International Journal of Digitalization and Applied Management

Journal homepage:
https://ojs.nmdjournals.org/index.php/ijdam
ISSN: 2976-0453

The Role of Industry 4.0 in Sustainable Supply Chain: A Systematic Literature Review

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Article Info

Keywords:
Industry 4.0; Sustainable Supply Chain; PRISMA; Digital Transformation; Circular Economy; Systematic Literature Review.

JEL Classification :
L23, M11, M15, O32, O33, Q01, Q55

Received 10 November 2025
Accepted 30 November 2025
Published 21 January 2026

Abstract

In recent years, companies have increasingly turned to Industry 4.0 (I4.0) technologies to enhance supply chain performance while meeting sustainability requirements. Despite growing interest, the specific mechanisms through which I4.0 supports Sustainable Supply Chain Management (SSCM) remain insufficiently explored. This study addresses this gap by conducting a systematic literature review (SLR), following the PRISMA protocol, of peer-reviewed articles published between 2019 and 2024. The review identified 20 high-quality studies that investigate the interplay between digital technologies and SSCM. The findings show that I4.0 technologies, particularly the Internet of Things (IoT), Big Data analytics, artificial intelligence (AI), and blockchain, contribute to sustainability through four mechanisms: data acquisition, data processing, performance monitoring, and decision support. These mechanisms enhance environmental sustainability by reducing emissions and waste, strengthen social sustainability by improving working conditions and stakeholder trust, and support economic sustainability by lowering costs, improving forecasting, and increasing resilience. The study contributes theoretically by bridging the literature on I4.0 and SSCM, clarifying how digitalization enables sustainability, and highlighting contextual moderators such as organizational culture, IT maturity, and supplier readiness. From a managerial perspective, the results emphasize the importance of aligning digital transformation with sustainability strategies, engaging suppliers, and implementing robust data governance. Overall, the review demonstrates that I4.0 is not merely a technological upgrade but a transformative enabler of sustainable, resilient, and competitive supply chains.

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DOI : https://doi.org/10.23882/ijdam.26241

Peer-review under responsibility of the scientific committee of the IJDAM Review

1. Introduction

Building sustainable supply chains has become a strategic priority in the contemporary global economy, particularly in the wake of large-scale disruptions such as the COVID-19 pandemic and the Russia–Ukraine conflict. These crises exposed structural vulnerabilities in global value chains, including excessive geographical concentration, limited visibility, and insufficient coordination among supply chain partners. As a result, firms and policymakers increasingly recognize the need for supply chains that are not only cost-efficient but also resilient, transparent, and resource-efficient. In parallel, the emergence of Industry 4.0 (I4.0) technologies—such as the Internet of Things (IoT), Big Data analytics, artificial intelligence (AI), blockchain, and advanced automation—has accelerated digital transformation across supply chains, offering new capabilities to monitor, coordinate, and optimize material and information flows in real time.

At the same time, sustainability has evolved from a voluntary corporate initiative into a strategic and institutional imperative. Firms are facing mounting pressure from regulators, customers, investors, and other stakeholders to integrate environmental protection and social responsibility into supply chain operations. While traditional supply chain management (SCM) research has extensively examined practices related to lean management, green supply chains, and supply chain resilience, the role of digital technologies as systematic enablers of sustainability remains insufficiently theorized. Existing studies largely emphasize the operational and economic benefits of I4.0 adoption—such as productivity improvements, cost reduction, and risk mitigation—whereas its contributions to environmental and social sustainability dimensions are more fragmented and unevenly explored.

This situation reveals both a theoretical gap and an empirical gap in the literature. From a theoretical perspective, prior research lacks an integrated framework explaining how different I4.0 technologies collectively enable sustainable supply chain management (SSCM) and through which underlying mechanisms—such as enhanced data visibility, real-time performance monitoring, and decision-support capabilities—these effects occur. From an empirical perspective, the literature remains dispersed across industries, regions, and sustainability dimensions, making it difficult to identify consistent patterns, dominant technologies, or contextual conditions that shape successful outcomes. Consequently, managers and researchers face uncertainty regarding which digital investments most effectively support sustainability objectives and under what organizational or supply chain conditions these investments yield the greatest impact.

Against this background, a systematic synthesis of the existing literature is needed to consolidate current knowledge and clarify the interrelationship between Industry 4.0 and SSCM. Accordingly, this study addresses the following overarching research question:

RQ: How does the adoption of Industry 4.0 technologies enhance sustainability in supply chains?

To operationalize this question, four sub-questions are formulated:

1. Which specific Industry 4.0 technologies contribute most significantly to supply chain sustainability?

2. Through which mechanisms (e.g., data integration, performance monitoring, decision support) do these technologies influence sustainable supply chain practices?
3. What organizational and supply chain factors (e.g., digital culture, IT infrastructure, supplier readiness) moderate the effectiveness of Industry 4.0 in promoting sustainability?
4. How can firms strategically integrate Industry 4.0 technologies and SSCM practices to achieve long-term competitive advantage?

By adopting a systematic literature review (SLR) in accordance with the PRISMA framework, this study provides a transparent and structured synthesis of recent scholarly contributions. The review identifies converging findings, conflicting evidence, and underexplored research areas, and it proposes an integrative conceptual framework linking Industry 4.0 technologies to sustainability outcomes across supply chains. The originality of this study lies in its dual contribution: first, it advances theory by clarifying the mechanisms through which digital technologies enable sustainable supply chain outcomes; second, it offers actionable insights for practitioners seeking to align digital transformation initiatives with sustainability and resilience objectives.

2. Theoretical framework

2.1. Industry 4.0

Industry 4.0 (I4.0), commonly described as the fourth industrial revolution, refers to the integration of advanced digital technologies into industrial and supply chain systems. Unlike previous industrial paradigms, I4.0 is characterized by the convergence of cyber–physical systems, real-time data exchange, and interconnected digital networks across organizational boundaries. Through this integration, supply chains become increasingly data-driven, transparent, and adaptive, enabling firms to respond more effectively to uncertainty, complexity, and sustainability challenges.

From a supply chain perspective, Industry 4.0 facilitates enhanced visibility, coordination, and decision-making across production and logistics processes. Prior studies emphasize that the adoption of digital technologies associated with I4.0 can improve resource allocation, operational transparency, and responsiveness, while also enabling new business models and value-creation mechanisms (Pereira et al., 2017; Nicolae et al., 2019). In this context, I4.0 technologies constitute a foundational enabler for the digital transformation of supply chains and provide the technological basis for integrating sustainability objectives into supply chain management.

Figure 1 illustrates the main Industry 4.0 technologies and their representative applications within supply chain contexts.

Figure 1: Applications of I4.0 technologies in SC

Source : *Karmaker, C. L., Al Aziz, R., Ahmed, T., Misbauddin, S. M., & Moktadir, M. A. (2023).*

While the preceding theoretical discussion identified the core technologies underpinning Industry 4.0, a systematic literature review also requires clarifying how these technologies are operationalized within supply chain contexts. Table 1 serves this purpose by translating abstract Industry 4.0 concepts into analytically observable categories, linking each technology to its dominant application domains, expected supply chain performance outcomes, and illustrative empirical cases reported in prior studies.

Rather than providing anecdotal evidence, Table 1 plays a structuring role within the theoretical framework of this review. It operationalizes the technological dimension of Industry 4.0 and establishes a consistent analytical lens for examining how digital technologies enable key supply chain capabilities—such as visibility, coordination, flexibility, and responsiveness—that are foundational to sustainable supply chain management. By synthesizing applications and benefits across industries, the table supports subsequent thematic analysis and facilitates comparison across technologies, sustainability mechanisms, and empirical contexts.

Table1: Industry 4.0 Technologies, Applications in Supply Chain Management, and Real Company Examples

Technology	Practical Applications in Industry	Supply Chain Benefits	Company Examples
IoT (Internet of Things) & Sensors	Real-time monitoring of inventory, transport conditions, temperature, and freshness	Improved visibility, reduced waste, optimized inventory control	**Walmart** (IoT sensors for food freshness), **Maersk** (IoT for container tracking)
Big Data & Analytics	Demand forecasting, optimization of production planning, customer behavior analysis	Accurate planning, reduced bullwhip effect, cost savings	**Amazon** (predictive analytics for demand), **UPS** (route optimization with big data)
Blockchain	End-to-end product traceability, verification of suppliers, smart contracts	Transparency, fraud reduction, faster transactions	**IBM & Maersk (TradeLens)** for global shipping, **Carrefour**

			(blockchain for food traceability)
Robotics & Automation	Automated warehouses, robotic picking, packaging, handling	Increased efficiency, reduced lead times, improved accuracy	**Amazon Robotics (Kiva systems)** in warehouses, **Zara/Inditex** (automated logistics centers)
3D Printing (Additive Manufacturing)	On-demand production of spare parts, decentralized production	Reduced stockholding, faster prototyping, increased flexibility	**General Electric (GE)** (aircraft spare parts), **BMW** (custom tools & car parts)
Artificial Intelligence (AI) & Machine Learning	Predictive maintenance, intelligent delivery routing, demand sensing	Higher efficiency, reduced downtime, data-driven decisions	**Siemens** (predictive maintenance in factories), **DHL** (AI for route optimization)
Cyber-Physical Systems (CPS)	Integration of physical assets with digital control	Real-time responsiveness and system coordination	**Bosch** (smart manufacturing CPS integration), **Tesla** (connected production systems)
Cloud Computing	Centralized data storage and real-time collaboration	Improved partner collaboration, scalability, and accessibility	**Unilever** (cloud for supply chain planning), **Procter & Gamble** (SAP cloud systems)
Augmented Reality (AR) & Virtual Reality (VR)	Training workers, remote assistance, warehouse navigation	Safer operations, reduced training time, fewer errors	**DHL** (AR smart glasses for picking), **Boeing** (AR for aircraft wiring assembly)
Drones & Autonomous Vehicles	Last-mile delivery, warehouse inventory scanning	Faster delivery, cost savings, reduced errors	**Amazon Prime Air** (drone delivery), **JD.com (China)** (autonomous delivery vehicles)
Renewable Energy & Smart Grids	Integration of clean energy in factories and logistics hubs	Reduced carbon footprint, long-term savings, regulatory compliance	**Tesla Gigafactories** (solar-powered production), **IKEA** (renewable-powered logistics)

Source: Authors

2.2. Sustainable supply chain management

Sustainable supply chain management (SSCM) extends beyond traditional efficiency-driven SCM by incorporating environmental, social, and economic dimensions. Seuring and Müller (2008) define SSCM as the integration of material, information, and financial flows while simultaneously addressing sustainability goals across the triple bottom line. This involves practices such as eco-design, green procurement, waste reduction, closed-loop logistics, and stakeholder engagement.

Recent pressures from regulatory frameworks, consumers, and investors have accelerated the adoption of sustainability-oriented practices. Importantly, studies indicate that supply chains account for a significantly larger share of a firm's environmental impact compared to internal operations alone. As a result, SSCM is increasingly viewed not only as a compliance requirement but also as a source of long-term competitive advantage, enhancing resilience, reputation, and stakeholder trust.

The increasing effect of supply chain operations on non-renewable resources and global warming is prompting businesses to evaluate the significance of sustainability in their supply chain processes

(Narimissa et al.,2020). Moreover, current pressures from government regulations and laws, consumers with their growing concerns, investors, and other stakeholders are pushing organizations to integrate sustainability concepts into their decision-making objectives (Jian et al.,2019). This growing awareness and the need to address the issue of sustainability in their operations has led to the advent of the concept of Sustainable Supply Chain, which is defined as: "The management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements" (Seuring et al.,2008). Simply put, the Sustainable Supply Chain principle logically emphasizes the need to address economic, social, and environmental dimensions

3. Industry 4.0 and Sustainable Supply Chain Management (SSCM)

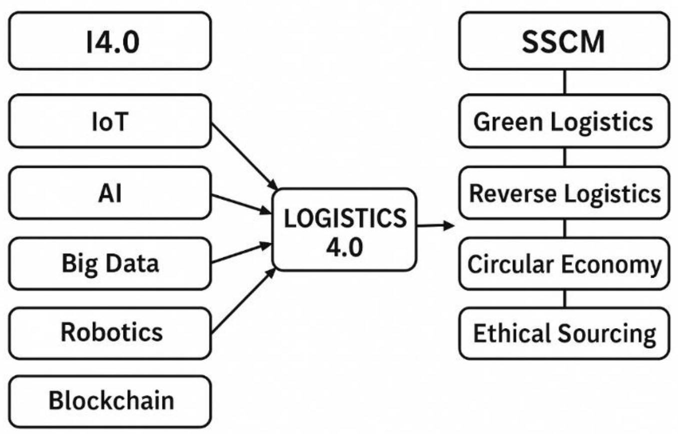
The integration of I4.0 and SSCM has become a focal point in recent literature, as digital technologies are increasingly recognized as enablers of sustainability. Scholars argue that I4.0 tools enhance environmental outcomes by reducing waste and emissions (e.g., IoT-enabled logistics optimization), support social sustainability through improved working conditions (e.g., automation reducing repetitive tasks), and strengthen economic performance via efficiency gains (Khan et al., 2023; Karmaker et al., 2023).

Theoretical perspectives such as the Resource-Based View (RBV) and the Practice-Based View (PBV) provide explanatory lenses for this integration. While the RBV emphasizes the role of unique resources and capabilities in generating competitive advantage, the PBV highlights the importance of systematic practices—such as digital adoption and green supply chain initiatives—in achieving superior performance. Within this framework, I4.0 technologies act as dynamic enablers that operationalize SSCM principles across supply chains.

However, despite growing academic interest, several gaps persist. First, the literature remains fragmented, with many studies focusing on individual technologies (e.g., blockchain or AI) without examining their combined effects. Second, empirical evidence on the mediating role of SSCM practices between I4.0 adoption and sustainability performance is still limited. Third, contextual factors—such as organizational culture, digital maturity, and supplier readiness are often overlooked, though they critically influence implementation outcomes.

For example, logistics 4.0 systems supported by IoT sensors and predictive analytics enable companies to reduce their carbon footprint by optimizing transportation routes and minimizing fuel consumption, directly contributing to green logistics. Similarly, blockchain technology enhances transparency and traceability across the supply chain, ensuring compliance with environmental regulations and fostering stakeholder trust. As Khan et al. (2023) underline, the synergy between I4.0 and SSCM not only reduces environmental risks but also positions companies to respond proactively to institutional pressures for sustainability. Therefore, the convergence of digital transformation and sustainability represents a paradigm shift, where technological innovation and environmental responsibility are no longer considered separately but rather as mutually reinforcing dimensions of modern supply chains.

Figure 2: conceptual framework



Source: Authors

Building on the technological operationalization presented in Table 1, this study further examines how Industry 4.0 adoption translates into sustainability outcomes across multiple organizational dimensions. While Table 1 focuses on the application domains and performance-related benefits of individual technologies, Table 2 shifts the analytical focus toward sustainability by mapping Industry 4.0 technologies and practices onto the economic, social, operational, and organizational dimensions of sustainable supply chain management.

By structuring the evidence along these four dimensions, Table 2 highlights the multidimensional nature of sustainability impacts enabled by digital technologies. This perspective allows for a systematic comparison of how different Industry 4.0 technologies contribute not only to efficiency and cost reduction but also to workforce well-being, organizational learning, and process integration. In doing so, Table 2 complements the technology-oriented overview of Table 1 and provides an integrative lens for interpreting the broader sustainability implications of Industry 4.0 adoption in supply chains.

Table 2: Multidimensional sustainability impacts of Industry 4.0 technologies in supply chain management

Technology / Practice	Economic Dimension	Social Dimension	Operational Dimension	Organizational Dimension
IoT Sensors (Internet of Things)	Reduction of raw material losses (e.g., food distribution: monitoring stocks and expiration dates)	Improved food safety for consumers	Real-time monitoring of logistics flows	Supports decision-making through reliable data

Big Data & Analytics	Cost optimization (reduced waste, better demand forecasting)	Increased transparency for stakeholders (traceability)	Anticipation of shortages and proactive planning	Promotes data-driven culture and adoption of sustainable KPIs
Blockchain	Fraud reduction and increased trust in transactions	Enhanced safety and transparency for consumers and producers	Full traceability of the supply chain	Stronger collaboration between partners through secure information sharing
Robotics & Automation	Lower production costs by automating repetitive tasks	Improved working conditions by reducing physical strain	Increased reliability and reduced human error	Redefinition of roles and upskilling of employees
3D Printing (Additive Manufacturing)	Reduced prototyping and small-batch production costs	Product customization to meet specific needs	Shorter lead times and greater production flexibility	New business models (on-demand production)
Artificial Intelligence (AI)	Process optimization (predictive maintenance, resource planning)	Better customer experience through personalization	Reduced downtime and increased efficiency	Digital transformation of management and decision-making
Renewable Energy Integrated in Smart Factories	Lower long-term energy costs	Social commitment to environmental protection	Cleaner production and reduced emissions	Alignment with CSR strategies and improved corporate image

Source : Authors

4. Methodology

4.1. Research Design

This study adopts a Systematic Literature Review (SLR) to provide a rigorous, transparent, and replicable synthesis of existing research on the relationship between Industry 4.0 (I4.0) and Sustainable Supply Chain Management (SSCM). The SLR approach is particularly appropriate for consolidating fragmented knowledge, identifying dominant research streams, and uncovering theoretical and empirical gaps in an emerging interdisciplinary field.

To ensure methodological rigor and transparency, the review follows the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Page et al., 2021). PRISMA provides a structured framework for the identification, screening, eligibility assessment, and inclusion of studies, thereby minimizing selection bias and enhancing the replicability of the review process.

4.2. Database Selection and Search Strategy

The literature search was conducted across four major academic databases recognized for their coverage and quality: Scopus, Web of Science (WoS), ScienceDirect, and Cairn.info. These databases were selected to ensure comprehensive coverage of both international and francophone research outputs.

The search strings were designed around three clusters of keywords, combining synonyms and related terms using Boolean operators (AND, OR):

•Cluster 1 (Industry 4.0): "Industry 4.0" OR "Digital manufacturing" OR "Smart factory"
•Cluster 2 (Logistics 4.0 / Supply Chain): "Supply Chain 4.0" OR "Digital supply chain" OR "Logistics 4.0"
•Cluster 3 (Sustainability): "Sustainable supply chain" OR "Green supply chain management" OR "Circular economy".

This systematic search yielded an initial pool of 423 documents (Scopus = 300, ScienceDirect = 80, Cairn.info = 40, WoS = 3).

4.3. Inclusion and Exclusion Criteria

To ensure relevance and quality, several inclusion and exclusion criteria were applied:

•Inclusion criteria:

- ✓ Peer-reviewed journal articles or review papers
- ✓ Published between 2019 and 2024 (to capture the most recent and mature developments in I4.0 and SSCM)
- ✓ Written in English or French
- ✓ Explicitly addressing the intersection between I4.0 technologies and SSCM practices

•Exclusion criteria:

- ✓ Articles published before 2019
- ✓ Non-peer-reviewed sources (conference abstracts, working papers, reports)
- ✓ Studies focusing solely on I4.0 or sustainability without linking both domains

The decision to start from 2019 is motivated by the rapid technological evolution of I4.0, as earlier studies were largely conceptual rather than empirical, and by the transformative impact of the COVID-19 pandemic on supply chains.

4.4. Screening Process

The PRISMA four-step process was followed:

1.Identification: 423 records initially identified.
2.Screening: After removing duplicates and irrelevant items, 258 documents remained.
3.Eligibility: Titles, abstracts, and keywords were screened; 60 studies were considered potentially relevant.
4.Inclusion: After full-text review, 20 high-quality articles were retained for in-depth analysis.

A PRISMA flow diagram bellow illustrates this selection process, ensuring transparency and replicability.

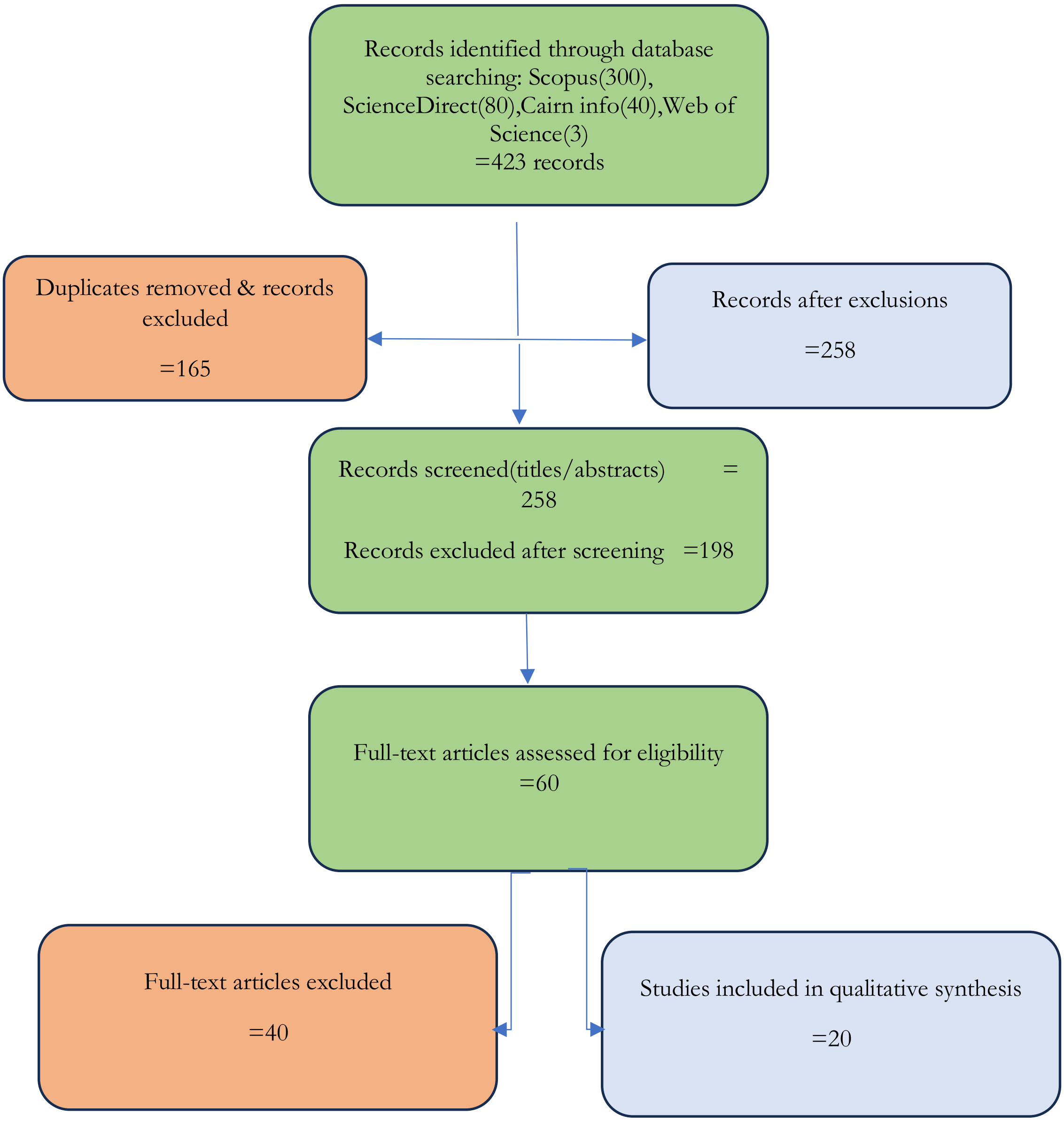
4.5. Data Extraction and Analysis

For each selected study, relevant information was extracted, including:

- Authors, year, and country of study
- Research methodology (empirical, conceptual, mixed)
- Technologies of Industry 4.0 investigated
- Sustainability dimensions addressed (economic, environmental, social)
- Main findings and contributions

The data were then systematically coded and synthesized to identify recurring patterns, emerging themes, and gaps in the literature. Zotero software was used for reference management and to avoid duplication during the screening process.

Figure 3: PRISMA Process



Source : Authors

5. Results and discussion

Beyond the descriptive patterns reported in the subsections that follow, a cross-study synthesis reveals several important convergences, divergences, and unresolved gaps in the literature on Industry 4.0 and sustainable supply chain management. A strong convergence emerges around the positive role of data-centric technologies—particularly IoT, Big Data analytics, and artificial intelligence—in enhancing supply chain visibility, operational efficiency, and environmental performance. Across empirical and conceptual studies, these technologies are consistently identified as foundational enablers of sustainability through real-time monitoring, predictive capabilities, and resource optimization.

However, the literature also exhibits notable divergences regarding the social and organizational impacts of Industry 4.0 adoption. While some studies report improvements in worker safety, skill development, and stakeholder trust—especially through automation and blockchain-enabled transparency—others highlight risks related to job displacement, skills polarization, and uneven digital readiness among supply chain partners. These conflicting findings suggest that social sustainability outcomes are highly context-dependent and mediated by organizational culture, governance structures, and workforce capabilities.

Several critical research gaps are also evident. First, despite the growing interest in sustainability, the majority of studies prioritize economic and operational outcomes, with comparatively limited empirical attention to social and organizational dimensions. Second, emerging technologies such as augmented reality, additive manufacturing, and renewable energy integration remain underexplored, particularly in multi-tier and cross-border supply chains. Third, most existing studies adopt static or firm-level perspectives, offering limited insight into the long-term, systemic, and inter-organizational effects of Industry 4.0 adoption. Addressing these gaps requires more longitudinal, multi-actor, and theory-driven research capable of capturing the complex and dynamic relationship between digital transformation and sustainable supply chain performance.

5.1. General Characteristics of the Selected Studies

Out of the 423 initially identified publications, 20 high-quality peer-reviewed articles were retained for in-depth analysis. These studies were published between 2019 and 2024, reflecting the rapid evolution of digital technologies and their growing application in sustainable supply chains. Geographically, the contributions span both developed and emerging economies, with a significant number of studies focusing on Asia and Europe, regions where Industry 4.0 adoption has been particularly pronounced.

In terms of research design, the selected studies included empirical investigations (case studies, surveys, econometric analyses) and conceptual/theoretical papers that explored frameworks linking Industry 4.0 technologies with sustainability performance. This diversity of approaches provides a balanced view of both theory-building and practical applications.

5.2. Industry 4.0 Technologies Most Frequently Investigated

The systematic review highlights that some technologies are more frequently addressed in the literature than others. IoT and Big Data analytics are the most prominent, followed by AI, blockchain, and robotics/automation. Technologies such as 3D printing, augmented/virtual reality, and renewable energy integration are discussed less frequently, though they represent emerging fields of interest.

Table 3: Frequency of Industry 4.0 Technologies in the Selected Studies

Technology	Frequency (out of 20)	Main Focused Benefits	Example studies
IoT & Sensors	15	Real-time monitoring, visibility, waste reduction	Karmaker et al. (2023)
Big Data & Analytics	15	Forecasting, optimization, decision-making	Khan et al. (2023)
Artificial Intelligence (AI)	12	Predictive maintenance, process automation	Lai et al. (2019)
Blockchain	9	Transparency, traceability, trust	Sun et al. (2022)
Robotics & Automation	8	Efficiency, cost reduction, safety	Frank et al. (2019)
3D Printing	4	Flexibility, customization	GE, BMW (case evidence)
Cloud Computing	7	Scalability, collaboration	Han & Trimi (2022)
AR/VR	3	Training, warehouse navigation	DHL, Boeing (case evidence)
Renewable Energy Systems	3	Carbon reduction, energy efficiency	Tesla Gigafactories, IKEA

5.3. Mechanisms Through Which I4.0 Enhances Sustainability

The reviewed studies suggest that I4.0 contributes to sustainability through four core mechanisms:

1. Data Acquisition and Storage – enabled by IoT and cloud platforms.
2. Data Processing and Assessment – driven by Big Data and AI.
3. Performance Monitoring and Evaluation – through predictive analytics and real-time KPIs.
4. Decision Support and Optimization – leveraging AI and blockchain for enhanced strategic choices.

These mechanisms collectively improve visibility, traceability, and resource efficiency, thereby supporting the environmental, social, and economic pillars of sustainability.

5.4. Sustainability Outcomes Observed

The integration of Industry 4.0 technologies was found to generate measurable benefits across the triple bottom line:

- Environmental outcomes: reduction of emissions, energy efficiency, waste minimization, eco-friendly production (IoT-enabled logistics optimization, blockchain-based traceability).
- Social outcomes: improved worker safety (automation), increased consumer trust (blockchain transparency), and better stakeholder engagement (real-time reporting).

- Economic outcomes: cost reduction, improved demand forecasting, enhanced resilience, and long-term competitiveness.

5.5. Contextual Moderators

The effectiveness of I4.0 in enabling SSCM depends on several organizational and contextual factors:

- Organizational culture: openness to innovation and digital transformation.
- IT infrastructure maturity: ability to integrate advanced systems.
- Supplier readiness: alignment of upstream and downstream partners.
- Governance and regulations: institutional frameworks promoting sustainability and digital adoption.

These factors often explain why some firms succeed in leveraging I4.0 for sustainability while others struggle to capture tangible benefits.

6. Conclusion and Recommendations

6.1. Conclusion

This study examined how Industry 4.0 (I4.0) technologies contribute to Sustainable Supply Chain Management (SSCM) through a systematic literature review of twenty peer-reviewed studies published between 2019 and 2024. Rather than reiterating descriptive findings, the conclusion highlights four core contributions of the review.

First, this study makes a theoretical contribution by consolidating fragmented research on I4.0 and SSCM into an integrated perspective. It clarifies how digital technologies—particularly IoT, Big Data analytics, artificial intelligence, and blockchain—enable sustainability through four interrelated mechanisms: data acquisition, data processing, performance monitoring, and decision support. By explicitly linking these mechanisms to sustainability outcomes, the review advances understanding of how digital transformation functions as a foundational enabler of sustainable supply chains.

Second, the study provides a conceptual contribution by distinguishing between the technological implementation of I4.0 and its multidimensional sustainability impacts. Through the structured synthesis of existing studies, it demonstrates that I4.0 adoption influences not only economic and operational performance but also social and organizational dimensions, thereby extending sustainability analysis beyond the traditional efficiency-oriented perspective.

Third, this review offers methodological value by applying the PRISMA 2020 protocol to an emerging and interdisciplinary research domain. The transparent and replicable review process contributes to research rigor and provides a systematic baseline for future reviews examining digital transformation and sustainability in supply chains.

Finally, the study delivers managerial insights by highlighting that the sustainability benefits of Industry 4.0 are contingent upon contextual factors such as organizational culture, digital infrastructure maturity, and supply chain partner readiness. These findings underscore that firms must strategically align digitalization initiatives with sustainability objectives to realize long-term competitive and societal value.

Taken together, these contributions position Industry 4.0 not merely as a set of efficiency-enhancing technologies but as a strategic catalyst for sustainable supply chain transformation.

6.2. Managerial Implications

The findings of this review offer several implications for managers seeking to leverage Industry 4.0 technologies to advance sustainable supply chain management. First, firms should adopt an integrated strategic approach in which digital transformation initiatives are explicitly aligned with sustainability objectives, rather than implemented as isolated technological upgrades. Such alignment ensures that investments in Industry 4.0 generate value across environmental, social, and economic dimensions.

Second, sustainability-oriented digital transformation requires active collaboration across the supply chain. Firms should engage suppliers and logistics partners to assess digital readiness, promote data sharing, and align sustainability goals, thereby extending the benefits of Industry 4.0 beyond organizational boundaries. Third, a phased implementation strategy is recommended, allowing organizations to manage technological complexity, reduce operational risks, and facilitate employee adaptation.

Finally, managers should recognize the importance of organizational enablers, including robust data governance structures and continuous employee training. Developing digital competencies and fostering a culture supportive of both innovation and sustainability are critical conditions for translating technological capabilities into measurable sustainability outcomes.

6.3. Limitations of the Study

Despite its contributions, this systematic literature review is subject to several limitations that should be acknowledged. First, the review was restricted to articles published between 2019 and 2024, which ensured a focus on recent developments but may have excluded earlier foundational studies relevant to Industry 4.0 or sustainable supply chain management. Second, although multiple high-quality databases were used, the review may have overlooked relevant studies indexed in other sources or published in languages beyond English and French.

Third, the methodological profile of the selected studies reveals a predominance of conceptual and qualitative research, limiting the availability of large-scale empirical evidence and statistically generalizable findings. Finally, the geographical distribution of the reviewed studies is uneven, with a stronger emphasis on developed economies, potentially underrepresenting the dynamics of Industry 4.0 adoption and sustainability challenges in emerging and developing contexts.

6.4. Directions for Future Research

Building on the identified limitations and research gaps, several avenues for future research emerge. First, sector-specific empirical studies are needed to examine how Industry 4.0 technologies influence sustainability outcomes in industries such as automotive, textiles, agri-food, and pharmaceuticals, where supply chain structures and sustainability pressures differ significantly.

Second, comparative studies between developed and emerging economies would enhance understanding of contextual factors shaping digital adoption and sustainability performance. Third, future research should empirically test the mediating and moderating roles of sustainable supply chain management practices, organizational culture, and governance mechanisms in the relationship between Industry 4.0 adoption and sustainability outcomes.

Moreover, emerging technologies, such as additive manufacturing, augmented and virtual reality, and renewable energy integration, remain underexplored and warrant deeper investigation, particularly in multi-tier and global supply chains. Finally, longitudinal studies are needed to assess the long-term impacts of Industry 4.0 on supply chain resilience, adaptability, and sustainability performance over time.

6.5. Final Remark

Overall, this study reinforces the view that Industry 4.0 represents more than a technological evolution; it constitutes a transformative paradigm for rethinking supply chain design and governance. When strategically integrated with sustainable supply chain management practices, digital technologies can support resilient, transparent, and responsible supply chains that balance environmental stewardship, social well-being, and economic performance. By clarifying mechanisms, contextual conditions, and research gaps, this review provides a foundation for both scholarly advancement and informed managerial decision-making.

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