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Article

A Strategic Framework for Designing Environmentally Sustainable Supply Chains in the Digital Transformation Era

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Abstract

This study aimed to develop a strategic framework for designing environmentally sustainable supply chains in the digital transformation era, focusing on how digital technologies influence sustainability integration across supply chain networks. A qualitative research design was employed, using semi-structured interviews with supply chain professionals and supporting secondary data from organizational reports and industry sources. Thematic analysis was used to identify key patterns related to digital adoption, sustainability practices, organizational alignment, and supply chain collaboration. The findings reveal that digital transformation significantly enhances supply chain visibility, transparency, and efficiency, enabling organizations to monitor environmental impacts in real time and make data-driven decisions. Strategic alignment between sustainability goals and business objectives emerged as a critical factor for successful implementation, supported by leadership commitment and innovation-driven practices. Collaboration among supply chain partners and the integration of circular economy principles further strengthen environmental outcomes. However, challenges such as high implementation costs, technological complexity, and organizational resistance remain significant barriers. The study implies that organizations must adopt a holistic and integrated approach, combining digital capabilities with strong governance, stakeholder engagement, and continuous improvement to achieve sustainable supply chain performance in a rapidly evolving digital landscape.

Keywords: sustainable supply chain; digital transformation; environmental sustainability; circular economy; supply chain management; digital technologies; strategic framework; organizational innovation

1. Introduction

The increasing urgency of environmental sustainability has fundamentally reshaped the discourse surrounding supply chain management, particularly in the context of rapid digital transformation. Organizations across industries are now confronted with the dual imperative of enhancing operational efficiency while simultaneously minimizing their ecological footprint (Emon & Ahmed, 2025). This paradigm shift is driven by a confluence of factors, including heightened regulatory pressures, evolving stakeholder expectations, and the growing recognition of environmental degradation as a critical global challenge. In this evolving landscape, the integration of digital technologies into supply chain processes presents both unprecedented opportunities and complex challenges for achieving sustainability objectives (Emon & Ahmed, 2025). The emergence of advanced technologies such as artificial intelligence, the Internet of Things, blockchain, and big data analytics has enabled organizations to reimagine traditional supply chain models, offering new pathways for enhancing transparency, traceability, and resource efficiency. Consequently, the design of environmentally sustainable supply chains in the digital transformation era necessitates a strategic and holistic approach that aligns technological innovation with environmental stewardship (Shi et al., 2026).

Digital transformation has emerged as a key enabler of sustainable supply chain practices by facilitating real-time data collection, predictive analytics, and intelligent decision-making. These capabilities allow organizations to optimize resource utilization, reduce waste, and improve overall environmental performance (Ahmed et al., 2026). For instance, the deployment of IoT sensors in logistics and transportation systems enables the monitoring of energy consumption and emissions, thereby supporting more sustainable operational practices. Similarly, big data analytics provides valuable insights into supply chain dynamics, enabling organizations to identify inefficiencies and implement targeted interventions (Ahmed & Ahmed, 2026). However, the adoption of digital technologies also introduces new complexities, including increased energy consumption associated with data centers and the need for robust cybersecurity measures. Therefore, organizations must carefully balance the benefits and challenges of digital transformation to ensure that sustainability objectives are not compromised (Jia et al., 2026).

The concept of environmentally sustainable supply chains extends beyond the traditional focus on cost and efficiency to encompass broader environmental considerations, including carbon emissions, resource depletion, and waste management. This expanded perspective requires organizations to adopt a life-cycle approach to supply chain design, considering the environmental impact of products and processes from raw material extraction to end-of-life disposal (Hasan Emon et al., 2026). In this context, circular economy principles have gained significant traction, emphasizing the importance of resource recovery, recycling, and reuse. Digital technologies play a crucial role in enabling circular supply chains by enhancing visibility and coordination across different stages of the product life cycle. For example, blockchain technology can be used to track the provenance of materials, ensuring that they are sourced sustainably and responsibly. Furthermore, digital platforms facilitate collaboration among supply chain partners, enabling the sharing of information and resources to achieve common sustainability goals (Srinivasan, 2026).

Despite the potential benefits of digital transformation for sustainable supply chain design, several challenges persist that hinder the effective implementation of these initiatives (Hasan Emon et al., 2026). One of the primary challenges is the lack of integration between different digital systems, which can result in fragmented data and limited visibility across the supply chain. Additionally, organizations often face resource constraints, including limited financial and technical capabilities, which can impede the adoption of advanced technologies (Emon et al., 2026). Cultural and organizational barriers also play a significant role, as employees may resist changes to established processes and practices. Moreover, the complexity of global supply chains introduces additional challenges, including varying regulatory requirements and differences in technological infrastructure across regions. Addressing these challenges requires a comprehensive and strategic approach that considers both technological and organizational dimensions (Yan et al., 2026).

Another critical aspect of designing environmentally sustainable supply chains in the digital transformation era is the role of stakeholders. Stakeholder expectations have evolved significantly in recent years, with increasing demands for transparency, accountability, and ethical practices (Hassan et al., 2025). Customers, investors, regulators, and non-governmental organizations are now actively scrutinizing the environmental performance of organizations, placing pressure on companies to adopt sustainable practices. In response, organizations are leveraging digital technologies to enhance transparency and communication with stakeholders. For instance, digital platforms enable the dissemination of real-time information on environmental performance, allowing stakeholders to make informed decisions. Additionally, the use of blockchain technology enhances trust by providing immutable records of transactions and processes. These developments underscore the importance of stakeholder engagement in the design and implementation of sustainable supply chains (Fahim et al., 2026).

The integration of sustainability into supply chain design also necessitates a shift in organizational mindset, moving from a reactive approach to a proactive and strategic orientation. Organizations must embed sustainability considerations into their core business strategies, aligning them with overall organizational goals and objectives (Hassan et al., 2025). This requires the

development of new capabilities, including sustainability-oriented innovation and cross-functional collaboration. Digital transformation plays a pivotal role in enabling this shift by providing the tools and capabilities needed to support sustainable practices. For example, advanced analytics can be used to model different scenarios and assess the environmental impact of various supply chain configurations, enabling organizations to make informed decisions. Furthermore, digital technologies facilitate collaboration across different functions and departments, fostering a more integrated and holistic approach to sustainability (Yu & Xin, 2026).

In addition to internal organizational factors, external environmental factors also influence the design of sustainable supply chains. Regulatory frameworks, industry standards, and market dynamics all play a significant role in shaping organizational practices. Governments around the world are increasingly implementing policies and regulations aimed at reducing environmental impact, such as carbon pricing mechanisms and emissions standards (Jamil et al., 2025). These regulatory pressures compel organizations to adopt more sustainable practices and invest in digital technologies to ensure compliance. At the same time, market dynamics, including competition and consumer preferences, drive organizations to differentiate themselves through sustainability initiatives. In this context, digital transformation serves as a critical enabler, allowing organizations to respond effectively to external pressures and capitalize on emerging opportunities (Shen & Jiang, 2026).

The concept of resilience has also gained prominence in the context of sustainable supply chain design, particularly in light of recent global disruptions such as the COVID-19 pandemic and geopolitical tensions. Resilient supply chains are characterized by their ability to adapt to changing conditions and recover from disruptions while maintaining operational continuity (Arafat et al., 2025). Sustainability and resilience are closely interconnected, as environmentally sustainable practices often contribute to long-term resilience. For instance, reducing dependence on finite resources and minimizing waste can enhance the stability and reliability of supply chains (Hossen et al., 2024). Digital technologies play a crucial role in enhancing resilience by providing real-time visibility and enabling rapid response to disruptions. For example, predictive analytics can be used to anticipate potential risks and develop contingency plans, while digital platforms facilitate coordination among supply chain partners (Jum'a et al., 2026).

Furthermore, the role of innovation in driving sustainable supply chain design cannot be overstated. Innovation encompasses not only technological advancements but also new business models, processes, and practices. Digital transformation acts as a catalyst for innovation by enabling organizations to experiment with new approaches and develop creative solutions to sustainability challenges (Hassan et al., 2024). For example, the adoption of platform-based business models can facilitate the sharing of resources and reduce overall consumption. Similarly, the use of digital twins allows organizations to simulate and optimize supply chain processes, improving efficiency and reducing environmental impact. These innovations highlight the transformative potential of digital technologies in shaping the future of sustainable supply chains (Rahman et al., 2026).

The human dimension of digital transformation and sustainability is another critical factor that influences the success of sustainable supply chain initiatives. Employees play a central role in implementing and sustaining these initiatives, and their skills, knowledge, and attitudes significantly impact organizational outcomes (Emon et al., 2026). As such, organizations must invest in training and development programs to equip employees with the necessary competencies to navigate the complexities of digital transformation and sustainability. Additionally, fostering a culture of sustainability is essential for ensuring long-term success. This involves promoting awareness, encouraging responsible behavior, and aligning individual actions with organizational goals (Emon, 2025). Digital technologies can support these efforts by providing tools for communication, collaboration, and knowledge sharing, thereby enhancing employee engagement and participation (Wang et al., 2026).

Moreover, the measurement and evaluation of environmental performance are critical components of sustainable supply chain design. Organizations must establish robust metrics and

indicators to assess their environmental impact and track progress towards sustainability goals. Digital technologies facilitate the collection and analysis of data, enabling organizations to monitor performance in real time and identify areas for improvement. For example, carbon footprint tracking systems provide insights into emissions across different stages of the supply chain, allowing organizations to implement targeted reduction strategies (Emon, 2025). Additionally, the use of standardized reporting frameworks enhances transparency and comparability, enabling stakeholders to evaluate organizational performance effectively. These capabilities underscore the importance of data-driven decision-making in achieving sustainability objectives (Cheng & Zhang, 2026).

The integration of digital technologies into supply chains also raises important ethical and social considerations. While digital transformation offers significant benefits, it also introduces risks related to data privacy, security, and inequality. Organizations must address these issues to ensure that their sustainability initiatives are inclusive and equitable (Emon, 2025). For instance, the digital divide may limit the ability of smaller suppliers to adopt advanced technologies, potentially excluding them from supply chains. To address this challenge, organizations can implement capacity-building initiatives and provide support to suppliers, enabling them to participate in sustainable supply chain practices. Furthermore, ethical considerations related to data usage and governance must be addressed to build trust and ensure compliance with regulatory requirements (Abourida et al., 2026).

Collaboration and partnerships are essential for achieving sustainability in supply chains, as no single organization can address these challenges independently. Supply chains are inherently interconnected, involving multiple stakeholders with diverse interests and capabilities (Emon, 2025). Digital technologies facilitate collaboration by enabling the sharing of information and resources across organizational boundaries. For example, cloud-based platforms allow supply chain partners to access and exchange data in real time, improving coordination and decision-making. Additionally, collaborative initiatives such as industry consortia and public-private partnerships play a crucial role in driving collective action towards sustainability. These collaborations enable organizations to leverage shared knowledge and resources, accelerating the adoption of sustainable practices (Fang et al., 2026).

Finally, the strategic design of environmentally sustainable supply chains in the digital transformation era requires a comprehensive framework that integrates technological, organizational, and environmental dimensions. Such a framework must consider the interplay between different factors, including digital capabilities, stakeholder engagement, regulatory requirements, and organizational culture (Emon, 2025). By adopting a holistic approach, organizations can align their supply chain strategies with sustainability objectives, creating value for both the organization and society. The development of such frameworks is essential for guiding organizations in navigating the complexities of digital transformation and sustainability, enabling them to achieve long-term success in an increasingly dynamic and uncertain environment (Azis et al., 2026).

2. Literature Review

Rapid advancements in digital technologies have significantly reshaped the theoretical and empirical understanding of supply chain sustainability, particularly in the context of environmental considerations. Contemporary research emphasizes that the convergence of digital transformation and sustainable supply chain management has created a multidimensional paradigm in which environmental performance, operational efficiency, and technological innovation are deeply intertwined. Scholars have increasingly highlighted the importance of leveraging digital tools such as artificial intelligence, blockchain, big data analytics, and the Internet of Things to enhance visibility, traceability, and coordination across supply chain networks (Emon, 2025). These technologies are not only enabling real-time monitoring and optimization but are also fostering more sustainable decision-making processes by integrating environmental metrics into operational frameworks. For instance, advanced analytics have been shown to support carbon footprint

reduction by identifying inefficiencies and enabling predictive modeling, thereby enhancing environmental performance across supply chains (Cheng & Zhang, 2026).

The integration of sustainability into supply chain management has evolved from a peripheral concern to a central strategic priority, driven by increasing regulatory pressures, stakeholder expectations, and environmental challenges (Emon, 2025). Digital transformation has emerged as a key enabler in this transition, facilitating the adoption of sustainable practices through enhanced data availability and decision-making capabilities. Research indicates that organizations that effectively integrate digital technologies into their supply chains are better positioned to achieve environmental sustainability goals (Emon, 2025). For example, blockchain technology has been widely recognized for its ability to enhance transparency and accountability by providing immutable records of transactions, thereby ensuring the traceability of materials and processes. This is particularly relevant in addressing issues related to unethical sourcing and environmental degradation, as organizations can verify compliance with sustainability standards throughout the supply chain (Abourida et al., 2026).

Another significant stream of literature focuses on the role of circular economy principles in shaping environmentally sustainable supply chains. Circular supply chains emphasize resource efficiency, waste reduction, and the reuse and recycling of materials, thereby minimizing environmental impact. Digital technologies play a crucial role in enabling circularity by facilitating information sharing and coordination among supply chain partners. For instance, digital platforms allow organizations to track product life cycles and identify opportunities for resource recovery and reuse (Emon, 2025). Furthermore, the use of digital twins enables organizations to simulate supply chain processes and evaluate the environmental impact of different scenarios, thereby supporting more sustainable decision-making. These developments underscore the importance of integrating digital transformation with circular economy principles to achieve sustainable supply chain outcomes (Fang et al., 2026).

The relationship between digital transformation and supply chain resilience has also received considerable attention in recent research. Resilience and sustainability are increasingly viewed as complementary objectives, as both aim to enhance the long-term viability of supply chains (Emon, 2025). Digital technologies contribute to resilience by providing real-time visibility and enabling rapid response to disruptions, which in turn supports sustainable practices by minimizing waste and resource inefficiencies. For example, predictive analytics can be used to anticipate disruptions and optimize inventory management, thereby reducing excess inventory and associated environmental impacts. Additionally, digital platforms facilitate collaboration among supply chain partners, enabling coordinated responses to disruptions and enhancing overall system resilience (Azis et al., 2026).

The human and organizational dimensions of digital transformation and sustainability have also been extensively explored in the literature. The successful implementation of sustainable supply chain initiatives requires not only technological capabilities but also organizational readiness and cultural alignment (Emon, 2023). Studies have highlighted the importance of leadership commitment, employee engagement, and cross-functional collaboration in driving sustainability initiatives. Digital technologies can support these efforts by providing tools for communication, knowledge sharing, and performance monitoring. However, the adoption of digital technologies also presents challenges, including resistance to change, skill gaps, and the need for continuous learning and adaptation. Addressing these challenges requires a holistic approach that considers both technological and human factors (Ashraf et al., 2026).

In addition to organizational factors, external environmental factors such as regulatory frameworks, market dynamics, and stakeholder pressures play a critical role in shaping sustainable supply chain practices. Governments and regulatory bodies are increasingly implementing policies aimed at reducing environmental impact, such as emissions standards and carbon pricing mechanisms (Emon et al., 2025). These regulations compel organizations to adopt more sustainable practices and invest in digital technologies to ensure compliance. At the same time, market dynamics,

including competition and consumer preferences, drive organizations to differentiate themselves through sustainability initiatives. Digital transformation enables organizations to respond effectively to these external pressures by providing the tools and capabilities needed to monitor and improve environmental performance (Zhang, 2026).

A growing body of research also examines the role of data-driven decision-making in sustainable supply chain management. The availability of large volumes of data, combined with advanced analytics capabilities, allows organizations to gain deeper insights into supply chain dynamics and environmental impacts (Emon & Chowdhury, 2025). For instance, machine learning algorithms can be used to analyze historical data and identify patterns that can inform more sustainable decision-making. Additionally, real-time data collection through IoT devices enables continuous monitoring of environmental performance, allowing organizations to identify and address issues promptly. These capabilities highlight the transformative potential of data-driven approaches in enhancing the sustainability of supply chains (Palandella et al., 2026).

Collaboration and integration across supply chain networks are also critical for achieving sustainability objectives. Supply chains are inherently complex and involve multiple stakeholders with diverse interests and capabilities. Digital technologies facilitate collaboration by enabling the sharing of information and resources across organizational boundaries (Emon & Chowdhury, 2025). For example, cloud-based platforms allow supply chain partners to access and exchange data in real time, improving coordination and decision-making. Furthermore, collaborative initiatives such as industry consortia and public-private partnerships play a crucial role in driving collective action towards sustainability. These collaborations enable organizations to leverage shared knowledge and resources, thereby accelerating the adoption of sustainable practices (Zhang et al., 2026).

The literature also highlights the importance of integrating environmental considerations into supply chain design and planning processes. This involves adopting a life-cycle perspective that considers the environmental impact of products and processes from raw material extraction to end-of-life disposal. Digital technologies support this approach by providing the tools needed to assess and optimize environmental performance across the entire supply chain. For example, life-cycle assessment tools can be integrated with digital platforms to evaluate the environmental impact of different supply chain configurations. Additionally, optimization models can be used to identify the most sustainable options for sourcing, production, and distribution, thereby reducing environmental impact (Raza et al., 2026).

Another important area of research focuses on the role of innovation in driving sustainable supply chain practices. Innovation encompasses not only technological advancements but also new business models, processes, and practices. Digital transformation acts as a catalyst for innovation by enabling organizations to experiment with new approaches and develop creative solutions to sustainability challenges. For instance, the adoption of platform-based business models can facilitate the sharing of resources and reduce overall consumption. Similarly, the use of digital twins allows organizations to simulate and optimize supply chain processes, improving efficiency and reducing environmental impact. These innovations highlight the transformative potential of digital technologies in shaping the future of sustainable supply chains (Tahmouresi & Behnamian, 2026).

The measurement and evaluation of environmental performance are critical components of sustainable supply chain management. Organizations must establish robust metrics and indicators to assess their environmental impact and track progress towards sustainability goals. Digital technologies facilitate the collection and analysis of data, enabling organizations to monitor performance in real time and identify areas for improvement. For example, carbon footprint tracking systems provide insights into emissions across different stages of the supply chain, allowing organizations to implement targeted reduction strategies. Additionally, the use of standardized reporting frameworks enhances transparency and comparability, enabling stakeholders to evaluate organizational performance effectively (Dey et al., 2026).

Ethical and social considerations are also increasingly being incorporated into the discourse on sustainable supply chains. While environmental sustainability is a primary focus, organizations must

also consider the broader social and ethical implications of their supply chain practices. Digital transformation introduces new challenges related to data privacy, security, and inequality, which must be addressed to ensure that sustainability initiatives are inclusive and equitable. For instance, the digital divide may limit the ability of smaller suppliers to adopt advanced technologies, potentially excluding them from supply chains. To address this challenge, organizations can implement capacity-building initiatives and provide support to suppliers, enabling them to participate in sustainable supply chain practices (Hasanein et al., 2026).

Recent studies have also explored the role of governance and policy frameworks in shaping sustainable supply chain practices. Effective governance mechanisms are essential for ensuring compliance with sustainability standards and promoting accountability among supply chain partners. Digital technologies can enhance governance by providing tools for monitoring and enforcing compliance, such as blockchain-based systems that enable transparent and immutable record-keeping. Additionally, policy frameworks at the national and international levels play a crucial role in setting standards and providing incentives for sustainable practices. These frameworks create an enabling environment for organizations to adopt sustainable supply chain strategies (Borana et al., 2026).

The intersection of digital transformation and sustainability has also led to the emergence of new theoretical perspectives and conceptual frameworks. Researchers have proposed various models to explain the relationship between digital capabilities and environmental performance, highlighting the mediating role of factors such as organizational culture, innovation, and stakeholder engagement. These frameworks provide valuable insights into the mechanisms through which digital transformation influences sustainability outcomes, thereby informing the design of more effective strategies and interventions (Chin et al., 2026).

Furthermore, the role of artificial intelligence in sustainable supply chain management has gained significant attention in recent years. AI technologies enable advanced analytics and automation, allowing organizations to optimize processes and reduce environmental impact. For example, AI-driven optimization algorithms can be used to improve route planning in logistics, thereby reducing fuel consumption and emissions. Similarly, machine learning models can be used to predict demand more accurately, reducing excess inventory and associated waste. These applications demonstrate the potential of AI to enhance the sustainability of supply chains (Pun & Sakurai, 2026).

The importance of stakeholder engagement in sustainable supply chain management is also widely recognized in the literature. Stakeholders, including customers, investors, regulators, and non-governmental organizations, play a critical role in influencing organizational behavior and driving sustainability initiatives. Digital technologies facilitate stakeholder engagement by enabling transparent communication and information sharing. For example, digital platforms allow organizations to provide real-time updates on their environmental performance, enhancing accountability and trust. Additionally, social media and other digital channels enable stakeholders to voice their concerns and expectations, thereby influencing organizational decision-making (Wang et al., 2026).

The concept of sustainable supply chain finance has also emerged as an important area of research. This involves the use of financial mechanisms to support sustainable practices, such as green financing and incentives for environmentally friendly initiatives. Digital technologies play a key role in enabling sustainable supply chain finance by providing platforms for data sharing and risk assessment. For example, blockchain technology can be used to verify the sustainability credentials of suppliers, thereby facilitating access to financing for those that meet sustainability criteria. These developments highlight the role of financial mechanisms in promoting sustainable supply chain practices (Wei & Xia, 2026).

In addition, the role of emerging technologies such as the Internet of Things and blockchain in enhancing supply chain sustainability has been extensively explored. IoT devices enable real-time monitoring of environmental conditions, such as temperature and humidity, which is particularly

important in industries such as food and pharmaceuticals. Blockchain technology, on the other hand, enhances transparency and traceability, enabling organizations to verify the sustainability of their supply chains. These technologies complement each other, providing a comprehensive solution for enhancing supply chain sustainability (Ullah et al., 2026).

The challenges associated with implementing sustainable supply chain practices in the digital transformation era have also been widely discussed in the literature. These challenges include technological barriers, such as the high cost of implementation and the complexity of integrating different systems, as well as organizational barriers, such as resistance to change and lack of expertise. Additionally, external challenges, such as regulatory uncertainty and market volatility, can further complicate the implementation of sustainable practices. Addressing these challenges requires a comprehensive and strategic approach that considers both internal and external factors (Bahamón-Monje et al., 2026). Finally, the importance of continuous improvement and learning in sustainable supply chain management has been emphasized in recent research. Organizations must continuously monitor and evaluate their performance, identify areas for improvement, and adapt their strategies accordingly. Digital technologies facilitate this process by providing the tools needed for data collection, analysis, and feedback. For example, performance dashboards and analytics platforms enable organizations to track their progress towards sustainability goals and make data-driven decisions. These capabilities support a culture of continuous improvement, which is essential for achieving long-term sustainability (Fiałkowska-Filipek et al., 2026).

3. Research Methodology

The study adopted a qualitative research approach to explore the development of a strategic framework for designing environmentally sustainable supply chains in the era of digital transformation. A qualitative design was considered appropriate as it enabled an in-depth understanding of complex phenomena, particularly the interplay between digital technologies and sustainability practices within supply chain contexts. This approach facilitated the exploration of participants' perspectives, experiences, and insights, which were essential for developing a comprehensive and contextually grounded framework. The research was grounded in an interpretivist paradigm, recognizing that reality is socially constructed and that understanding is derived from the meanings individuals assign to their experiences.

A purposive sampling strategy was employed to select participants who possessed relevant knowledge and experience in supply chain management, sustainability practices, and digital transformation initiatives. The sample consisted of professionals from diverse industries, including manufacturing, logistics, retail, and technology sectors, ensuring a broad range of perspectives. Participants were selected based on criteria such as their involvement in supply chain decision-making, experience with digital technologies, and familiarity with environmental sustainability practices. This sampling approach ensured that the data collected was rich, relevant, and aligned with the objectives of the study.

Data were collected through semi-structured interviews, which allowed for flexibility in exploring participants' views while maintaining a consistent focus on key research themes. An interview guide was developed to ensure that all relevant topics were covered, including the role of digital technologies in supply chain operations, challenges in implementing sustainable practices, and strategies for integrating sustainability into supply chain design. The semi-structured format enabled participants to elaborate on their experiences and provide detailed insights, while also allowing the researcher to probe deeper into emerging themes. Interviews were conducted through virtual platforms and, where possible, face-to-face interactions, depending on participant availability and accessibility. Each interview lasted approximately 45 to 60 minutes and was recorded with the consent of the participants to ensure accuracy in data capture.

In addition to interviews, secondary data sources were also utilized to enhance the robustness of the study. These sources included organizational reports, sustainability disclosures, policy documents, and industry publications related to digital transformation and sustainable supply

chains. The inclusion of secondary data provided contextual background and enabled triangulation, thereby enhancing the credibility and validity of the findings. Field notes were also maintained during the data collection process to capture observations, reflections, and contextual information that supported the interpretation of the data.

The data analysis process followed a thematic analysis approach, which involved systematically identifying, analyzing, and interpreting patterns within the data. The analysis began with the transcription of interview recordings, followed by a thorough reading of the transcripts to gain familiarity with the data. Initial codes were generated to capture key ideas and concepts emerging from the data. These codes were then grouped into broader categories and themes that reflected the underlying patterns and relationships. An iterative process was followed, where themes were continuously refined and validated against the data to ensure consistency and coherence. This approach allowed for the development of a structured and meaningful representation of the findings, which informed the proposed strategic framework.

To ensure the trustworthiness of the study, several measures were implemented, including credibility, transferability, dependability, and confirmability. Credibility was enhanced through prolonged engagement with the data, member checking, and triangulation of multiple data sources. Participants were given the opportunity to review and validate the interpretations of their responses, ensuring that their perspectives were accurately represented. Transferability was addressed by providing detailed descriptions of the research context, participants, and processes, enabling readers to assess the applicability of the findings to other settings. Dependability was ensured by maintaining a clear and transparent research process, including documentation of data collection and analysis procedures. Confirmability was achieved by minimizing researcher bias through reflexivity and by maintaining an audit trail of decisions made throughout the research process.

Ethical considerations were carefully addressed throughout the study to ensure the protection of participants and the integrity of the research. Informed consent was obtained from all participants prior to data collection, and they were assured of the confidentiality and anonymity of their responses. Participants were informed of their right to withdraw from the study at any stage without any consequences. Data were securely stored and accessed only by the researcher, ensuring compliance with ethical standards and data protection requirements. Additionally, the study adhered to principles of honesty, transparency, and respect for participants, ensuring that the research was conducted in an ethical and responsible manner.

The methodological approach adopted in this study provided a comprehensive and in-depth understanding of the factors influencing the design of environmentally sustainable supply chains in the digital transformation era. By combining primary and secondary data sources and employing a rigorous analytical process, the study was able to generate valuable insights and develop a strategic framework that reflects both theoretical and practical considerations. The qualitative nature of the research allowed for the exploration of complex relationships and contextual factors, contributing to a nuanced understanding of the subject and offering meaningful implications for both academia and industry.

4. Results

The analysis of qualitative data generated a rich and nuanced understanding of how organizations are designing environmentally sustainable supply chains in the digital transformation era. The findings revealed that sustainability is no longer treated as an isolated objective but is increasingly embedded within digital transformation strategies. Participants emphasized that digital tools enable greater visibility across supply chain networks, allowing firms to monitor environmental performance in real time and respond proactively to inefficiencies. Many respondents described how technologies such as IoT sensors, data analytics platforms, and automation systems have facilitated the tracking of emissions, energy consumption, and waste generation. This enhanced visibility has significantly improved decision-making processes, allowing organizations to align operational efficiency with environmental sustainability. Participants further noted that the integration of digital

systems across supply chain functions has helped break down traditional silos, creating a more coordinated and responsive network that supports sustainability objectives.

Another prominent finding was the role of strategic alignment in achieving sustainability outcomes. Organizations that successfully implemented environmentally sustainable supply chains demonstrated a strong alignment between corporate strategy, sustainability goals, and digital transformation initiatives. Participants highlighted that leadership commitment was a critical driver in this alignment, as top management support ensured the allocation of resources and the prioritization of sustainability initiatives. In contrast, organizations lacking strategic alignment often struggled to integrate sustainability into their supply chain operations effectively. The findings also revealed that aligning sustainability with business value creation, such as cost savings and competitive advantage, increased organizational commitment and facilitated the adoption of sustainable practices.

Participants also emphasized the importance of collaboration and partnerships in achieving sustainability objectives. Supply chains are inherently interconnected, and no single organization can achieve sustainability independently. Digital platforms were identified as key enablers of collaboration, allowing organizations to share information, coordinate activities, and align sustainability efforts with suppliers and partners. Many participants described how collaborative initiatives, such as joint sustainability programs and shared digital platforms, have led to improved environmental performance across the supply chain. However, challenges related to trust, data sharing, and technological compatibility were also identified as barriers to effective collaboration.

The findings further highlighted the significance of innovation in driving sustainable supply chain practices. Digital transformation has created opportunities for organizations to experiment with new business models, processes, and technologies that enhance sustainability. For example, participants discussed the use of predictive analytics to optimize inventory levels and reduce waste, as well as the adoption of circular economy practices supported by digital tracking systems. Innovation was not limited to technological advancements but also included organizational and process innovations, such as new approaches to supplier engagement and performance measurement.

The role of organizational culture and human factors emerged as another critical theme. Participants noted that the successful implementation of sustainable supply chain practices requires a cultural shift towards sustainability and continuous improvement. Employees at all levels must be engaged and empowered to contribute to sustainability initiatives. Training and development programs were identified as essential for building the necessary skills and knowledge, particularly in relation to digital technologies. Resistance to change and lack of awareness were cited as common challenges, highlighting the need for effective change management strategies.

The integration of sustainability metrics into performance measurement systems was also identified as a key factor influencing sustainable supply chain design. Participants indicated that traditional performance metrics focused primarily on cost and efficiency are no longer sufficient. Instead, organizations are increasingly incorporating environmental indicators, such as carbon emissions and resource utilization, into their performance measurement systems. Digital technologies play a crucial role in enabling the collection and analysis of these metrics, providing organizations with the data needed to monitor progress and identify areas for improvement.

The findings also revealed that external factors, such as regulatory requirements and market pressures, significantly influence the adoption of sustainable supply chain practices. Participants noted that increasing regulatory scrutiny and customer demand for environmentally responsible products have compelled organizations to adopt more sustainable practices. Digital transformation has enabled organizations to respond to these external pressures more effectively by providing the tools needed to ensure compliance and communicate sustainability efforts to stakeholders.

Despite the potential benefits, participants identified several challenges associated with implementing sustainable supply chains in the digital transformation era. These challenges included high implementation costs, technological complexity, and the need for significant organizational

change. Additionally, issues related to data security and privacy were highlighted as concerns, particularly in the context of increased data sharing across supply chain networks. Participants emphasized the importance of addressing these challenges through strategic planning, investment in technology and skills, and the development of robust governance frameworks.

The thematic analysis resulted in the identification of ten key themes, each of which contributes to the development of a strategic framework for environmentally sustainable supply chains. These themes are presented in the following tables.

Table 1. Digital Visibility and Transparency.

Codes	Sub-themes	Themes
Real-time monitoring	Data integration	Digital visibility
Emission tracking	Analytics platforms	Transparency
Sensor-based data	IoT systems	Environmental monitoring
Data dashboards	Performance tracking	Visibility enhancement
Supply chain mapping	Network insights	Traceability
Automated reporting	System integration	Information flow
Environmental metrics	Digital tools	Sustainability tracking

The data presented in this table demonstrate that digital visibility and transparency are foundational elements of sustainable supply chain design. Participants consistently emphasized the importance of real-time data and integrated systems in enhancing environmental monitoring and enabling informed decision-making. The ability to track and analyze environmental metrics has allowed organizations to identify inefficiencies and implement targeted interventions.

Table 2. Strategic Alignment.

Codes	Sub-themes	Themes
Leadership support	Vision alignment	Strategic integration
Sustainability goals	Business strategy	Alignment
Resource allocation	Investment planning	Organizational commitment
Policy integration	Strategic frameworks	Governance
Long-term planning	Sustainability focus	Strategic orientation
Performance linkage	Value creation	Alignment outcomes
Decision-making	Strategic priorities	Integration

The findings reflected in this table highlight the critical role of aligning sustainability initiatives with organizational strategy. Participants indicated that strategic integration ensures that sustainability is embedded within core business processes, leading to more effective implementation and long-term success.

Table 3. Collaboration and Partnerships.

Codes	Sub-themes	Themes
Supplier engagement	Information sharing	Collaboration
Joint initiatives	Partnership models	Cooperation
Digital platforms	Data exchange	Connectivity
Trust building	Relationship management	Partnerships
Network coordination	Shared goals	Integration
Stakeholder involvement	Communication channels	Engagement
Cross-functional teams	Internal collaboration	Coordination

The data illustrate that collaboration and partnerships are essential for achieving sustainability across supply chains. Digital platforms have facilitated communication and coordination among stakeholders, enabling collective efforts towards sustainability goals.

Table 4. Innovation and Technology Adoption.

Codes	Sub-themes	Themes
Predictive analytics	Process optimization	Innovation
Automation systems	Efficiency improvement	Technology adoption
Digital twins	Simulation models	Advanced technologies
AI applications	Intelligent systems	Innovation drivers
Circular practices	Resource efficiency	Sustainable innovation
Process redesign	Workflow improvement	Transformation
Experimentation	New models	Innovation culture

The table shows that innovation and technology adoption are key drivers of sustainable supply chain practices. Organizations are leveraging digital technologies to optimize processes and reduce environmental impact.

Table 5. Organizational Culture and Human Factors.

Codes	Sub-themes	Themes
Employee engagement	Awareness programs	Culture
Training initiatives	Skill development	Capability building
Change management	Adaptation	Organizational readiness
Leadership influence	Cultural shift	Commitment
Knowledge sharing	Learning systems	Development
Resistance factors	Behavioral change	Challenges
Motivation	Incentive systems	Engagement

The data highlight the importance of organizational culture and human factors in implementing sustainable supply chain practices. Building a culture that supports sustainability and continuous learning is essential for success.

Table 6. Performance Measurement.

Codes	Sub-themes	Themes
Environmental metrics	KPI systems	Measurement
Carbon tracking	Emission analysis	Monitoring
Resource utilization	Efficiency metrics	Evaluation
Data analytics	Performance insights	Measurement tools
Reporting systems	Transparency	Accountability
Benchmarking	Comparative analysis	Performance
Continuous improvement	Feedback loops	Optimization

This table demonstrates that performance measurement systems are evolving to incorporate environmental indicators. Digital technologies enable organizations to track and evaluate sustainability performance effectively.

Table 7. External Pressures.

Codes	Sub-themes	Themes
Regulatory requirements	Compliance	External drivers
Market demand	Customer expectations	Pressure
Industry standards	Benchmarking	Influence
Competitive forces	Market positioning	Dynamics
Stakeholder demands	Accountability	Engagement
Environmental policies	Legal frameworks	Regulation

Global trends	Sustainability focus	Drivers
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The findings indicate that external pressures play a significant role in driving the adoption of sustainable supply chain practices. Organizations are responding to regulatory and market demands by integrating sustainability into their operations.

Table 8. Challenges and Barriers.

Codes	Sub-themes	Themes
High costs	Investment barriers	Challenges
Technological complexity	System integration	Barriers
Data security	Privacy concerns	Risks
Skill gaps	Workforce limitations	Constraints
Resistance to change	Organizational inertia	Barriers
Infrastructure limitations	Resource constraints	Challenges
Uncertainty	Risk management	Issues

This table highlights the various challenges organizations face in implementing sustainable supply chains. Addressing these barriers requires strategic planning and investment.

Table 9. Governance and Policy Frameworks.

Codes	Sub-themes	Themes
Sustainability policies	Organizational rules	Governance
Compliance systems	Monitoring mechanisms	Control
Ethical standards	Responsible practices	Accountability
Data governance	Information management	Regulation
Risk management	Policy enforcement	Governance
Transparency measures	Reporting standards	Oversight
Strategic guidelines	Framework development	Direction

The data emphasize the importance of governance and policy frameworks in ensuring the effective implementation of sustainability initiatives. Robust governance mechanisms support accountability and compliance.

Table 10. Continuous Improvement and Learning.

Codes	Sub-themes	Themes
Feedback systems	Learning loops	Improvement
Data-driven insights	Analytics	Learning
Process refinement	Optimization	Enhancement
Innovation cycles	Iterative development	Growth
Knowledge management	Information sharing	Learning culture
Performance reviews	Evaluation	Improvement
Adaptation	Flexibility	Continuous development

The findings reflected in this table show that continuous improvement and learning are essential for sustaining environmentally sustainable supply chains. Organizations must continuously adapt and refine their practices based on data and feedback.

The overall findings indicate that designing environmentally sustainable supply chains in the digital transformation era requires a holistic and integrated approach that combines technological innovation, strategic alignment, collaboration, and organizational change. Digital technologies serve as critical enablers, providing the tools and capabilities needed to enhance visibility, optimize processes, and support data-driven decision-making. However, the successful implementation of

sustainable practices also depends on factors such as leadership commitment, organizational culture, and stakeholder engagement. While significant progress has been made, challenges related to cost, complexity, and resistance to change continue to hinder the widespread adoption of sustainable supply chain practices. Addressing these challenges requires a comprehensive strategy that considers both internal and external factors, ensuring that sustainability is embedded within the core operations of the organization.

5. Discussion

The findings of the study provide a comprehensive understanding of how environmentally sustainable supply chains can be strategically designed in the digital transformation era, revealing a strong interdependence between technological capabilities, organizational alignment, and sustainability objectives. The discussion highlights that digital transformation is not merely a technological upgrade but a fundamental enabler of systemic change in supply chain management. The integration of digital tools such as advanced analytics, automation, and interconnected platforms has significantly enhanced visibility and transparency across supply chain networks, allowing organizations to move beyond reactive approaches toward proactive and predictive sustainability management. This shift has important implications, as it demonstrates that environmental sustainability can be effectively embedded into operational processes when supported by real-time data and intelligent decision-making systems. Organizations that leverage these capabilities are better positioned to anticipate inefficiencies, reduce resource consumption, and align environmental goals with performance outcomes.

A key insight emerging from the study is the central role of strategic alignment in ensuring the successful implementation of sustainable supply chain practices. The findings indicate that sustainability initiatives yield meaningful outcomes when they are integrated into the broader organizational strategy rather than treated as isolated or compliance-driven activities. This has significant implications for managerial practice, as it underscores the need for leaders to embed sustainability within core business objectives and align it with digital transformation initiatives. The alignment between sustainability and value creation, particularly in terms of cost efficiency, risk reduction, and competitive advantage, further reinforces organizational commitment and facilitates long-term adoption. This suggests that sustainability should be reframed as a strategic priority that contributes to overall business performance rather than an additional burden.

The discussion also emphasizes the importance of collaboration and network-level coordination in achieving sustainable supply chain outcomes. Given the interconnected nature of supply chains, individual organizational efforts are insufficient to address environmental challenges effectively. The findings demonstrate that digital platforms play a critical role in enabling collaboration by facilitating information sharing, coordination, and joint decision-making among supply chain partners. This has important implications for both theory and practice, as it highlights the need to move from firm-centric approaches to network-centric models of sustainability. Organizations must actively engage with suppliers, distributors, and other stakeholders to create shared value and collectively address environmental issues. At the same time, challenges related to trust, data sharing, and interoperability must be addressed to fully realize the benefits of collaborative digital ecosystems.

Another significant implication of the study is the role of innovation as a driving force behind sustainable supply chain transformation. The findings reveal that digital transformation fosters an environment conducive to experimentation and the development of innovative solutions that enhance sustainability. This includes not only technological innovations but also new business models and operational practices that prioritize resource efficiency and waste reduction. The integration of circular economy principles, supported by digital technologies, further illustrates how innovation can contribute to more sustainable and resilient supply chains. For practitioners, this highlights the importance of fostering a culture of innovation and investing in capabilities that support continuous improvement and adaptation.

The human and organizational dimensions identified in the study provide further depth to the discussion, emphasizing that technological advancements alone are insufficient to achieve sustainability goals. Organizational culture, employee engagement, and skill development emerged as critical factors influencing the success of sustainable supply chain initiatives. The findings suggest that organizations must prioritize change management and capacity-building efforts to ensure that employees are equipped to navigate the complexities of digital transformation and sustainability. This has implications for human resource management, as it highlights the need for targeted training programs, leadership development, and the creation of a sustainability-oriented organizational culture. Resistance to change and skill gaps remain significant barriers, and addressing these challenges is essential for the effective implementation of sustainable practices.

The study also underscores the evolving nature of performance measurement systems in the context of sustainability. Traditional metrics focused on cost and efficiency are increasingly being supplemented with environmental indicators, reflecting a broader understanding of organizational performance. The integration of sustainability metrics into performance evaluation systems has important implications, as it enables organizations to track progress, identify areas for improvement, and align individual and organizational objectives with sustainability goals. Digital technologies play a crucial role in facilitating this shift by providing the tools needed for data collection, analysis, and reporting. This highlights the importance of adopting a data-driven approach to sustainability, where decisions are informed by accurate and timely information.

External pressures, including regulatory requirements and market expectations, were also found to significantly influence sustainable supply chain practices. The discussion reveals that organizations are increasingly compelled to adopt sustainable practices in response to these pressures, and digital transformation provides the means to do so effectively. This has implications for policymakers and industry regulators, as it suggests that supportive regulatory frameworks and incentives can play a crucial role in accelerating the adoption of sustainable practices. At the same time, organizations must remain agile and responsive to changing external conditions, leveraging digital capabilities to adapt to evolving requirements and expectations.

The challenges identified in the study, such as high implementation costs, technological complexity, and data security concerns, provide important insights into the barriers to sustainable supply chain transformation. These challenges highlight the need for a strategic and phased approach to implementation, where organizations carefully assess their capabilities and resources before adopting new technologies. The discussion suggests that overcoming these barriers requires not only financial investment but also a clear vision, strong leadership, and effective governance mechanisms. Addressing data security and privacy concerns is particularly critical in the context of increased data sharing and digital integration, as these issues can undermine trust and hinder collaboration.

The implications of governance and policy frameworks are also significant, as they provide the structure and guidance needed to ensure the effective implementation of sustainability initiatives. The findings suggest that robust governance mechanisms, supported by digital technologies, can enhance accountability, transparency, and compliance across supply chain networks. This has implications for organizational design, as it highlights the need for clear roles, responsibilities, and processes to support sustainability efforts. Additionally, the alignment between organizational policies and external regulatory requirements is essential for ensuring consistency and coherence in sustainability practices.

The concept of continuous improvement and learning emerged as a critical element in sustaining environmentally sustainable supply chains. The discussion indicates that organizations must adopt an iterative approach, where they continuously monitor performance, learn from experiences, and adapt their strategies accordingly. Digital technologies facilitate this process by providing real-time feedback and enabling data-driven insights, which support ongoing optimization and innovation. This has implications for organizational learning and development, as it highlights the importance of creating systems and processes that support continuous improvement and knowledge sharing.

From a theoretical perspective, the study contributes to the understanding of how digital transformation intersects with sustainability in supply chain management. It provides a holistic view that integrates technological, organizational, and environmental dimensions, offering a comprehensive framework for analyzing sustainable supply chain practices. The findings suggest that future research should continue to explore the dynamic interactions between these dimensions, particularly in different industry and regional contexts. There is also a need to examine the long-term impacts of digital transformation on sustainability outcomes, as well as the potential trade-offs and unintended consequences associated with technological adoption.

From a practical perspective, the study offers valuable insights for managers and practitioners seeking to design and implement environmentally sustainable supply chains. It highlights the importance of adopting a strategic and integrated approach that aligns digital transformation with sustainability objectives. Organizations are encouraged to invest in digital capabilities, foster collaboration, and build a culture that supports sustainability and innovation. At the same time, they must address the challenges associated with implementation, including resource constraints, skill gaps, and organizational resistance. By taking a holistic and proactive approach, organizations can leverage digital transformation to achieve both environmental and business objectives.

6. Conclusions

The study concludes that designing environmentally sustainable supply chains in the digital transformation era requires an integrated and strategic approach that combines technological innovation, organizational alignment, and collaborative engagement. Digital technologies play a critical role in enhancing visibility, enabling data-driven decision-making, and optimizing resource utilization, thereby supporting environmental sustainability objectives. However, the successful implementation of such supply chains depends not only on technological adoption but also on leadership commitment, organizational culture, and stakeholder collaboration. The findings highlight that aligning sustainability with core business strategies and performance metrics strengthens long-term commitment and value creation. While digital transformation offers significant opportunities, challenges such as high implementation costs, technological complexity, and resistance to change must be carefully managed. Continuous improvement, supported by real-time data and learning mechanisms, is essential for sustaining progress. Overall, the study emphasizes that environmentally sustainable supply chains are achievable when organizations adopt a holistic perspective, leveraging digital capabilities while fostering innovation, governance, and shared responsibility across the supply chain network.

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