann. Oper. Res.* **2021**, 1–45. [CrossRef]
46. Saberi, S.; Kouhizadeh, M.; Sarkis, J.; Shen, L. Blockchain Technology and Its Relationships to Sustainable Supply Chain Management. *Int. J. Prod. Res.* **2019**, *57*, 2117–2135. [CrossRef]
47. Stroumpoulis, A.; Kopanaki, E. Theoretical Perspectives on Sustainable Supply Chain Management and Digital Transformation: A Literature Review and a Conceptual Framework. *Sustainability* **2022**, *14*, 4862. [CrossRef]
48. Tarigan, Z.J.H.; Siagian, H.; Jie, F. Impact of Internal Integration, Supply Chain Partnership, Supply Chain Agility, and Supply Chain Resilience on Sustainable Advantage. *Sustainability* **2021**, *13*, 5460. [CrossRef]
49. Kumar, V.; Chibuzo, E.N.; Garza-Reyes, J.A.; Kumari, A.; Rocha-Lona, L.; Lopez-Torres, G.C. The Impact of Supply Chain Integration on Performance: Evidence from the UK Food Sector. *Procedia Manuf.* **2017**, *11*, 814–821. [CrossRef]
50. Kim, D.Y. Relationship between Supply Chain Integration and Performance. *Oper. Manag. Res.* **2013**, *6*, 74–90. [CrossRef]
51. Cheng, J.; Zhao, S.; Feng, T.; Sheng, H. Business Model Design and Mass Customization Capability: Is Supply Chain Integration a Missing Link? *Bus. Process Manag. J.* **2022**, *28*, 1183–1206. [CrossRef]
52. Danese, P.; Romano, P.; Formentini, M. The Impact of Supply Chain Integration on Responsiveness: The Moderating Effect of Using an International Supplier Network. *Transp. Res. Part E Logist. Transp. Rev.* **2013**, *49*, 125–140. [CrossRef]
53. Moyano-Fuentes, J.; Sacristán-Díaz, M.; Garrido-Vega, P. Improving Supply Chain Responsiveness through Advanced Manufacturing Technology: The Mediating Role of Internal and External Integration. *Prod. Plan. Control* **2016**, *27*, 686–697. [CrossRef]
54. Ketokivi, M.; Mahoney, J.T. Transaction Cost Economics as a Theory of Supply Chain Efficiency. *Prod. Oper. Manag.* **2020**, *29*, 1011–1031. [CrossRef]
55. Zhao, X.; Huo, B.; Selen, W.; Yeung, J.H.Y. The Impact of Internal Integration and Relationship Commitment on External Integration. *J. Oper. Manag.* **2011**, *29*, 17–32. [CrossRef]
56. Espino-Rodríguez, T.F.; Taha, M.G. Supplier Innovativeness in Supply Chain Integration and Sustainable Performance in the Hotel Industry. *Int. J. Hosp. Manag.* **2022**, *100*, 103103. [CrossRef]
57. Bagchi, P.K.; Chun Ha, B.; Skjoett-Larsen, T.; Boege Soerensen, L. Supply Chain Integration: A European Survey. *Int. J. Logist. Manag.* **2005**, *16*, 275–294. [CrossRef]
58. Wong, C.W.Y.; Wong, C.Y.; Boon-itt, S. The Combined Effects of Internal and External Supply Chain Integration on Product Innovation. *Int. J. Prod. Econ.* **2013**, *146*, 566–574. [CrossRef]

59. Oubrahim, I.; Sefiani, N. Supply Chain Performance Measurement Systems: Benefits and Drawbacks. *Int. J. Latest Eng. Manag. Res.* **2022**, *7*, 24–28. [CrossRef]
60. Raut, R.D.; Mangla, S.K.; Narwane, V.S.; Dora, M.; Liu, M. Big Data Analytics as a Mediator in Lean, Agile, Resilient, and Green (LARG) Practices Effects on Sustainable Supply Chains. *Transp. Res. Part E Logist. Transp. Rev.* **2021**, *145*, 102170. [CrossRef]
61. Hafi, M.; Ujianto, U.; Andjarwati, T. The Effects of Sustainable Supply Chain Management and Organizational Learning Abilities on the Performance of the Manufacturing Companies. *Uncertain Supply Chain. Manag.* **2022**, *10*, 1345–1358. [CrossRef]
62. Aliakbari Nouri, F.; Shafiei Nikabadi, M.; Olfat, L. Developing the Framework of Sustainable Service Supply Chain Balanced Scorecard (SSSC BSC). *Int. J. Product. Perform. Manag.* **2019**, *68*, 148–170. [CrossRef]
63. Sarkis, J.; Kouhizadeh, M.; Zhu, Q.S. Digitalization and the Greening of Supply Chains. *Ind. Manag. Data Syst.* **2020**, *121*, 65–85. [CrossRef]
64. Kumar, G.; Goswami, M. Sustainable Supply Chain Performance, Its Practice and Impact on Barriers to Collaboration. *Int. J. Product. Perform. Manag.* **2019**, *68*, 1434–1456. [CrossRef]
65. Neri, A.; Cagno, E.; Lepri, M.; Trianni, A. A Triple Bottom Line Balanced Set of Key Performance Indicators to Measure the Sustainability Performance of Industrial Supply Chains. *Sustain. Prod. Consum.* **2021**, *26*, 648–691. [CrossRef]
66. Acquaye, A.; Ibn-Mohammed, T.; Genovese, A.; Afrifa, G.A.; Yamoah, F.A.; Oppon, E. A Quantitative Model for Environmentally Sustainable Supply Chain Performance Measurement. *Eur. J. Oper. Res.* **2018**, *269*, 188–205. [CrossRef]
67. Forslund, H.; Björklund, M. Toward circular supply chains for flat glass: Challenges of transforming to more energy-efficient solutions. *Energies* **2022**, *15*, 7282. [CrossRef]
68. Cagno, E.; Neri, A.; Howard, M.; Brenna, G.; Trianni, A. Industrial Sustainability Performance Measurement Systems: A Novel Framework. *J. Clean. Prod.* **2019**, *230*, 1354–1375. [CrossRef]
69. Badri Ahmadi, H.; Kusi-Sarpong, S.; Rezaei, J. Assessing the Social Sustainability of Supply Chains Using Best Worst Method. *Resour. Conserv. Recycl.* **2017**, *126*, 99–106. [CrossRef]
70. Yeh, T.M.; Pai, F.Y.; Wu, L.C. Relationship Stability and Supply Chain Performance for SMEs: From Internal, Supplier, and Customer Integration Perspectives. *Mathematics* **2020**, *8*, 1902. [CrossRef]
71. Mani, V.; Jabbour, C.J.C.; Mani, K.T.N. Supply Chain Social Sustainability in Small and Medium Manufacturing Enterprises and Firms' Performance: Empirical Evidence from an Emerging Asian Economy. *Int. J. Prod. Econ.* **2020**, *227*, 107656. [CrossRef]
72. Gimenez, C.; Sierra, V.; Rodon, J. Sustainable Operations: Their Impact on the Triple Bottom Line. *Int. J. Prod. Econ.* **2012**, *140*, 149–159. [CrossRef]
73. Shibin, K.T.; Gunasekaran, A.; Dubey, R. Explaining Sustainable Supply Chain Performance Using a Total Interpretive Structural Modeling Approach. *Sustain. Prod. Consum.* **2017**, *12*, 104–118. [CrossRef]
74. Happonen, A.; Santti, U.; Auvinen, H.; Räsänen, T.; Eskelinen, T. Digital Age Business Model Innovation for Sustainability in University Industry Collaboration Model. *E3S Web Conf.* **2020**, *211*, 04005. [CrossRef]
75. Uddin, M.; Rahman, A.A. Energy Efficiency and Low Carbon Enabler Green IT Framework for Data Centers Considering Green Metrics. *Renew. Sustain. Energy Rev.* **2012**, *16*, 4078–4094. [CrossRef]
76. Sharma, M.; Kumar, A.; Luthra, S.; Joshi, S.; Upadhyay, A. The Impact of Environmental Dynamism on Low-carbon Practices and Digital Supply Chain Networks to Enhance Sustainable Performance: An Empirical Analysis. *Bus. Strategy Environ.* **2022**, *31*, 1776–1788. [CrossRef]
77. Lee, K.L.; Azmi, N.A.N.; Hanaysha, J.R.; Alzoubi, H.M.; Alshurideh, M.T. The Effect of Digital Supply Chain on Organizational Performance: An Empirical Study in Malaysia Manufacturing Industry. *Uncertain Supply Chain. Manag.* **2022**, *10*, 495–510. [CrossRef]
78. Nayal, K.; Kumar, S.; Raut, R.D.; Queiroz, M.M.; Priyadarshinee, P.; Narkhede, B.E. Supply Chain Firm Performance in Circular Economy and Digital Era to Achieve Sustainable Development Goals. *Bus. Strategy Environ.* **2022**, *31*, 1058–1073. [CrossRef]
79. Kim, H.K.; Lee, C.W. Relationships among Healthcare Digitalization, Social Capital, and Supply Chain Performance in the Healthcare Manufacturing Industry. *Int. J. Environ. Res. Public. Health* **2021**, *18*, 1417. [CrossRef]
80. Kamble, S.S.; Gunasekaran, A.; Subramanian, N.; Ghadge, A.; Belhadi, A.; Venkatesh, M. Blockchain Technology's Impact on Supply Chain Integration and Sustainable Supply Chain Performance: Evidence from the Automotive Industry. *Ann. Oper. Res.* **2021**, 1–26. [CrossRef]
81. Alsufyani, N.; Gill, A.Q. Digitalisation Performance Assessment: A Systematic Review. *Technol. Soc.* **2022**, *68*, 101894. [CrossRef]
82. Chiappetta Jabbour, C.J.; Fiorini, P.D.C.; Ndubisi, N.O.; Queiroz, M.M.; Piato, É.L. Digitally-Enabled Sustainable Supply Chains in the 21st Century: A Review and a Research Agenda. *Sci. Total Environ.* **2020**, *725*, 138177. [CrossRef]
83. Koçoğlu, İ.; İmamoğlu, S.Z.; İnce, H.; Keskin, H. The Effect of Supply Chain Integration on Information Sharing:Enhancing the Supply Chain Performance. *Procedia Soc. Behav. Sci.* **2011**, *24*, 1630–1649. [CrossRef]
84. Lee, S.Y. Sustainable Supply Chain Management, Digital-Based Supply Chain Integration, and Firm Performance: A Cross-Country Empirical Comparison between South Korea and Vietnam. *Sustainability* **2021**, *13*, 7315. [CrossRef]
85. Wang, M.; Wang, B.; Abareshi, A. Blockchain Technology and Its Role in Enhancing Supply Chain Integration Capability and Reducing Carbon Emission: A Conceptual Framework. *Sustainability* **2020**, *12*, 10550. [CrossRef]
86. Li, G.; Yang, H.; Sun, L.; Sohal, A.S. The Impact of IT Implementation on Supply Chain Integration and Performance. *Int. J. Prod. Econ.* **2009**, *120*, 125–138. [CrossRef]

87. Shi, Y.; Zheng, X.; Venkatesh, V.G.; Humdan, E.A.; Paul, S.K. The Impact of Digitalization on Supply Chain Resilience: An Empirical Study of the Chinese Manufacturing Industry. *J. Bus. Ind. Mark.* **2022**, *38*, 1–11. [CrossRef]
88. Ahmed Khamis al Naqbi, R.; Bin MD Yusoff, R.; Binti Ismail, F. Supply Chain Integration and Sustainable Supply Chain Performance: A Case of Manufacturing Firms from UAE. *Int. J. Eng. Technol.* **2018**, *7*, 424. [CrossRef]
89. Prajogo, D.; Olhager, J. Supply Chain Integration and Performance: The Effects of Long-Term Relationships, Information Technology and Sharing, and Logistics Integration. *Int. J. Prod. Econ.* **2012**, *135*, 514–522. [CrossRef]
90. Abdallah, A.B.; Rawadiah, O.M.; Al-Byati, W.; Alhyari, S. Supply Chain Integration and Export Performance: The Mediating Role of Supply Chain Performance. *Int. J. Product. Perform. Manag.* **2021**, *70*, 1907–1929. [CrossRef]
91. Mackelprang, A.W.; Robinson, J.L.; Bernardes, E.; Webb, G.S. The Relationship Between Strategic Supply Chain Integration and Performance: A Meta-Analytic Evaluation and Implications for Supply Chain Management Research. *J. Bus. Logist.* **2014**, *35*, 71–96. [CrossRef]
92. Han, Z.; Huo, B. The Impact of Green Supply Chain Integration on Sustainable Performance. *Ind. Manag. Data Syst.* **2020**, *120*, 657–674. [CrossRef]
93. Mofokeng, T.M.; Chinomona, R. Supply Chain Partnership, Supply Chain Collaboration and Supply Chain Integration as the Antecedents of Supply Chain Performance. *S. Afr. J. Bus. Manag.* **2019**, *50*, 1–10. [CrossRef]
94. Erboz, G.; Yumurtacı Hüseyinoğlu, I.Ö.; Szegedi, Z. The Partial Mediating Role of Supply Chain Integration between Industry 4.0 and Supply Chain Performance. *Supply Chain Manag.* **2022**, *27*, 538–559. [CrossRef]
95. Delic, M.; Eyers, D.R. The Effect of Additive Manufacturing Adoption on Supply Chain Flexibility and Performance: An Empirical Analysis from the Automotive Industry. *Int. J. Prod. Econ.* **2020**, *228*, 107689. [CrossRef]
96. Haenlein, M.; Kaplan, A.M. A Beginner's Guide to Partial Least Squares Analysis. *Underst. Stat.* **2004**, *3*, 283–297. [CrossRef]
97. Marodin, G.A.; Frank, A.G.; Tortorella, G.L.; Saurin, T.A. Contextual Factors and Lean Production Implementation in the Brazilian Automotive Supply Chain. *Supply Chain Manag.* **2016**, *21*, 417–432. [CrossRef]
98. Hair, J.; Hollingsworth, C.L.; Randolph, A.B.; Chong, A.Y.L. An Updated and Expanded Assessment of PLS-SEM in Information Systems Research. *Ind. Manag. Data Syst.* **2017**, *117*, 442–458. [CrossRef]
99. Qader, G.; Junaid, M.; Abbas, Q.; Mubarik, M.S. Industry 4.0 Enables Supply Chain Resilience and Supply Chain Performance. *Technol. Forecast. Soc. Change* **2022**, *185*, 122026. [CrossRef]
100. Habib, A.; Bao, Y.; Ilmudeen, A. The Impact of Green Entrepreneurial Orientation, Market Orientation and Green Supply Chain Management Practices on Sustainable Firm Performance. *Cogent Bus. Manag.* **2020**, *7*, 1743616. [CrossRef]
101. Iqbal, S.; Moleiro Martins, J.; Nuno Mata, M.; Naz, S.; Akhtar, S.; Abreu, A. Linking Entrepreneurial Orientation with Innovation Performance in SMEs; the Role of Organizational Commitment and Transformational Leadership Using Smart PLS-SEM. *Sustainability* **2021**, *13*, 4361. [CrossRef]
102. Saad, N.A.; Elgazzar, S.; Mlaker Kac, S. Investigating the Impact of Resilience, Responsiveness, and Quality on Customer Loyalty of MSMEs: Empirical Evidence. *Sustainability* **2022**, *14*, 5011. [CrossRef]
103. Hair, J.F., Jr.; Sarstedt, M.; Matthews, L.M.; Ringle, C.M. Identifying and Treating Unobserved Heterogeneity with FIMIX-PLS: Part I—Method. *Eur. Bus. Rev.* **2016**, *28*, 63–76. [CrossRef]
104. Fornell, C.; Larcker, D.F. Evaluating Structural Equation Models with Unobservable Variables and Measurement Error. *J. Mark. Res.* **1981**, *18*, 39. [CrossRef]
105. Henseler, J.; Ringle, C.M.; Sarstedt, M. A New Criterion for Assessing Discriminant Validity in Variance-Based Structural Equation Modeling. *J. Acad. Mark. Sci.* **2015**, *43*, 115–135. [CrossRef]
106. Hussain, M.; Al-Aomar, R.; Melhem, H. Assessment of Lean-Green Practices on the Sustainable Performance of Hotel Supply Chains. *Int. J. Contemp. Hosp. Manag.* **2019**, *31*, 2448–2467. [CrossRef]
107. Henseler, J.; Hubona, G.; Ray, P.A. Using PLS Path Modeling in New Technology Research: Updated Guidelines. *Ind. Manag. Data Syst.* **2016**, *116*, 2–20. [CrossRef]
108. Munabi, I.G.; Buwembo, W. Partial Least Squares Structural Equation Path Modelling Determined Predictors of Students Reported Human Cadaver Dissection Activity. *Forensic Med. Anat. Res.* **2020**, *8*, 18–37. [CrossRef]
109. Chin, W.W. How to Write Up and Report PLS Analyses. In *Handbook of Partial Least Squares*; Esposito Vinzi, V., Chin, W.W., Henseler, J., Wang, H., Eds.; Springer: Berlin/Heidelberg, Germany, 2010; pp. 655–690. ISBN 978-3-540-32825-4.
110. Kock, N. Common Method Bias in PLS-SEM: A Full Collinearity Assessment Approach. *Int. J. E-Collab.* **2015**, *11*, 10. [CrossRef]
111. Munim, Z.H.; Noor, T. Young People's Perceived Service Quality and Environmental Performance of Hybrid Electric Bus Service. *Travel Behav. Soc.* **2020**, *20*, 133–143. [CrossRef]
112. Lowry, P.B.; Gaskin, J. Partial Least Squares (PLS) Structural Equation Modeling (SEM) for Building and Testing Behavioral Causal Theory: When to Choose It and How to Use It. *IEEE Trans. Prof. Commun.* **2014**, *57*, 123–146. [CrossRef]
113. Yousefi, S.; Mohamadpour Tosarkani, B. An Analytical Approach for Evaluating the Impact of Blockchain Technology on Sustainable Supply Chain Performance. *Int. J. Prod. Econ.* **2022**, *246*, 108429. [CrossRef]
114. Hämäläinen, H.; Salmela, E.; Happonen, A. RFID on Item Level Tagging in Supply Chain with High-Valued Products. In Proceedings of the 12th International Symposium on Logistics, Budapest, Hungary, 8–10 July 2007; p. 3376601. [CrossRef]
115. Minashkina, D.; Happonen, A. Decarbonizing warehousing activities through digitalization and automatization with WMS integration for sustainability supporting operations. *E3S Web Conf.* **2020**, *158*, 03002. [CrossRef]

116. García Alcaraz, J.L.; Díaz Reza, J.R.; Arredondo Soto, K.C.; Escobedo, G.H.; Happonen, A.; Vidal, R.P.I.; Macías, E.J. Effect of Green Supply Chain Management Practices on Environmental Performance: Case of Mexican Manufacturing Companies. *Mathematics* **2022**, *10*, 1877. [CrossRef]
117. Kilpeläinen, M.; Happonen, A. Awareness Adds to Knowledge. Stage of the Art Waste Processing Facilities and Industrial Waste Treatment Development. *Curr. Approaches Sci. Technol. Res.* **2021**, *4*, 125–148. [CrossRef]
118. Auvinen, H.; Santti, U.; Happonen, A. Technologies for Reducing Emissions and Costs in Combined Heat and Power Production. *E3S Web Conf.* **2020**, *158*, 03006. [CrossRef]
119. Happonen, A.; Siljander, V. Gainsharing in Logistics Outsourcing: Trust Leads to Success in the Digital Era. *Int. J. Collab. Enterp.* **2020**, *6*, 150. [CrossRef]
120. Salmela, E.; Happonen, A. Synchronization of Demand and Supply in a Supply Chain Manufacturing Industrial Products. In Proceedings of the 16th International Annual EurOMA Conference (EurOMA 2009), Göteborg, Sweden, 14–17 June 2009. [CrossRef]
121. Ivanov, D.; Dolgui, A.; Sokolov, B. The Impact of Digital Technology and Industry 4.0 on the Ripple Effect and Supply Chain Risk Analytics. *Int. J. Prod. Res.* **2019**, *57*, 829–846. [CrossRef]
122. Khan, I.; Jemai, J.; Lim, H.; Sarkar, B. Effect of Electrical Energy on the Manufacturing Setup Cost Reduction, Transportation Discounts, and Process Quality Improvement in a Two-Echelon Supply Chain Management under a Service-Level Constraint. *Energies* **2019**, *12*, 3733. [CrossRef]
123. Marchi, B.; Zanoni, S. Supply Chain Management for Improved Energy Efficiency: Review and Opportunities. *Energies* **2017**, *10*, 1618. [CrossRef]
124. Nasiri, M.; Ukko, J.; Saunila, M.; Rantala, T. Managing the Digital Supply Chain: The Role of Smart Technologies. *Technovation* **2020**, *96–97*, 102121. [CrossRef]
125. Gupta, S.; Meissonier, R.; Drave, V.A.; Roubaud, D. Examining the Impact of Cloud ERP on Sustainable Performance: A Dynamic Capability View. *Int. J. Inf. Manag.* **2020**, *51*, 102028. [CrossRef]