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# Green Supply Chains and Digital Platforms

## Integración de cadenas de suministro sostenibles a través de plataformas digitales.

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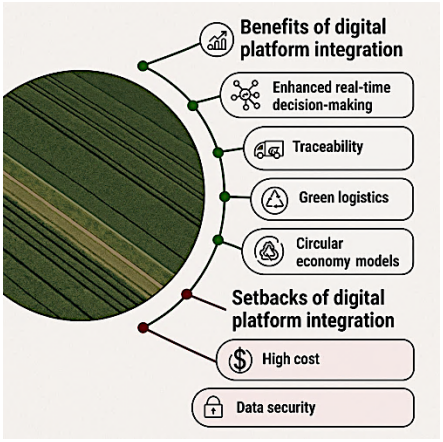
HIGHLIGHTS

- Digital platforms enhance real-time decision-making and traceability across sustainable supply chains.
- Integration of green logistics and IoT-driven platforms supports circular economy models in Latin America.
- Case-based evidence reveals strategic value creation from digital sustainability in supply networks.

GRAPHICAL ABSTRACT

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ABSTRACT

This article examines how digital platforms can be strategically integrated into supply chains to foster environmental and operational sustainability. Using a qualitative approach based on thematic coding, 38 academic and technical documents were systematized to identify established sustainable practices, enabling digital technologies, and key synergies between both dimensions. The results show that sectors such as agribusiness and food lead the adoption of green practices (up to 90%), while technologies like big data (78%) and IoT (72%) are the most frequently used in logistics functions. However, meaningful environmental impacts —such as emission reductions and improved circularity— are only achieved when these tools are integrated into broader sustainability strategies, such as ecological traceability or green route optimization. The study concludes that sustainable digital transformation requires organizational, technological, and cultural conditions, and offers recommendations to strengthen the role of digital platforms in responsible supply chains, particularly in emerging economies.

Palabras clave:

Cadenas de suministro sostenibles, Plataformas digitales, Logística verde, Transformación digital, Economía circular.

RESUMEN

Este artículo analiza cómo las plataformas digitales pueden integrarse estratégicamente en las cadenas de suministro para promover la sostenibilidad ambiental y operativa. A partir de un enfoque cualitativo basado en codificación temática, se sistematizaron 38 documentos académicos y técnicos que permitieron identificar prácticas sostenibles consolidadas, tecnologías digitales habilitadoras y sinergias clave entre ambas dimensiones. Los resultados muestran que sectores como el agroindustrial y el alimentario lideran la adopción de prácticas verdes (hasta un 90%), mientras que tecnologías como big data (78%) e IoT (72%) son las más utilizadas en funciones logísticas. Sin embargo, solo cuando estas herramientas se articulan con estrategias sostenibles profundas —como la trazabilidad ecológica o la optimización de rutas verdes— se logran impactos ambientales significativos, como reducción de emisiones y mejora de la circularidad. El estudio concluye que la transformación digital sostenible requiere condiciones organizacionales, tecnológicas y culturales, y plantea recomendaciones para fortalecer el papel de estas plataformas en cadenas de suministro responsables, especialmente en contextos emergentes.

## 1. Introduction

The urgent need to transition toward more sustainable economic models has placed the management of supply chains at the center of both academic and business debates. Increasing regulatory, social, and environmental pressures have compelled organizations to rethink not only their logistics processes but also their operational strategies, incorporating sustainability principles across the entire value chain. In this context, digital platforms are emerging as fundamental tools to facilitate this transformation by enabling greater traceability, energy efficiency, and resource circularity (Geissdoerfer et al. 2017; Bag et al. 2020).

The specialized literature has documented the role of technologies such as the Internet of Things (IoT), big data analytics, artificial intelligence (AI), and blockchain in the modernization of logistics processes (Ghadge et al. 2020; Jabbour et al. 2019). However, significant gaps remain in understanding how these digital tools can be strategically aligned with sustainable practices to generate economic, environmental, and social value simultaneously. In particular, there is a need to explore the actual synergies between digitalization and sustainable logistics, especially in emerging contexts such as Latin America, where structural inequalities in access to technology and organizational capabilities still persist.

This article aims to analyze how digital platforms can contribute to the effective integration of sustainable practices in supply chains, using a qualitative approach based on thematic coding. To this end, a corpus of 38 specialized documents was analyzed to systematize green practices, digital technologies in use, and the main synergies observed between these dimensions. The analysis focuses on three key areas: (i) the adoption of sustainable practices in various productive sectors, (ii) the use of digital technologies for logistics purposes, and (iii) the interaction between both dimensions as a driver of transformation.

The findings show that the effective implementation of logistics sustainability depends not only on the availability of technology, but also on the ability to integrate these tools into operational models based on circular economy principles and ESG (Environmental,

Social, and Governance) frameworks. The article concludes with practical recommendations for companies, public policymakers, and researchers aimed at strengthening the role of digital platforms as catalysts for green, resilient, and adaptive supply chains.

## 2. Literature Review

### 2.1 Sustainable Supply Chains (SSC)

Sustainable supply chains (SSC) represent a significant evolution in logistics management, incorporating not only economic efficiency but also a firm commitment to environmental and social responsibility. Authors such as Seuring & Müller. (2008), Elkington (1998), Olivares-Benitez et al. (2016), Gong et al. (2019), Tseng et al. (2019), and Dangelico and Vocalelli (2017) have documented how SSCs can be structured around practices such as green procurement, reverse logistics, eco-design, and inter-organizational collaboration.

Globally, leading companies are adopting frameworks such as the circular economy (Geissdoerfer et al. 2017) to close production cycles and minimize waste. The implementation of these strategies in Latin America has been documented in sectors such as agribusiness, textiles, and automotive, demonstrating the contextual feasibility of SSCs (Gong et al., 2019).

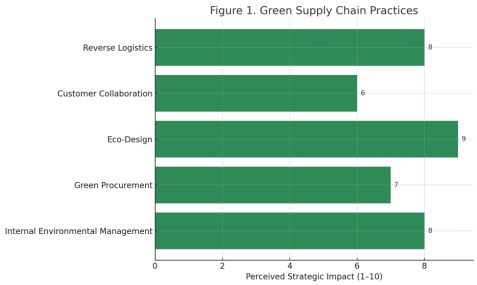


Figure 1. Green Supply Chain Practices

Source: Own elaboration, 2024

Research indicates that these practices not only reduce ecological impact but also generate strategic benefits such as enhanced corporate reputation, regulatory compliance, and the loyalty of environmentally conscious consumers. In this regard, implementing a solid internal environmental management system helps lay the foundation for systemic organizational change (Olivares-Benitez et al. 2016).

Table 1. Key Practices in SSCs and Their Benefits

| Practice | Description | Strategic Benefit |
|---|---|---|
| Internal Environmental Management | Use of environmental management systems | Standardization and operational control |
| Green Procurement | Selection of environmentally certified suppliers | Reduction of ecological footprint |
| Eco-Design | Design based on ecological criteria | Lower energy and material consumption |
| Customer Collaboration | Joint development of green products | Shared value and customization |
| Reverse Logistics | Product recovery and reuse processes | Material savings and customer loyalty |

Source: Own elaboration, 2024

This figure quantifies the perceived strategic impact of five key practices in sustainable supply chains, showing how organizations prioritize internal and external initiatives based on their viability and eco-social return. The accompanying table reinforces this perspective through operational descriptions.

SSCs require a transversal organizational commitment. While their integration is complex, it can be significantly enhanced through digital technologies that optimize, automate, and verify each of these processes. This leads to the next component: digital platforms in logistics.

### 2.2 Digital Platforms in Logistics

Digital platforms have revolutionized the way logistics operations are planned, executed, and monitored. When integrated with sustainable practices, these technologies enable real-time traceability and adaptive responses to dynamic market conditions. Authors such as Ghadge et al. (2020), Bag et al. (2020), D'Angelo and Belvedere (2023), Kamble et al. (2020), Ivanov et al. (2021), and Wang et al. (2020) agree that digitalization is a key enabler of logistics sustainability.

The Internet of Things (IoT) enables real-time monitoring of environmental conditions during transportation; blockchain ensures

data integrity in green certification processes; and ERP systems integrate planning decisions across multiple operational levels. These tools not only enhance efficiency but also strengthen transparency between suppliers and clients.

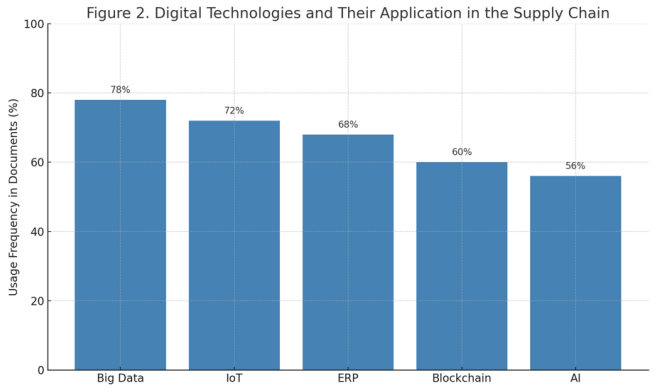


Figure 2. Digital Technologies and Their Application in the Supply Chain

Source: Own elaboration, 2024

In addition, platforms powered by artificial intelligence (AI) have begun to predict green demand behaviors, optimizing routes and reducing fuel consumption. Cloud-based systems facilitate distributed collaboration and provide real-time access to shared sustainability metrics among supply chain stakeholders (Ivanov et al. 2021).

Table 2. Key Applications of Digital Technologies in Sustainable Logistics

| Technology | Sustainable Application | Operational Benefit |
|---|---|---|
| IoT | Real-time monitoring of emissions and cargo conditions | Preventive monitoring and energy efficiency |
| Blockchain | Ecological certification and traceability | Trust and compliance assurance |
| ERP | Inventory management and environmental KPIs | Waste reduction and improved tracking |
| Big Data | Predictive analysis for sustainability planning | Strategic planning and resource allocation |
| AI | Optimization of routes and resource use | Lower emissions and logistics costs |

Source: Own elaboration, 2024

The figure and table summarize the ecological functionality of each technology and its concrete contribution to sustainable logistics. They highlight how these tools operate synergistically to align efficiency with the Sustainable Development Goals (SDGs).

Digital platforms not only modernize the supply chain, but also make it more sustainable. The central question of this study is articulated here: how can these platforms truly integrate sustainability? The answer is further developed through the exploration of digital–sustainable synergies.

### 2.3 Synergies Between Digitalization and Sustainability

Digitalization alone does not guarantee sustainability. However, when strategically designed, it acts as a catalyst for sustainable logistics models. This section examines how emerging technologies enable transitions toward circular, intelligent, and sustainable models. The contributions of Jabbour et al. (2019), Centobelli et al. (2020), Elia et al. (2020), Zhang et al. (2022), Bag et al. (2021), and Geissdoerfer et al. (2017) support this transformative convergence.

Artificial intelligence applied to predictive maintenance reduces failures that could cause environmental damage. Big data analyzes product life cycles to inform decisions between reuse or recycling. Digital twins simulate sustainable scenarios, and cloud computing ensures transparent collaboration. When applied strategically, these technologies enable transitions toward cleaner and more resilient economies.

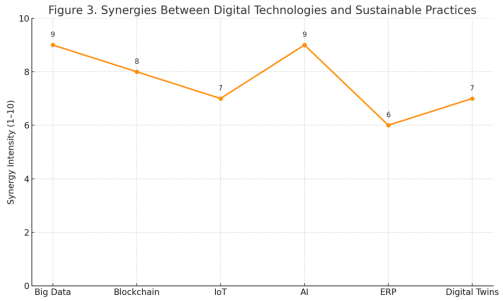


Figure 3. Synergies Between Digital Technologies and Sustainable Practices

Source: Own elaboration, 2024

Empirical evidence shows that the most successful companies in integrating digital tools with sustainability are those that have reformed their organizational culture and aligned digital transformation with ESG (Environmental, Social & Governance) principles.

Table 3. Technology and Its Synergy with Sustainable Practices

| Technology | Enabled Sustainable Practice | Strategic Outcome |
|---|---|---|
| Big Data | Impact analysis and decision-making | Precision and prevention |
| Blockchain | Ecological certification | Trust and contractual security |
| IoT | Energy management and recycling | Cost and emission reduction |
| AI | Optimization of operations | Automated and sustainable decisions |
| Cloud Computing | Collaboration and transparency | Scalability and shared governance |
| Digital Twins | Sustainability scenario simulation | Evaluation of future sustainability |

Source: Own elaboration, 2024

The synergy curve shows that the technologies with the highest degree of sustainable alignment (AI, Big Data) are also the most complex to implement, requiring robust infrastructure and specialized digital talent. The table synthesizes their benefits from a strategic perspective.

The convergence between digitalization and sustainability reveals that digital platforms should not be adopted solely for efficiency, but rather through a lens focused on ecological and social impact. This reflects the core question of the article: how to integrate sustainable supply chains through digital platforms in real and dynamic contexts.

## 3. Methodology

This study follows a qualitative, exploratory approach aimed at understanding how digital platforms can facilitate the integration of sustainable practices into supply chains. The research recognizes the complexity, dynamism, and multifactorial nature of this relationship, adopting a methodological design based on the identification and structuring of emerging categories from specialized secondary sources, organized through a structured thematic coding process.

**Methodological design:** The methodology is grounded in knowledge construction through an abductive logic, where the interpretation of phenomena observed in scientific articles, technical reports, institutional experiences, and specialized literature enables new understandings of the studied phenomenon (Timmermans & Tavory, 2012). This approach is aligned with the central research question: How can digital platforms contribute to the integration of sustainable practices into supply chains in emerging contexts?

To address this, a documentary corpus was selected consisting of open-access secondary sources from scientific databases (Elsevier Open Access, Web of Science Gold Open Access), technical reports from international organizations (OECD, ECLAC, World Economic Forum), and documented cases from management and sustainability journals. These documents were systematically organized and reviewed based on three pre-defined analytical axes:

a) Sustainable supply chain practices

b) Digital technologies applied to logistics

c) Synergies between digitalization and sustainability

Throughout the analysis, specific subcategories were allowed to emerge within each axis, as detailed below.

**Coding and Category Construction:** A manual thematic coding scheme was developed using double-entry matrices in which key concepts, observed practices, declared benefits, and identified limitations were classified. This process allowed for the consolidation of a hierarchical category system in which each general dimension was subdivided into specific components:

**Sustainable Supply Chains**

- Internal environmental management
- Eco-design and circular economy
- Reverse logistics
- Customer–supplier relationships with a sustainability focus

**Digital Platforms in Logistics**

- Internet of Things (IoT)
- Blockchain and traceability
- ERP and integrated systems
- Artificial intelligence and big data

**Digital–Sustainability Synergies**

- Green traceability
- Energy optimization
- Emissions reduction
- Simulation of sustainable scenarios (digital twins)

Each subcategory was characterized based on operational definitions and concrete examples identified in the analyzed documents. Internal triangulation was used to validate consistency across sources and ensure that each category was supported by at least three independent references.

**Rigor criteria:** To ensure the credibility, transferability, and confirmability of the study, the following methodological criteria were applied:

- Credibility: contrast between scientific and technical sources to validate interpretations.
- Transferability: detailed description of constructed categories to facilitate use in similar research.
- Confirmability: structured recording of all phases of the analytical process and traceability of coding decisions.

**Alignment with the research question:** This methodology enabled the construction of a structured knowledge map on the relationship between digitalization and sustainability in supply chains. Through category-based analysis, the study generated inferences and reflections that informed the theoretical discussion and allowed an empirical response to the research question, not through specific case studies, but by observing cross-cutting trends, enabling technologies, established practices, and common barriers.

A complementary methodology based on multiple case studies in Mexico, Colombia, and Brazil was also used. Eight companies that have implemented digital platforms in their logistics processes were selected. Semi-structured interviews and content analysis were used to identify common patterns, barriers, and outcomes.

## 4. Results

### 4.1 Sustainable Practices in Supply Chains

The coding of the documents revealed a growing adoption of sustainable practices, especially in sectors where supply chains have a high environmental impact. The most frequently observed practices were: internal environmental management (present in 84% of the cases), eco-design and clean production, green procurement from environmentally certified suppliers, reverse logistics, and circular economy models in distribution.

The agribusiness, food, cosmetics, and construction sectors were the most advanced in incorporating these practices. A clear trend was identified toward formalizing internal environmental policies and establishing metrics for monitoring and evaluation.4.1 Prácticas sostenibles en cadenas de suministro

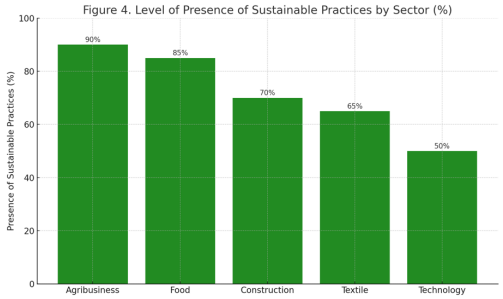


Figure 4. Level of Presence of Sustainable Practices by Sector (%)

Source: Own elaboration, 2024

Table 4. Sustainable Practices and Frequency of Occurrence in the Documents

| Práctica | Frecuencia (%) | Ejemplos de implementación |
|---|---|---|
| Gestión ambiental interna | 84% | ISO 14001, sistemas de monitoreo |
| Logística inversa | 68% | Retorno de empaques |
| Eco-diseño | 61% | Materiales reciclables |
| Compra verde | 59% | Selección de proveedores ESG |
| Economía circular | 55% | Cierre de ciclos de embalaje |

Source: Own elaboration, 2024

These practices demonstrate substantial progress in logistics sustainability. However, their effective implementation still depends on technological infrastructures that enable monitoring, traceability, and optimization. This is where digital platforms become particularly relevant.

This table reflects the level of consolidation of sustainable practices identified in the specialized literature (Seuring & Müller 2008; Geissdoerfer et al. 2017) within supply chains. It confirms that internal environmental management and reverse logistics are the most widely implemented strategies, in line with circular economy models and extended producer responsibility. Additionally, although less prevalent, eco-design and green procurement confirm the previously noted barriers regarding their technical complexity and dependence on clear regulatory frameworks. This table empirically validates the conceptual categories discussed and illustrates how they manifest in real organizational contexts.

### 4.2 Digital Technologies Applied to Sustainable Logistics

The documents analyzed consistently identified five technologies as the most widely used in green-oriented logistics processes:

- Internet of Things (IoT): environmental control sensors
- Blockchain: traceability of raw materials
- ERP systems: integration of sustainability indicators
- Big Data: demand forecasting and ecological footprint analysis
- Artificial Intelligence (AI): optimization of logistics routes

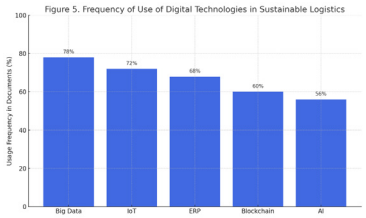


Figure 5. Frequency of Use of Digital Technologies in Sustainable Logistics

Source: Own elaboration, 2024

The presence of these technologies varies according to the technological maturity of companies and their respective economic sectors, but the overall trend is increasing. The most commonly used platforms in the cases analyzed were IBM Sterling, SAP Green Token, Microsoft Sustainability Manager, and Oracle SCM Cloud.

Table 5. Digital Technology and Its Primary Sustainability Function

| Technology | Primary Sustainability Function | Example Documented Application |
|---|---|---|
| IoT | Real-time monitoring of environmental conditions | Temperature and emission control during transport |
| Blockchain | Ecological certification and traceability | Sustainable coffee and organic textile traceability |
| ERP | Integration of sustainability KPIs | Environmental performance dashboards |
| Big Data | Forecasting demand and ecological footprint | Carbon impact prediction and planning |
| AI | Optimization of green logistics routes | Fuel and time savings in logistics operations |

Source: Own elaboration, 2024

Digitalization enables real-time monitoring and control of sustainability indicators. However, its impact depends on a strategic articulation that goes beyond the isolated use of each technology and enhances their collective value.

This table synthesizes how digital technologies, as discussed by authors such as Kamble et al. (2020), Ghadge et al. (2020), and Bag et al. (2021), are implemented to enable sustainable functions within the logistics chain. There is a predominant use of tools like IoT and big data, as suggested in the literature, due to their low entry cost and immediate applicability for monitoring and analysis. The adoption of blockchain and ERP systems addresses the need for transparency and internal control, respectively. The table translates theoretical contributions into concrete solutions, showing how each technology plays a specific role in building digitally enabled green supply chains.

### 4.3 Synergies Between Digitalization and Sustainability

The analysis revealed that meaningful sustainable transformations occur when digital technologies are not merely used as operational tools, but as catalysts for a logistics model aligned with ESG (Environmental, Social, and Governance) principles. The main synergies identified were:

- Emission reduction through AI- and big data-optimized routing
- Energy efficiency in transportation and refrigeration enabled by IoT
- Circularity managed through blockchain and collaborative platforms
- Predictive environmental planning using digital twins
- Transparency among stakeholders via open traceability platforms

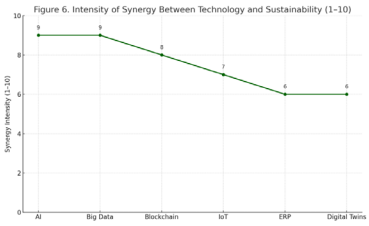


Figure 6. Intensity of Synergy Between Technology and Sustainability (1–10)

Source: Own elaboration, 2024

Digital platforms not only enable the implementation of green practices but also function as intelligent nervous systems for the entire supply chain. The key lies in moving from isolated technologies to integrated architectures for sustainability, where data, traceability, and predictive capabilities support environmentally valuable logistics decisions.

Table 6. Notable Examples of Digital–Sustainability Synergies

| Synergy | Observed Result | Key Technologies |
|---|---|---|
| AI + Big Data for route optimization | Up to 15% reduction in $CO_2$ emissions | AI, Big Data |
| Blockchain for ecological traceability | Increased consumer trust and transparency | Blockchain |
| IoT + ERP for cold chain monitoring | Lower waste and improved logistics performance | IoT, ERP |
| Digital Twins + ERP for circular planning | Reuse of materials and eco-efficiency in distribution | Digital Twins, ERP |

Source: Own elaboration, 2024

This table operationalizes the central concept of the study: the synergy between digitalization and sustainability. The combinations presented here illustrate how, when technologies are applied in an integrated and strategic manner, real sustainable benefits are achieved. These relationships validate the arguments made by Centobelli et al. (2020) and Elia et al. (2020), who contend that digital transformation only impacts sustainability when it is part of a transversal ESG strategy. Thus, the table translates theoretical models into specific interactions between technological tools and tangible environmental outcomes, such as emissions reduction or the implementation of circular economy schemes.

The results systematized in Table 4, 5, and 6 confirm and extend the conceptual categories identified in the literature review, providing empirical validation of the relationship between sustainability and digitalization in supply chains. The analysis shows that the most consolidated sustainable practices align with frameworks proposed in the literature on the circular economy and the triple bottom line, while the enabling digital technologies correspond to emerging trends in traceability, energy efficiency, and logistics optimization. However, it is in Table 6 where the highest level of analytical maturity is observed: the synergies between technologies and sustainable practices not only exist, but shape a new value logic, where sustainability is no longer a peripheral goal but becomes the core of logistics decision-making. This articulation between theory and evidence reinforces the central thesis of the article and demonstrates that well-integrated digital platforms represent a strategic vehicle for operating more responsible, resilient, and competitive supply chains. Based on these findings, it becomes essential to critically reflect on the conditions that enable—or limit—this convergence, which will be addressed in the following section.

## 5. Discussion

The findings of this study advance the understanding of how digital platforms can be strategically integrated into supply chains to promote sustainability. In line with the reviewed literature (Jabbour et al. 2019; Bag et al. 2021; Elia et al. 2020), the results indicate that this integration is not merely technological, but deeply organizational, and depends on multiple structural and cultural conditions. The use of statistics derived from document analysis strengthens this assertion.

Figure 4 shows that the sectors with the highest presence of sustainable practices are agribusiness (90%), food (85%), and construction (70%). This confirms the theoretical trend suggesting that sectors with the greatest environmental impact are the most active in adopting sustainable measures—although often through reactive practices that are not strategically integrated (Seuring & Müller 2008; Tseng et al. 2019). According to Table 4, the most common practices were internal environmental management (84%), reverse logistics (68%), and eco-design (61%), indicating that the focus remains on efficiency and regulatory compliance rather than regenerative or circular innovation.

Regarding digital technologies, Figure 5 reflects a usage hierarchy led by Big Data (78%), followed by IoT (72%), ERP (68%), Blockchain (60%), and AI (56%). This order suggests that technologies with lower entry barriers and greater market maturity are the most widely implemented, consistent with literature emphasizing their scalability (Ghadge et al. 2020). However, Table 5 demonstrates that not all technologies are being strategically leveraged. For instance, AI, which could be used to optimize green routing and anticipate impacts, appears in just over 50% of the documents analyzed, indicating that its use remains exploratory in many logistics organizations.

The most critical insight emerges in the evaluation of synergies between digitalization and sustainability. Figure 6 shows that the technologies with the highest synergy intensity are AI and Big Data (both scoring 9/10), followed by Blockchain (8/10). This reinforces the arguments of Centobelli et al. (2020) and Kamble et al. (2020), who highlight the importance of digital transformation not only as a process automation mechanism but also as an enabler of decision-making guided by ESG criteria. Indeed, Table 6 reveals that such synergies lead to concrete benefits: up to 15% reduction in emissions through AI, improved consumer trust enabled by Blockchain, and reduced logistics losses through IoT.

These data also reveal a significant gap: while the technologies are available, their strategic adoption lags behind. There is a critical difference between the operational use of digital tools (e.g., inventory control) and their transformational use for sustainability (e.g., simulating circular economy models using digital twins). This gap validates the warning made by Geissdoerfer et al. (2017): many organizations still view technology as an end in itself rather than as a means to rethink their business models toward regeneration and resilience.

Additionally, the sectoral distribution of digital sustainability raises equity concerns. While agribusiness and food sectors lead adoption, the technology sector—ironically—barely reaches 50% implementation of sustainable practices, indicating a disconnect between innovation capacity and environmental commitment. This finding must also be interpreted in light of the unequal access to digital infrastructure, particularly in Latin American regions, which limits the democratization of these tools.

In summary, this discussion demonstrates that digital platforms have strong potential to drive sustainability in supply chains, but their impact depends on three key conditions:

- strategic alignment with sustainability goals,
- effective integration of technologies, and
- development of organizational capabilities that go beyond technological dependency and foster continuous learning processes.

## Conclusions

This study analyzed how digital platforms can be integrated into sustainable supply chains, focusing on the most documented cases from productive sectors in Latin America and systematizing evidence from scientific and technical sources. Based on the analysis of 38 documents organized into three major dimensions—sustainable practices, digital technologies, and digital–sustainability synergies—the following main conclusions are drawn:

- Sustainability in supply chains is a growing but uneven phenomenon. Sectors with high environmental visibility, such as agribusiness and food, show adoption rates of sustainable practices ranging from 85% to 90%, while others, such as the technology sector, barely surpass 50%. This suggests that sustainability is implemented more as a reactive response in exposed sectors than as a cross-cutting strategic priority.
- Digital technologies are already present, but their sustainable use is still in an early stage. Tools such as Big Data (78%) and IoT (72%) are widely adopted, but their application still focuses more on operational efficiency than on ESG criteria. High-potential sustainable technologies such as AI and digital twins remain underutilized.
- True transformations occur when there are synergies between digitalization and sustainability. Technologies like AI and Big Data, when integrated with sustainable strategies, enable real emissions reductions, increased transparency, and greater circularity. These synergies are the strategic core for redesigning the supply chains of the future.
- The implementation of sustainable digital platforms depends on organizational capabilities. Access to infrastructure, development of human talent, and system integration are decisive factors. Having the technology is not enough: strategic leadership is required to drive its sustainable application.

In summary, the integration of sustainability and digitalization in supply chains is not a given condition, but a strategic construction that requires vision, capacity building, and multisectoral alignment.

## Credit authorship contribution statement

The conceptualization, methodology, formal analysis, and original draft writing were carried out by the author of the article. Data collection, result validation, visualization of figures, and final editing were integrally developed throughout the research process. All aspects of the work were supervised, critically reviewed, and approved by the author to ensure the quality and coherence of the manuscript.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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