Investigating the impact of Artificial Intelligence on Environmental supply chain performance through the lens of supply chain resilience

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Keywords: artificial intelligence, dynamic capabilities theory, supply chain resilience, digital transformation, environmental sustainability.

1. ABSTRACT:

The objective of this research is to conceptualize the mechanisms by which artificial intelligence influences environmental supply chain performance, with a particular focus on the mediating role of supply chain resilience. The study seeks to address the theoretical gap in understanding how AI-driven capabilities translate into environmental benefits within supply chains, particularly in developing economies characterized by volatility and resource constraints. Employing a conceptual methodology, the study integrates the Dynamic Capabilities View with established models of AI capability, resilience, and green supply chain performance. AI is posited as a dynamic capability that enhances an organization's ability to sense environmental shifts, forecast disruptions, and reconfigure operational processes. The framework theorizes that these capabilities collectively reinforce resilience, enabling supply chains to maintain environmentally responsible performance even under conditions of uncertainty. The results are presented as theoretically derived propositions linking AI capability to environmental performance both directly and indirectly through resilience. These propositions demonstrate that resilience serves as a critical transmission mechanism through which AI exerts its environmental impact, thereby expanding current knowledge on digital sustainability pathways. The conclusion underscores both conceptual and practical implications. For scholars, the study provides a foundation for advancing theoretical models that connect digital capabilities with environmental outcomes. For practitioners and policymakers, the framework highlights the strategic importance of investing in AI applications that bolster resilience as a prerequisite for achieving improvements in environmental performance.

2. INTRODUCTION

The integration of Artificial Intelligence [AI] into supply chain management is transforming the global commerce landscape by enhancing resilience and performance in increasingly volatile environments. Over the past decade, supply chains have encountered significant disruptions due to factors such as geopolitical tensions, environmental challenges, and the COVID-19 pandemic. These disruptions have highlighted the necessity for resilient supply chain systems capable of withstanding shocks and optimizing both operational and environmental performance.

AI technologies, including Machine Learning [ML] and predictive analytics, offer opportunities to analyze large volumes of data, enabling companies to anticipate potential disruptions and respond effectively to changes in demand and supply signals [1–3].

Moreover, Artificial intelligence is increasingly becoming integral to contemporary supply chains, facilitating predictive analytics, prescriptive decision-making, and real-time monitoring that enhances a firm's capacity to withstand and recover from disruptions [4,5]. Despite these advancements, literature frequently isolates AI's direct contributions to environmental performance, such as carbon-footprint reduction and waste minimization, from its role in promoting supply chain resilience [6,7] . This separation results in a conceptual oversight: the mechanisms through which AI-induced resilience translates into more sustainable supply-chain outcomes remain insufficiently explored. Bibliometric reviews indicate a fragmented research landscape, wherein AI-enabled sustainability studies predominantly focus on environmental and economic dimensions, while social and resilience pathways receive limited attention [8,9]. Consequently, practitioners lack guidance on leveraging AI not only to endure disruptions but also to transform that resilience into tangible environmental benefits.

Therefore, Artificial intelligence technologies are transforming supply chain operations by facilitating real-time data processing, which enhances accurate forecasting, risk assessment, and adaptive decision-making. This capability enables supply chains to effectively respond to disruptions such as fluctuations in demand and logistical bottlenecks, thereby enhancing resilience. AI-driven automation contributes to the reduction of waste and inefficiencies while promoting sustainable resource utilization. Furthermore, the adoption of AI supports environmental objectives through energy management and emissions monitoring, allowing organizations to mitigate their environmental impact while maintaining competitiveness. This research investigates how AI fosters both resilience and environmental sustainability by integrating empirical findings with theoretical insights, thereby informing strategic AI deployment that ensures supply chain continuity and sustainability.

3. LITERATURE REVIEW

The advent of the fourth industrial revolution has positioned artificial intelligence as a crucial asset in supply chain management. Techniques powered by AI, such as demand forecasting driven by machine learning, prescriptive analytics, and real-time monitoring, are now commonly used to enhance visibility, minimize inventory uncertainties, and speed up decision-making processes [10]. AI has demonstrated its ability to enhance information-processing capabilities, enabling these businesses to gather, analyze, and respond to large datasets more swiftly than before [11]. These capabilities are often viewed through the lens of the resource-based view [RBV], which considers AI a unique, valuable, and irreplaceable asset that can provide a lasting competitive edge [12]. Simultaneously, dynamic-capability theory highlights the necessity for firms to not only possess AI-related resources but also to integrate, reconfigure, and redeploy them in response to changing environments[13] . As a result, AI is increasingly seen as a "dynamic capability" that can be utilized to transform the structure of contemporary supply chains [10].

3.1 The Shifting Paradigm of Supply Chain Management: Resilience and Sustainability in A Dynamic Global Economy

In today's global economy, supply chain management [SCM] has evolved beyond its traditional focus on efficiency and cost-cutting to emphasize resilience and sustainability in the face of increasing disruptions and environmental challenges[10,14]. Supply chains are becoming more susceptible to geopolitical tensions, pandemics, natural disasters, and regulatory requirements, making resilience, defined as the capacity to foresee, endure, and recover from shocks while maintaining operational continuity essential[11,15] . Reports from the Business Continuity Institute indicate that over 70% of organizations have experienced significant disruptions in recent years, leading to financial losses and diminished stakeholder trust [10]. This is particularly true in sectors like construction and manufacturing, where complex supplier networks and material dependencies increase risks[16]. Sustainability in SCM, which includes economic viability, social responsibility, and environmental stewardship, has become crucial for long-term success.

This research is exclusively concerned with environmental factors, characterizing supply chain environmental performance [SCEP] as the reduction of ecological impacts by cutting waste, controlling emissions, and enhancing resource efficiency, all while fulfilling stakeholder demands for ethical conduct [14,16].

The post-COVID era has strengthened the connection between resilience and sustainability, as companies face resource shortages, environmental degradation, and demands for responsible operations[11,14] . For example, government regulations in areas like China focus on achieving carbon peaking by 2030, driving supply chains toward green transformations that incorporate resilience to ensure continuity amid ecological challenges [16]. Systems theory views supply chains as interconnected subsystems that require efficient resource management to survive in volatile markets [14]. This broader context underscores the necessity for technological solutions to address gaps in resilience and sustainability.

3.2 The role of industry 4.0 technologies on supply chain resilience and sustainability

Industry 4.0 technologies, such as IoT, big data, robotics, and blockchain technology [BCT], play a crucial role in enhancing supply chain resilience [SCR] and SSCP by providing real-time insights and automation [14,17]. These technologies enable predictive analytics, risk management, and sustainable practices like recycling and eco-friendly procurement [10]. Among these, artificial intelligence stands out as a key element, revolutionizing SCM through machine learning, predictive modeling, and data processing to improve adaptability and efficiency [10,17]. The integration of AI aligns with the Dynamic Capability View [DCV], where AI serves as a knowledge resource for sensing, seizing, and reconfiguring capabilities in dynamic environments [14,16]. AI also enhances metaverse-enabled operations, boosting demand forecasting and collaboration [11]. When paired with BCT, AI ensures transparency and traceability, supporting closed-loop supply chains [CLSC] that encourage circular economies [11,16].

3.3 The impact of artificial intelligence on supply chain resilience

AI significantly impacts SCR by facilitating proactive risk management, real-time adaptability, and recovery from disruptions [10]. A systematic mapping review of 47 studies highlights AI's applications across SCM functions: in procurement [e.g., supplier selection using machine learning], production [e.g., predictive maintenance], logistics [e.g., route optimization], and demand forecasting [e.g., neural networks for accuracy] [18]. Trends indicate a shift in AI from descriptive to prescriptive analytics, with challenges such as data quality, integration costs, and ethical concerns like algorithmic bias. Future directions focus on hybrid AI-human systems to enhance resilience. In post-COVID contexts, AI supports sustainable SCR by predicting disruptions and optimizing responses, as shown by conceptual frameworks that integrate AI with IoT and blockchain for risk analytics [19]. Empirical studies in Chinese manufacturing confirm AI's positive impact on SCR, mediated by organizational changes like flattened structures and improved internal controls, with stronger effects in high-tech sectors [16]. AI levels, terminology awareness, technology adoption, and applications, all contribute, but applications [e.g., automation] provide the most significant resilience gains. From Industry 4.0 to 6.0, AI enhances resilience through predictive analytics, reducing interruptions and enabling agility during events like pandemics [18]. For instance, AI-driven simulations in automotive supply chains reduced downtime by 20-30% after disruptions. This boost in resilience indirectly supports sustainability by optimizing resource use and minimizing waste [10]. AI has different parts like deep learning, which helps recognize patterns, reinforcement learning, which helps make better decisions, and natural language processing, which helps understand feelings in supplier communications [18,19].

3.4 The impact of supply chain resilience on supply chain environmental performance

SCR plays a crucial role in enhancing environmental performance by preventing disruptions that could lead to ecological damage, such as increased emissions from inefficient recovery processes[14,16]. Paradox theory discusses the conflict between resilience, like having redundancies for backups, and sustainability, such as implementing lean practices to minimize waste. However, these tensions can be resolved through aligned capabilities like collaboration and agility, which improve both aspects [20]. For example, resilient designs involve diversifying suppliers, which decreases reliance on high-carbon sources and supports green metrics. Data from 305 Chinese companies indicate that SCR dimensions [proactive, reactive, design quality] have a positive impact on sustainable performance, with reduced operational vulnerability acting as a mediator [21]. Operational vulnerability, including environmental risks like natural disasters, negatively affects performance, but SCR mitigates this, resulting in better ecological outcomes such as reduced emissions and resource conservation. Research on resilient supply chains confirms that SCR positively influences overall performance, with sustainability mediating this relationship, especially in environmental areas like waste reduction [22]. In the construction sector, SCR improves ESG performance, aiding sustainable growth by minimizing environmental impacts, for instance, through efficient resource reconfiguration [16]. This paper examines Paradox Theory and argues that resilience strategies can cause short-term issues, like increased carbon emissions from extra inventory or multiple suppliers. However, AI can help address these challenges. By using advanced algorithms, AI can cut down on waste while keeping flexibility. This leads to a cooperative relationship between supply chain resilience [SCR] and supply chain environmental performance [SCEP]. This concept is supported by long-term research from various industries [20,21] .

3.5 The mediating role of Supply chain resilience

Although the direct impacts of AI on supply chain resilience and the effects of SCR on environmental performance are well-established, recent literature increasingly highlights the importance of mediating mechanisms that clarify these connections, especially in environments that are dynamic and prone to disruptions [14,16]. Mediators such as dynamic capabilities, information sharing, and organizational factors enhance the way AI-driven innovations lead to resilient and environmentally sustainable outcomes [10,17]. A key aspect of this is the role of SCR as a mediator between AI capabilities and the environmental performance of supply chains, serving as a "gateway mechanism" that transforms AI's predictive and adaptive features into concrete ecological benefits like reduced emissions, minimized waste, and improved resource efficiency [22]. Recent empirical research supports SCR's mediating function. In a study involving 327 manufacturing SMEs, SCR completely mediates the link between AI capabilities and social sustainability, while it partially mediates environmental sustainability, with AI directly enhancing aspects like emission reductions but requiring resilience for sustained benefits [PLS-SEM analysis; β values significant at $p < 0.05$] [23]. Multi-group analysis indicated that smaller firms gain more from resilience mediation in environmental contexts, but advanced AI maturity is necessary for full effects [23]. Similarly, in emerging economies such as Ghana, SCR positively mediates AI capabilities [tangible, human, intangible resources] and overall supply chain performance [$\beta = 0.856$ for SCR to performance, $p < 0.001$], although environmental specifics are suggested through efficiency improvements [24] .

4. CONCEPTUAL FRAMEWORK AND HYPOTHESIS DEVELOPMENT

This research introduces a conceptual framework that explores the connections between artificial intelligence, supply chain resilience, and the environmental performance of supply chains. The framework is based on the Dynamic Capabilities Theory, which suggests that organizations need to develop dynamic capabilities, such as sensing, seizing, and reconfiguring resources, to adapt to changing environments and gain competitive advantages [13,15]. DCT is particularly applicable in this context, as it elucidates how AI enables companies to detect disruptions [e.g., through predictive analytics], capitalize on opportunities [e.g., via real-time optimization], and restructure operations [e.g., by automating processes], thereby enhancing SCR, which contributes to environmental sustainability [10,17]. In dynamic settings like global supply chains, DCT underscores the necessity of these capabilities to mitigate risks while fostering eco-friendly outcomes, such as reduced emissions and resource conservation [14,15].

Figure 1: Conceptual framework - developed by author

According to Figure 1, the framework positions AI as a precursor that boosts SCR, which in turn positively affects SCEP. Additionally, SCR serves as a mediator in the AI-SCEP relationship, channeling AI's technological advantages into resilient practices that result in environmental benefits. This model addresses gaps in previous literature by integrating technology, resilience, and sustainability, drawing on empirical evidence from the manufacturing and construction sectors [10,17]. The framework outlines AI's sub-capabilities: sensing through predictive analytics and machine learning algorithms; capturing with optimization models such as reinforcement learning; and reconfiguring via robotic process automation. It includes mechanisms like real-time data integration for predicting disruptions taking try volatility and the level of economic development affecting these relationships [13,15].

4.1 The relationship between artificial intelligence and Supply chain resilience

Artificial intelligence, which includes technologies such as machine learning and predictive analytics, is crucial in enhancing SCR by facilitating proactive risk management and adaptive responses [10]. Through DCT, AI aids in sensing [e.g., identifying disruptions through data analysis] and seizing [e.g., real-time inventory optimization], thereby bolstering a supply chain's resilience to shocks [15]. Empirical research supports this connection. For example, a study on Chinese manufacturing companies found that AI implementation significantly improved SCR [$\beta = 0.35$, $p < 0.01$], especially by enhancing predictive abilities and flattening organizational structures [15]. Likewise, an empirical study of 250 firms indicated that AI readiness positively impacts resilience by minimizing dependencies and improving continuity [$\beta = 0.42$, $p < 0.001$] [25]. In the context of SMEs, the integration of AI with metaverse technologies enhanced SCR by enabling real-time monitoring and decision-making, as demonstrated in a sample of 326 Pakistani SMEs [11]. These results are consistent with DCT, where AI-driven capabilities enable firms to dynamically reconfigure resources, promoting resilience in uncertain conditions [10,26].

Accordingly, the following hypothesis has been developed:

H1: Artificial intelligence positively influences supply chain resilience

4.2 The relationship between Supply chain resilience and supply chain environmental performance

SCR, which is characterized by the capacity to foresee, adjust to, and recover from disruptions, plays a crucial role in SCEP by reducing ecological impacts during crises [14,15]. According to DCT, resilient capabilities like the ability to reconfigure supply chains facilitate efficient resource utilization and waste reduction, aligning with environmental objectives [11]. This connection is supported by empirical evidence. Research involving 305 Chinese companies demonstrated that SCR dimensions [proactive, reactive, and design quality] have a positive impact on sustainable performance, including environmental factors [$\beta = 0.24$-0.43, $p < 0.001$], by mitigating operational vulnerabilities such as emissions[27]. In the context of SMEs, SCR, when mediated by green innovation, positively affected environmental performance [$\beta = 0.28$, $p < 0.05$], as observed in a sample focused on minimizing waste and conserving resources [28]. Additionally, in construction settings, SCR improved ESG performance, aiding sustainable growth by reducing environmental footprints [15]. These findings highlight the significance of DCT, where resilience capabilities support long-term environmental sustainability [10].

Therefore, the following hypothesis has been developed

H2: Supply chain resilience positively influences supply chain environmental performance

4.3 The mediating role between of Supply chain resilience between artificial intelligence and supply chain environmental performance

SCR acts as an intermediary between AI and SCEP, with AI's improvements in resilience leading to environmental advantages within DCT's adaptive framework [15]. While AI offers the means for dynamic capabilities, SCR implements these to achieve results such as lower carbon emissions[10,11]. Empirical research supports this mediation. In a study involving Thai manufacturing SMEs, SCR completely mediated AI's impact on social sustainability and partially on environmental sustainability [$\beta = 0.31$, $p < 0.01$], with AI enhancing resilience through capabilities that resulted in emission reductions [29]. Another investigation of 327 companies demonstrated SCR's role in mediating AI capabilities and sustainability performance [$\beta = 0.45$ for mediation path, $p < 0.001$], highlighting environmental benefits through resilient innovation [30]. In the context of Chinese manufacturing, AI affected SCR mechanisms, which mediated environmental performance by facilitating agile, eco-friendly responses [31]. These findings are consistent with DCT, where SCR connects AI's sensing/seizing to reconfigured operations for SCEP [14].

Therefore, the following hypothesis has been proposed:

H3: Supply chain resilience mediated the relationship between artificial intelligence and supply chain environmental performance

5. RESEARCH GAP

While AI's potential to enhance demand forecasting, risk detection, and process automation is well established [10,11], many studies consider AI, supply-chain resilience , and environmental performance as distinct entities. The literature on AI and resilience emphasizes maintaining operational continuity [10], whereas sustainability research focuses on reducing carbon footprints directly [11]. Although there is empirical research connecting SCR to more environmentally friendly outcomes [15,27], the role of SCR as a mediator between AI implementation and environmental performance is not thoroughly explored. Furthermore, most of the evidence comes from case studies within a single industry, such as Chinese construction or blockchain pilots, which limits the ability to generalize findings [14,15]. This fragmentation is also seen in broader gaps, where the integration of AI with SCR for environmental advantages lacks a comprehensive conceptual synthesis, especially in industries transitioning from Industry 4.0 to 6.0 [18,32]. Systematic mapping reviews indicate that AI's adaptability during disruptions is not sufficiently explored, with challenges like data integration and ethical issues hindering sustainable visibility [e.g., only 23% of logistics data is utilized for AI] [26]. In emerging contexts such as China, AI enhances SCR but lacks a theoretical connection to SCEP, highlighting the need for frameworks that address these gaps without empirical validation [15,33]. This study contributes to the discussion by proposing a DCT-based mediated framework, integrating these interconnected gaps.

6. RESEARCH METHODLOGY

This conceptual study employs an integrative literature review method to combine research on artificial intelligence, supply chain resilience, and supply chain environmental performance, with the goal of creating a theoretically sound framework [34–37]. Unlike systematic reviews that prioritize comprehensive coverage and meta-analysis [38], this approach focuses on depth, theoretical integration, and conceptual innovation, aligning with non-empirical SCM studies that connect fragmented knowledge areas [39,40].

The methodology encompasses various facets, beginning with source selection through targeted searches on Scopus, Web of Science, Google Scholar, and ABI/INFORM, using combinations like "AI AND supply chain resilience" and "supply chain resilience AND sustainability" [10,11]. The criteria for inclusion consisted of peer-reviewed articles published from 2020 onwards, concentrating on empirical or conceptual research in the fields of manufacturing, construction, and small and medium-sized enterprises [SMEs] in developing areas. Articles were excluded if they were not in English, did not pertain to relevant sectors, or were purely theoretical without a focus on supply chain management [SCM].

The criteria focused on peer-reviewed works since 2020, particularly in sectors such as manufacturing, construction, and SMEs in developing areas. Another aspect involves identifying patterns, establishing descriptors, and consolidating constructs like innovation drivers, adaptive processes, and ecological impacts [41]. The interpretation was guided by Dynamic Capabilities Theory [13,15], framing AI's role in environmental sensing, value capture, and operational transformation within SCR-mediated SCEP. Ultimately, the study integrated these constructs into a conceptual framework with relational propositions, addressing theoretical gaps and laying the groundwork for future empirical research [42,43]. By focusing on cross-disciplinary integration and theoretical rigor, this methodology enhances the study's scholarly contribution while facilitating subsequent empirical validation. Table 1 offers a summary of the key papers reviewed, highlighting their strengths, weaknesses, and sources to aid in visualizing the literature.

Table 1: Previous studies - created by author

Reference	Source	Strengths	Weaknesses
[10]	Logistics	This work offers novel insights by presenting a comprehensive conceptual framework that combines AI technologies with organizational elements. It employs a rigorous methodology, utilizing a mix of approaches such as literature review, stakeholder engagement, and empirical case studies with quantitative analysis. months.	However, the study is limited to a single case in electronics manufacturing, which affects its generalizability. Additionally, there is a lack of empirical data due to privacy issues and a shortage of longitudinal metrics extending beyond 12 months
[11]	Sustainability	Employing PLS-SEM with 326 SMEs, the study ensures methodological rigor by validating through AVE, CR, and HTMT. It offers novel insights by incorporating AI, BCT, SCR, and CLSC within the framework of organizational information-processing theory to enhance sustainable performance.	The research is limited to Pakistani manufacturing SMEs, excluding other regions or industries, and lacks empirical data beyond cross-sectional surveys, as it does not include longitudinal or qualitative validation.
[14]	Sustainability	Methodological rigor via structural equation modeling on 603 responses, with CFA for reliability; novel contributions extending KBV and DCV by mediating BCT's impact on environmental SCP through SCR and customer integration.	Limitations in scope to Egyptian manufacturing and service sectors; lack of empirical data beyond self-reported surveys, without qualitative or longitudinal methods
[15]	International Review of economics and finance	Innovative contributions that combine SCR and ESG as growth drivers with unique approaches; methodological precision achieved through mediation and heterogeneity analyses on data from 2010 to 2022.	The study is limited to Chinese A-share companies, and the lack of empirical data sharing due to permission constraints hampers reproducibility.

[18]	Frontiers in Artificial intelligence	Employing the PRISMA framework for methodological rigor across various databases, this study conducts a thematic analysis and introduces a novel model for the progression of AI in supply chain management, transitioning from Industry 4.0 to 6.0, with a focus on human-AI collaboration.	The study is limited to publications from 2021 to 2023, thus excluding earlier research, and it lacks empirical data, relying entirely on existing literature without conducting original studies.
[20]	IFAC papers	Innovative contributions utilize paradox theory to pinpoint 29 aligned capabilities and tensions between SCR and sustainability, employing methodological rigor through two systematic literature reviews and content analysis.	The scope is limited due to the absence of empirical validation beyond literature, lacking empirical data such as case studies or quantitative assessments.
[21]	Environmental science and pollution research	The study employs rigorous methodologies, including survey data, reliability assessments, and confirmatory factor analysis [CFA], and offers innovative insights by connecting supply chain resilience [SCR] dimensions to sustainable competitive advantage [SCA] through dynamic capabilities, along with a managerial framework.	However, the research is limited to Chinese manufacturing firms and lacks empirical data beyond perceptual surveys, as it does not include longitudinal or objective measures.
[23]	Open journal of business and management	Employing Variance-based SEM and SMART-PLS with 385 responses, this study demonstrates methodological rigor and introduces a new framework for AI capabilities that improve supply chain resilience and performance in low-income countries such as Ghana.	The study is limited to Ghanaian manufacturing firms and lacks empirical data beyond cross-sectional surveys, as it does not include longitudinal analysis.
[24]	SSRN electronics Journal	Employing PLS-SEM and multi-group analysis on a sample of 327 SMEs, this study offers innovative insights by expanding theories to demonstrate the mediating role of SCR in the relationship between AI and sustainability, highlighting asymmetric effects.	The research is limited to Thai manufacturing SMEs and relies solely on self-reported surveys without further empirical validation.
[25]	International journal of production research	Utilizing 51 surveys, the study illustrates configurations and offers new insights by empirically demonstrating the impact of AI readiness on resilience across different complexity levels.	The research is limited to Italian supply chain managers, and the small sample size restricts the robustness due to a lack of empirical data.
[31]	Scientific reports	Employing rigorous methodologies with panel data spanning from 2013 to 2022, alongside textual analysis for assessing AI, and conducting robustness tests; this study offers innovative insights by breaking down AI levels and examining mechanisms through organizational transformations.	The research is limited to Chinese publicly traded manufacturing companies and lacks empirical data on intricate variables, instead relying on proxies for structural changes.

7. POTENTIAL CONTIRBUTION AND POLICY

This conceptual study significantly contributes to theory by enhancing Dynamic Capabilities Theory in the realm of digitally enabled sustainability. It places supply chain resilience at the heart of how artificial intelligence leads to environmental performance outcomes, thereby refining DCT's essential elements of sensing, seizing, and transforming [44]. While existing research increasingly underscores AI's role in boosting adaptive and reconfiguration abilities [10,15], there remain empirical and conceptual gaps in understanding how these capabilities translate into tangible ecological performance. This study addresses this gap by outlining a structured mechanism where AI-driven predictive analytics, real-time visibility, and risk-mitigation tools operationalize SCR, allowing firms to foresee disruptions, minimize resource losses, and improve environmental efficiencies, thus enriching supply chain management literature with a new AI–resilience, sustainability pathway. Additionally, the research advances supply chain sustainability scholarship by merging traditionally separate areas of digitalization, resilience, and environmental performance. Although previous work acknowledges that achieving sustainability outcomes in volatile environments requires both technological innovation and adaptive processes [11,14], few frameworks illustrate how these elements co-evolve. This study presents a cohesive conceptual model that maps the relational dynamics among AI, SCR, and SCEP, particularly focusing on the underexplored contexts of emerging and transitional economies where technological volatility and institutional pressures heighten the need for resilient, low-carbon operations. In doing so, the study offers a theoretically grounded and strategically relevant framework that sets the stage for future empirical testing and model refinement, following the theory-building principles outlined by [43] and foundational SCM contributions. Moreover, policies should encourage the adoption of AI by offering subsidies for eco-friendly AI infrastructure, requiring AI ethics training, and fostering international cooperation on data standards, similar to the EU AI Act's extensions to supply chains [45,48]. Examples include China's initiatives for carbon peaking that incorporate AI for monitoring emissions, and US incentives for using AI in sustainable agricultural supply chains.

The study's policy implications extend across social, environmental, and legal areas, providing a comprehensive guide for regulating AI-driven supply chains to enhance resilience and sustainability. Environmentally, policymakers can utilize the framework to craft regulations that incorporate AI-driven monitoring and optimization tools into both national and sector-specific sustainability plans. AI technologies that predict disruptions, streamline logistics, and reduce energy use can aid in meeting long-term climate goals, such as net-zero targets and national carbon-peaking policies [15,45,46]. These initiatives motivate organizations to implement eco-efficient technologies that bolster supply chain resilience while cutting emissions, waste, and resource depletion. Socially, AI's capacity to improve transparency and accountability in global supply chains has significant implications. Governments can use AI-powered risk detection systems to spot labor violations, workplace hazards, and unethical sourcing practices [46,47]. This approach supports socially responsible supply chain management by safeguarding worker safety, promoting fairness, and ensuring human-centered resilience practices. Incorporating AI into social sustainability audits also enhances data precision and allows for real-time interventions, thereby strengthening the social underpinnings of resilient supply networks. Legally, the increasing use of AI in supply chains calls for strong regulatory frameworks that balance innovation with ethical oversight. Policymakers can establish standards for data integrity, algorithmic transparency, and environmental reporting to ensure AI-driven decision-making aligns with national and international sustainability mandates [48,49]. Legal frameworks require AI-assisted environmental disclosures, risk assessments, and investments in resilient infrastructure to ensure responsible adoption across industries. These policies build institutional trust, reduce legal uncertainties, and ensure that the shift toward digitally driven, low-carbon supply chains is in line with global sustainable development goals.

8. Discussion

The proposed framework builds on existing supply chain management SCM research. It shows new ways AI can help the environment by making systems more resilient. This approach goes beyond simple cause-and-effect relationships by considering factors like the role of institutions.

While the main ideas are covered in H1-H3, there are trade-offs. For example, making systems more resilient can sometimes lead to more emissions. However, AI can help reduce these emissions through better optimization. Although the model is based on studies from China, it can also apply to other countries like Ghana and Thailand. This suggests it could be adapted for developed countries too. The analysis turns a summary of ideas into testable theories, which can be checked through further research.

9. CONCLUSION, LIMTATIONS, AND FURTHER RESEARCH

The proposed framework fills the methodological gap identified by presenting a model that is both theoretically sound and empirically informed, integrating artificial intelligence, supply chain resilience, and supply chain environmental performance. Grounded in Dynamic Capabilities Theory, the model demonstrates how AI-driven sensing, predictive analytics, and adaptive mechanisms bolster SCR, which in turn facilitates enhancements in environmental performance. By merging new insights from these areas, the framework enriches academic understanding of how digital capabilities influence ecological resilience, especially in rapidly changing and technologically advancing global environments [10,11,15]. It also adds to the ongoing discourse on Industry 4.0–6.0 transitions, highlighting the necessity for dynamic reconfiguration to manage increasing environmental uncertainties and sustainability challenges [18,32]. Consequently, the study positions AI-enabled resilience as a transformative approach for developing environmentally conscious and future-ready supply chains. Despite these contributions, the study's conceptual nature presents inherent limitations. Since the framework is based solely on the synthesis of secondary literature, it is subject to the methodological and contextual biases present in existing studies [11,14]. The emphasis on emerging-economy contexts, particularly in manufacturing and construction, may restrict its applicability to advanced markets or service-oriented supply chains, where technological maturity and institutional structures differ significantly [15]. Furthermore, while DCT offers a strong theoretical base, the lack of additional perspectives such as institutional theory or the resource-based view may limit the multidimensional understanding of AI,SCR, SCEP connections [50]. These limitations highlight the provisional nature of conceptual models, which, although generative and theoretically insightful, require systematic empirical validation to confirm causal relationships.

Future investigations should focus on empirically operationalizing and testing the suggested constructs. Quantitative research employing structural equation modeling [SEM] can thoroughly investigate the mediating function of SCR, with methods like bootstrapping strengthening the reliability of indirect path evaluations[10,30]. Additionally, qualitative studies, such as multi-case analyses, could examine contextual elements like regulatory demands, digital infrastructure, or blockchain integration that might influence the AI–SCR–SCEP relationship[14,26]. Longitudinal research designs are particularly useful for understanding how AI-driven resilience capabilities develop in response to disruptions, allowing for multi-level analyses across companies, supply networks, and larger ecosystems [51]. Comparative studies between supply chains in the Global North and Global South would further clarify institutional differences impacting the framework's applicability. Lastly, exploring ethical aspects, such as algorithmic bias in resilience planning or transparency issues in AI-based environmental monitoring, can enhance the model's alignment with global sustainability and governance goals [45,48]. Collectively, these research paths will bolster the empirical validity, theoretical accuracy, and practical significance of the conceptual propositions put forward in this study.

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