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REVIEW ARTICLE

Climate-Resilient Sustainable Supply Chains: A Review of Green Practices, Organizational Resilience, and Environmental Performance

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Abstract

Climate change is increasingly disrupting global supply chains through extreme weather events, resource scarcity, regulatory pressures, and market uncertainty. These challenges highlight the need for sustainable supply chain management strategies that integrate environmental responsibility with organizational resilience. This review examines how green supply chain practices contribute to climate resilience and environmental performance, emphasizing the interrelationships among sustainable procurement, eco-design, cleaner production, green logistics, circular economy strategies, and digital technologies. It explores how these practices strengthen organizational capabilities, including flexibility, adaptive capacity, risk preparedness, and recovery, while reducing greenhouse gas emissions, resource consumption, pollution, and waste. The review also discusses major implementation barriers, including financial constraints, technological limitations, supplier coordination challenges, regulatory inconsistencies, and competing sustainability priorities. Furthermore, it identifies research gaps concerning integrated assessment frameworks, long-term performance evaluation, digital innovation, climate-risk integration, and multi-tier supply chain collaboration. The review proposes a conceptual framework linking climate pressures, green supply chain practices, organizational resilience, and environmental outcomes. It highlights the importance of coordinated governance, technological innovation, and measurable sustainability indicators in advancing climate-resilient supply chains. These insights provide directions for researchers, policymakers, and business managers seeking to strengthen supply chain sustainability and resilience under changing climatic conditions.

Keywords: Sustainable supply chain management; Climate change; Green supply chain practices; Organizational resilience; Circular economy

1. Introduction

Global supply chains are fundamental to contemporary economic development, connecting raw-material extraction, manufacturing, transportation, distribution, consumption, and end-of-life management across geographical and organizational boundaries. However, the expansion and increasing complexity of global production networks have intensified environmental pressures, including greenhouse gas emissions, energy consumption, water depletion, material extraction, pollution, and waste generation. Supply chain activities are

also increasingly exposed to climate-related hazards, such as extreme temperatures, floods, droughts, storms, wildfires, and sea-level rise. These developments have made the environmental sustainability and climate resilience of supply chains important priorities for businesses, policymakers, and researchers.

The relationship between supply chains and climate change is particularly significant because environmental impacts extend beyond the direct operational boundaries of individual organizations. Greenhouse gas emissions associated with purchased goods and services, transportation, product use, and disposal can represent substantial portions of corporate value-chain emissions. The Greenhouse Gas Protocol distinguishes between direct emissions (Scope 1), indirect emissions from purchased energy (Scope 2), and other indirect value-chain emissions (Scope 3), providing a framework for identifying and accounting for these impacts (WRI and WBCSD, 2004). Consequently, corporate climate strategies increasingly require organizations to engage suppliers, logistics providers, distributors, and customers rather than focusing exclusively on internal operational efficiency. Sustainable supply chain management (SSCM) has developed as an approach for incorporating environmental, social, and economic considerations into supply chain decision-making. Seuring and Müller (2008) describe SSCM as the management of material, information, and capital flows, together with cooperation among organizations across the supply chain, while considering economic, environmental, and social objectives. Similarly, Carter and Rogers (2008) conceptualize sustainability in supply chain management through the integration of environmental and social considerations with economic performance and organizational resilience. These perspectives demonstrate that sustainable supply chains should not be evaluated exclusively through cost reduction or operational efficiency but also through their environmental consequences and capacity to maintain performance under changing conditions.

Green supply chain management (GSCM) represents an important operational dimension of SSCM. It involves incorporating environmental considerations into procurement, product design, manufacturing, transportation, packaging, distribution, and reverse logistics. Practices such as green purchasing, eco-design, cleaner production, energy efficiency, low-carbon transportation, waste minimization, and recycling can reduce the environmental footprint of supply chain activities (Srivastava, 2007; Zhu et al., 2008). However, the effectiveness of these interventions depends on organizational capabilities, supplier participation, technological readiness, regulatory conditions, and the availability of reliable environmental information. In addition to environmental mitigation, climate change has increased the importance of organizational resilience. Supply chains are vulnerable to both sudden disruptions, such as hurricanes and floods, and gradual environmental changes, including rising temperatures, water scarcity, and declining ecosystem productivity. These disturbances can affect transportation infrastructure, manufacturing facilities, agricultural production, energy availability, and the reliability of suppliers. Christopher and Peck (2004) emphasize the importance of developing resilient supply chains through risk management, collaboration, flexibility, and organizational preparedness. Similarly, Ponomarov and Holcomb (2009) conceptualize supply chain resilience as the adaptive capability of supply chains to prepare for unexpected events, respond to disruptions, and recover while maintaining operational continuity.

Although sustainable supply chain management and supply chain resilience are increasingly discussed together, their relationship is complex. Environmental initiatives may strengthen resilience by improving resource efficiency, reducing dependence on vulnerable resources, diversifying suppliers, and encouraging collaboration. For example, circular economy strategies can reduce dependence on virgin materials, while renewable energy adoption can decrease exposure to fossil-fuel price volatility. However, certain sustainability initiatives may also create vulnerabilities when they depend on geographically concentrated suppliers, specialized technologies, or limited material sources. Therefore, the relationship between green practices and resilience should be evaluated in terms of both environmental benefits and operational trade-offs. Environmental performance represents another central dimension of sustainable supply chain management. It encompasses measurable improvements in

greenhouse gas emissions, energy efficiency, water consumption, material utilization, waste generation, pollution prevention, and resource conservation. Empirical research has demonstrated that green supply chain practices can contribute to improved environmental and operational performance, although the magnitude and consistency of these outcomes vary across industries and organizational contexts (Zhu et al., 2008; Green et al., 2012). These findings suggest that effective sustainability management requires both the implementation of environmental practices and the development of performance measurement systems capable of evaluating their actual outcomes.
Despite the growing literature on green supply chain management, climate resilience, and corporate environmental performance, these research areas are frequently examined separately. A more integrated understanding is necessary to explain how climate-related pressures influence organizational strategies, how green practices contribute to resilience, and how these mechanisms ultimately affect environmental performance.
Accordingly, this review aims to synthesize the literature on sustainable supply chain management in the era of climate change, with particular emphasis on three interconnected dimensions: green supply chain management practices, organizational resilience, and environmental performance. The specific objectives are to: (1) examine the major environmental and climate-related pressures affecting global supply chains; (2) identify the principal green supply chain practices adopted to improve environmental sustainability; (3) explain how green supply chain practices and organizational capabilities contribute to climate resilience; (4) evaluate the relationships between sustainable supply chain strategies and environmental performance; and (5) identify implementation challenges, research gaps, and future research priorities.
The review develops an integrated conceptual framework connecting climate-related pressures, green supply chain practices, organizational resilience, and environmental performance. This framework provides a foundation for future empirical research and practical sustainability strategies.

2. Methodology

2.1. Review approach and literature identification

This review adopts a systematic literature review approach to synthesize research on sustainable supply chain management, climate change, green supply chain practices, organizational resilience, and environmental performance. A systematic approach is appropriate because these topics span several interconnected research areas, including supply chain management, environmental management, industrial ecology, operations management, climate adaptation, and sustainability science. The review is informed by established systematic review principles, particularly the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which provides guidance for transparent reporting of literature identification, screening, eligibility assessment, and inclusion. In addition, the review draws on established approaches to systematic synthesis in supply chain management, including the review framework developed by Seuring and Müller (2008).
Relevant literature was identified through major academic databases, including Scopus, Web of Science, ScienceDirect, SpringerLink, Wiley Online Library, and Google Scholar. The search strategy combined terms relating to sustainable supply chains, climate change, green practices, organizational resilience, and environmental performance. Representative search terms include "sustainable supply chain management" OR "green supply chain management"; "climate change" OR "climate risk" OR "supply chain decarbonization"; "green procurement" OR "eco-design" OR "sustainable logistics"; "supply chain resilience" OR "organizational resilience" OR "climate adaptation"; "environmental performance" OR "carbon emissions" OR "resource efficiency"; and "circular economy" OR "reverse logistics" OR "closed-loop supply chains". Boolean operators were used to combine these search terms and identify publications addressing multiple dimensions of the research

topic. For example: ("sustainable supply chain management" OR "green supply chain management") AND ("climate change" OR "climate risk" OR "climate resilience" OR "decarbonization") AND ("organizational resilience" OR "supply chain resilience" OR "environmental performance").

2.2. Inclusion and exclusion criteria

The review prioritized peer-reviewed journal articles, systematic reviews, meta-analyses, empirical studies, and influential conceptual contributions. Both foundational publications and recent studies were considered to capture the theoretical development and contemporary evolution of sustainable supply chain management. Publications were included when they address at least one of the following themes: (i) environmental sustainability in supply chains; (ii) green supply chain management practices; (iii) climate-related supply chain risks and adaptation; (iv) organizational or supply chain resilience; and (v) environmental performance measurement. Studies focusing exclusively on unrelated operational or financial supply chain issues without meaningful sustainability or climate relevance were excluded. Non-peer-reviewed promotional materials, duplicate publications, and studies without sufficient methodological or conceptual information were also excluded.

2.3. Literature synthesis and analytical framework

The selected literature was examined through thematic synthesis. Relevant findings were organized into four analytical categories: climate-related pressures, green supply chain practices, organizational resilience mechanisms, and environmental performance outcomes. The analysis also considered the relationships among these categories. Particular attention was given to the mechanisms through which green supply chain practices may improve resilience, the conditions under which these practices produce environmental benefits, and the organizational and institutional factors influencing their effectiveness. The synthesis draws on the natural resource-based view (NRBV), the resource-based view (RBV), stakeholder theory, and dynamic capabilities theory. These theoretical perspectives help explain why organizations develop environmental capabilities, collaborate with supply chain partners, and adapt operational strategies to changing environmental conditions (Hart, 1995; Barney, 1991; Freeman, 1984; Teece et al., 1997).

3. Sustainable supply chain management and climate change

3.1. Concept and evolution of sustainable supply chain management

Sustainable supply chain management has evolved from traditional supply chain management through the integration of environmental and social considerations into organizational and interorganizational decision-making. Traditional supply chain management emphasizes the coordination of material, information, and financial flows to improve efficiency, responsiveness, and customer satisfaction. However, conventional approaches may overlook environmental externalities associated with resource extraction, production, transportation, product consumption, and waste disposal.

Seuring and Müller (2008) identify two major approaches to SSCM: managing supply chains to address sustainability-related pressures and improving supply chain performance through sustainable practices. These approaches demonstrate that environmental sustainability is not simply an additional operational consideration but an increasingly important component of supply chain strategy. Carter and Rogers (2008) further emphasize that sustainable supply chain management integrates environmental and social considerations with economic

performance and organizational resilience. Their conceptual framework identifies the importance of risk management, transparency, strategy, and organizational culture in achieving long-term sustainability. This perspective is particularly relevant to climate change because environmental risks increasingly influence supply chain continuity, investment decisions, supplier relationships, and corporate competitiveness.

The evolution of SSCM has also been influenced by growing stakeholder expectations, environmental regulations, international sustainability commitments, and corporate climate targets. Organizations are increasingly expected to demonstrate environmental responsibility throughout their value chains rather than reporting only their direct operational emissions. Consequently, supplier selection, purchasing decisions, logistics management, product design, and end-of-life recovery have become important components of corporate sustainability strategies.

3.2. Climate-related pressures on global supply chains

Climate change affects supply chains through physical, transitional, and systemic risks. Physical risks arise from climate-related hazards that can damage infrastructure, disrupt production, reduce resource availability, and interrupt transportation networks. Acute hazards include floods, storms, hurricanes, wildfires, and heatwaves, whereas chronic risks include increasing temperatures, sea-level rise, changing precipitation patterns, and long-term water scarcity. The Intergovernmental Panel on Climate Change (IPCC, 2022) identifies climate-related risks to infrastructure, economic activities, ecosystems, and human systems. These risks have implications for supply chains because production and distribution systems depend on reliable transportation, energy, water, agricultural resources, and industrial infrastructure. For example, agricultural supply chains are particularly vulnerable to changing precipitation patterns, drought, heat stress, and extreme weather events. Food production, processing, storage, and distribution may be affected by declining agricultural productivity and disruptions to transportation and cold-chain infrastructure. Similarly, manufacturing supply chains may experience production interruptions when water or energy supplies become unreliable.

Climate-related disruptions can also affect geographically concentrated production networks. When organizations depend on a limited number of suppliers or transportation routes, extreme weather events can generate cascading disruptions across interconnected supply chain activities. Ivanov and Dolgui (2020) demonstrate the importance of understanding interconnected supply chain structures and the potential propagation of disruptions through complex networks.

Transitional risks arise from changes associated with the shift toward a low-carbon economy. These include stricter environmental regulations, carbon pricing, technological changes, changing consumer preferences, and increasing investor expectations for climate-related disclosure. Organizations that fail to adapt their supply chains may face higher compliance costs, reduced market access, reputational damage, and stranded assets.

Systemic risks occur when multiple environmental, economic, technological, and institutional disruptions interact. For example, extreme weather events may coincide with energy price volatility, transportation interruptions, and shortages of critical raw materials. These interactions demonstrate why climate risk management should be integrated into strategic supply chain planning.

3.3. Integrating climate mitigation and adaptation into supply chain management

Climate mitigation and adaptation represent complementary dimensions of sustainable supply chain management. Mitigation focuses on reducing greenhouse gas emissions and enhancing carbon efficiency, whereas adaptation involves adjusting supply chain operations to minimize vulnerability to actual or expected climate impacts.

Mitigation strategies include renewable energy adoption, energy-efficient manufacturing, low-carbon transportation, sustainable procurement, product redesign, material substitution, and circular resource management. These interventions aim to reduce emissions throughout supply chain operations and value chains. Climate adaptation requires a different but complementary set of organizational interventions. These include climate risk assessments, supplier diversification, infrastructure protection, alternative transportation routes, emergency inventory planning, water management, and business continuity strategies. The two dimensions should be integrated because mitigation without adaptation may produce environmentally efficient but climate-vulnerable supply chains. Conversely, adaptation without mitigation may improve operational continuity while maintaining high-emission production and distribution systems. For example, a manufacturing company may reduce its carbon footprint through renewable electricity and energy-efficient equipment while simultaneously strengthening climate resilience through water recycling, flood protection, and geographically diversified suppliers. This integrated approach helps organizations address both the causes and consequences of climate change.

Figure 1 illustrates the proposed conceptual relationships. Climate-related pressures stimulate the adoption of green supply chain practices and resilience-oriented organizational capabilities. Their interaction contributes to environmental performance and longer-term sustainability. This framework builds on the SSCM perspective of Carter and Rogers (2008), the green supply chain literature of Srivastava (2007), and the supply chain resilience perspective of Ponomarov and Holcomb (2009).

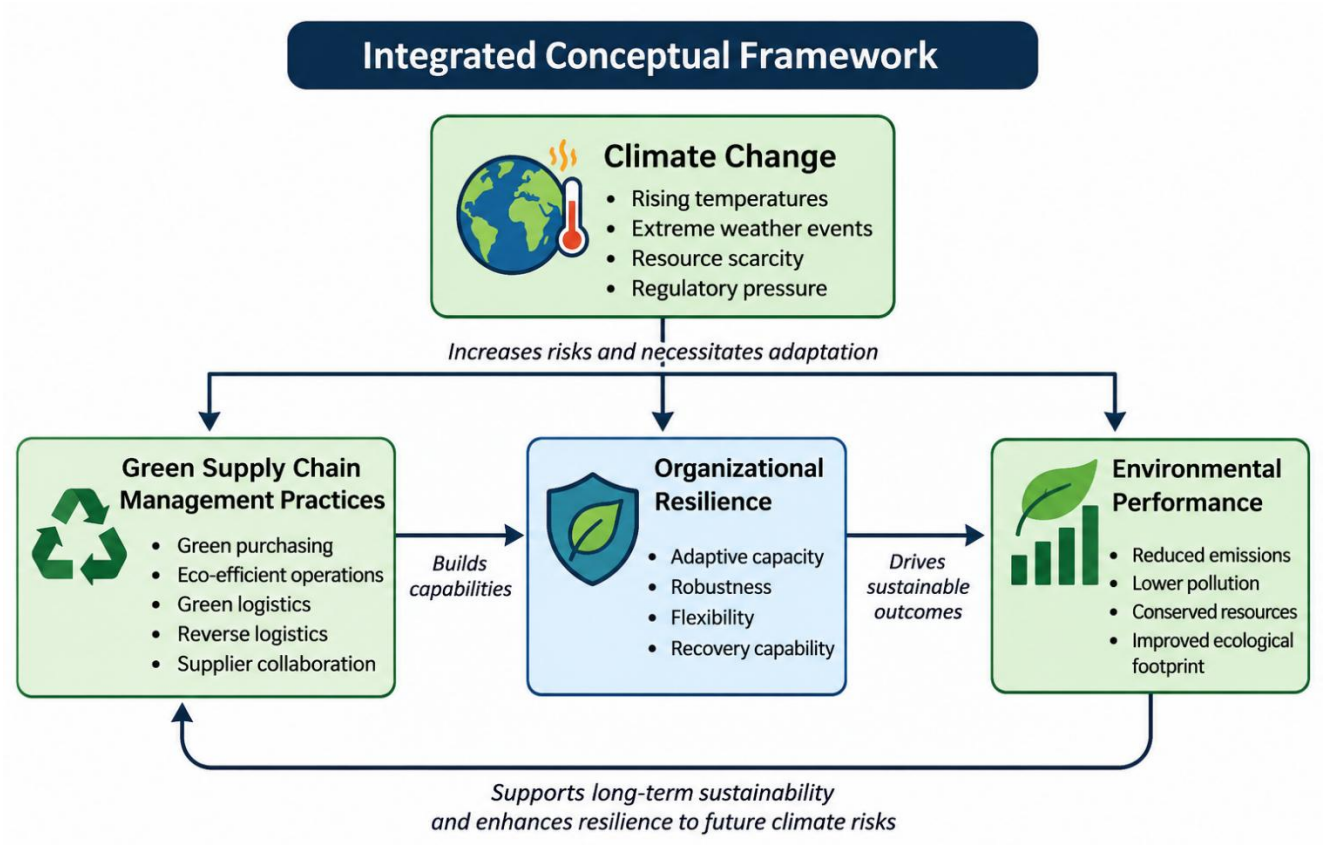


Figure 1. Integrated conceptual framework linking climate change, green supply chain management practices, organizational resilience, and environmental performance

4. Green supply chain practices and organizational resilience

4.1. Green procurement and sustainable supplier management

Green procurement is an important entry point for integrating environmental sustainability into supply chain operations. It involves selecting products, materials, and suppliers based on environmental criteria, including energy efficiency, resource consumption, emissions, pollution prevention, waste generation, and environmental management practices. Organizations can incorporate environmental requirements into supplier evaluation, purchasing contracts, product specifications, and procurement policies. Supplier selection may consider environmental certifications, carbon footprints, environmental compliance records, and the use of renewable or recycled materials. Supplier collaboration is particularly important because many environmental impacts occur outside the direct operational boundaries of purchasing organizations. Organizations can work with suppliers to improve energy efficiency, reduce packaging, minimize hazardous substances, optimize transportation, and develop lower-carbon materials. Vachon and Klassen (2008) demonstrate the importance of environmental collaboration and monitoring within supply chains. Their research highlights the role of interorganizational relationships in supporting environmental improvements across manufacturing networks.

Green procurement can also contribute to resilience by reducing dependence on environmentally vulnerable materials and suppliers. For example, supplier diversification and the identification of alternative sustainable materials can reduce exposure to localized resource shortages. However, organizations must avoid replacing one vulnerability with another by relying excessively on a small number of certified suppliers or geographically concentrated sources.

4.2. Eco-design and sustainable product development

Eco-design integrates environmental considerations into product development and design decisions. It aims to reduce environmental impacts throughout the product life cycle, including raw-material extraction, manufacturing, transportation, product use, and disposal. Important eco-design strategies include material reduction, design for durability, modular product architecture, repairability, recyclability, energy efficiency, and the substitution of hazardous materials. These practices can reduce resource consumption and waste while facilitating product recovery and reuse. Life-cycle thinking is particularly important because improvements in one supply chain stage may create environmental burdens elsewhere. For example, lightweight materials may reduce transportation emissions but require more energy-intensive production processes. Similarly, replacing conventional materials with recycled alternatives may improve resource efficiency but require additional collection and processing infrastructure. Life-cycle assessment (LCA) provides a methodological basis for evaluating these trade-offs. ISO 14040 and ISO 14044 establish principles and requirements for life-cycle assessment, including goal and scope definition, inventory analysis, impact assessment, and interpretation (ISO, 2006a, 2006b). Eco-design can improve organizational resilience by reducing dependence on scarce raw materials, facilitating component substitution, and extending product lifetimes. Modular designs and standardized components can also make maintenance and repair easier during supply disruptions.

4.3. Cleaner production and resource efficiency

Cleaner production focuses on preventing environmental pollution and reducing resource consumption at the source rather than relying exclusively on end-of-pipe treatment. It involves improvements in production

processes, energy management, material utilization, water efficiency, chemical management, and waste prevention. Industrial organizations can implement cleaner production through process optimization, equipment modernization, heat recovery, renewable energy, water recycling, and improved production planning. These measures can reduce operating costs while lowering environmental impacts. Energy efficiency is especially important because industrial energy consumption is associated with substantial greenhouse gas emissions in many sectors. Organizations can reduce emissions by adopting efficient motors, optimizing production schedules, improving insulation, recovering waste heat, and integrating renewable electricity.

Resource efficiency also contributes to climate resilience. Manufacturing systems that reduce water consumption and material requirements may be less vulnerable to shortages, price fluctuations, and climate-related resource constraints. Nevertheless, efficiency improvements should be evaluated carefully because reductions in environmental intensity do not necessarily produce absolute reductions in environmental impacts. Increased production volumes may offset efficiency gains, a phenomenon associated with rebound effects. Therefore, organizations should monitor both environmental intensity indicators and absolute environmental footprints.

4.4. Sustainable logistics and low-carbon transportation

Transportation and logistics are important sources of supply chain emissions. The environmental impacts of logistics depend on transportation modes, distances, vehicle technologies, fuel types, load factors, warehouse energy consumption, packaging, and distribution network structures. Green logistics strategies include transportation route optimization, shipment consolidation, improved vehicle utilization, modal shifts, fuel-efficient vehicles, electrification, alternative fuels, and improved warehouse energy management. Organizations can reduce emissions by shifting suitable freight from road to rail or maritime transport, improving vehicle loading, reducing empty returns, and optimizing delivery schedules. However, the environmental benefits of different transportation strategies depend on the characteristics of the goods, delivery requirements, geographical conditions, and energy sources.

Reverse logistics also plays an important role by facilitating the collection, repair, refurbishment, remanufacturing, and recycling of used products. These activities can reduce demand for virgin materials and decrease waste disposal requirements. From a resilience perspective, flexible transportation networks and alternative distribution routes can reduce vulnerability to extreme weather events and infrastructure disruptions. The development of multiple transportation options may also improve recovery capacity when primary routes become unavailable. However, transportation diversification can increase emissions if alternative routes are longer or less efficient. Consequently, logistics decisions should balance carbon efficiency, cost, delivery reliability, and climate-related risk exposure.

4.5. Circular economy and closed-loop supply chains

Circular economy principles provide an important foundation for sustainable supply chain transformation. Unlike linear production systems based on extraction, production, consumption, and disposal, circular systems aim to maintain the value of products, materials, and resources for as long as possible. Circular supply chain strategies include reuse, repair, refurbishment, remanufacturing, recycling, industrial symbiosis, and product-service systems. These strategies can reduce demand for virgin resources and minimize waste generation. Genovese et al. (2017) demonstrate the relevance of integrating sustainable supply chain management with circular economy principles, emphasizing the importance of evaluating environmental performance across interconnected production and recovery processes. Closed-loop supply chains connect forward distribution with reverse flows of

used products and materials. Guide and Van Wassenhove (2009) explain how effective closed-loop supply chains require coordination between product recovery, reverse logistics, and business processes.

Circularity can strengthen resilience by providing alternative sources of materials, reducing dependence on imported resources, and creating recovery pathways when conventional supply channels are disrupted. However, the effectiveness of circular strategies depends on material quality, collection infrastructure, product design, recycling technologies, and market demand for recovered materials. It is also important to recognize that recycling does not automatically guarantee lower environmental impacts. Collection, sorting, transportation, and processing may require substantial energy and generate additional emissions. Therefore, circular strategies should be evaluated using life-cycle approaches rather than relying exclusively on recycling rates.

4.6. Digital technologies and supply chain visibility

Digital technologies are increasingly important for improving the transparency, efficiency, and responsiveness of sustainable supply chains. Technologies such as artificial intelligence, the Internet of Things (IoT), blockchain, digital twins, cloud computing, and advanced analytics can improve environmental monitoring and operational decision-making. IoT sensors can monitor energy consumption, transportation conditions, temperature, water use, and equipment performance. Artificial intelligence can support demand forecasting, inventory optimization, transportation planning, and predictive maintenance. Digital twins can simulate supply chain operations and evaluate alternative configurations under different disruption scenarios. Blockchain and distributed ledger technologies may support the traceability of materials, product origins, supplier information, and environmental claims. However, their effectiveness depends on data quality, interoperability, governance, and the reliability of information entered into the system. Digital technologies can improve resilience by increasing supply chain visibility and enabling earlier identification of disruptions. They can also support environmental performance monitoring through more accurate tracking of emissions, energy consumption, and material flows. Nevertheless, digitalization introduces challenges related to cybersecurity, data privacy, technological costs, infrastructure requirements, and digital inequalities among suppliers. Smaller organizations may experience particular difficulties adopting advanced digital technologies.

4.7. The contribution of green practices to organizational resilience

Organizational resilience refers to the ability of an organization to anticipate, prepare for, respond to, recover from, and adapt to disruptive events. In supply chains, resilience depends on the capabilities of individual organizations and the coordination of multiple supply chain partners. Christopher and Peck (2004) identify supply chain resilience as an important strategic requirement in increasingly complex and uncertain business environments. Ponomarov and Holcomb (2009) further emphasize preparedness, response, and recovery as central dimensions of resilience.

Green supply chain practices can support resilience through several mechanisms. First, resource efficiency reduces dependence on energy, water, and raw materials, potentially lowering exposure to resource scarcity. Second, supplier collaboration improves information exchange and enables organizations to coordinate responses to environmental disruptions. Third, circular supply chains provide alternative material sources through reuse and recovery. Fourth, sustainable product design can improve repairability and material substitution. Finally, digital monitoring and predictive analytics can improve the identification and management of climate-related risks. However, sustainability and resilience should not be assumed to be automatically compatible. Lean inventory systems, for example, may improve resource efficiency but reduce the availability of materials during disruptions.

Similarly, geographically concentrated renewable energy or specialized low-carbon materials may create new dependencies. Therefore, organizations need to evaluate environmental and resilience objectives together. This requires combining efficiency with flexibility, supplier diversification, strategic inventory management, risk monitoring, and collaboration. The main green practices, applications, and resilience contributions are summarized in Table 1.

Table 1. Major green supply chain management practices, their applications, and climate-related benefits

Green practice	Principal applications	Environmental benefits	Potential resilience contribution
Green procurement	Sustainable supplier selection, environmental purchasing criteria, recycled materials	Reduced resource consumption, pollution, and upstream emissions	Supplier diversification and reduced exposure to resource scarcity
Sustainable supplier management	Environmental audits, supplier collaboration, joint improvement programs	Improved environmental compliance and supplier performance	Better information exchange and coordinated disruption response
Eco-design	Lightweight materials, durable products, modularity, recyclability	Reduced life-cycle impacts and material consumption	Easier repair, substitution, and product recovery
Cleaner production	Energy efficiency, process optimization, water recycling	Lower emissions, pollution, and resource use	Reduced dependence on energy and water resources
Green logistics	Route optimization, shipment consolidation, modal shifts, efficient vehicles	Reduced transportation emissions and fuel consumption	Alternative routes and more flexible distribution
Circular supply chains	Reuse, repair, remanufacturing, recycling	Reduced virgin material demand and waste	Alternative material sources and improved resource security
Renewable energy adoption	Solar, wind, renewable electricity procurement	Reduced fossil-fuel-related emissions	Lower exposure to fossil-fuel price volatility, subject to system reliability
Digital supply chain management	IoT, AI, blockchain, digital twins, analytics	Improved monitoring and resource optimization	Greater visibility, early warning, and predictive capabilities
Climate risk management	Climate screening, scenario analysis, business continuity planning	Supports climate-informed environmental decisions	Improved preparedness, adaptation, and recovery

Source: Synthesized from Carter and Rogers (2008), Srivastava (2007), Vachon and Klassen (2008), Zhu et al. (2008), Guide and Van Wassenhove (2009), and Ivanov and Dolgui (2020).

Figure 2 illustrates how environmental interventions generate organizational capabilities and operational improvements that can jointly contribute to resilience and environmental performance. The framework highlights that the environmental and resilience benefits of green supply chain management are interconnected but not

necessarily identical. Their achievement requires appropriate organizational capabilities, supplier participation, and performance monitoring.

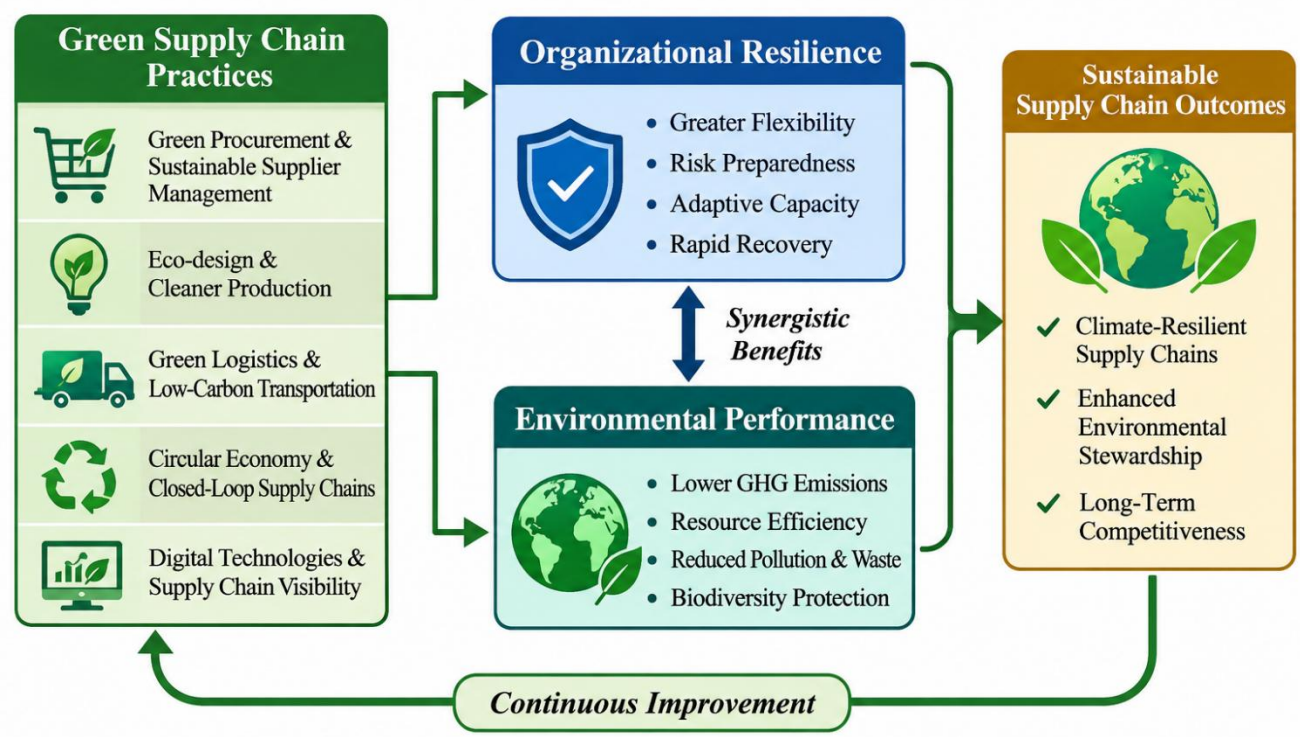


Figure 2. Pathways through which green supply chain practices enhance organizational resilience and environmental performance

5. Environmental performance and sustainability outcomes

5.1. Green supply chain management and environmental performance

Environmental performance is a central indicator of the effectiveness of sustainable supply chain management. It reflects the extent to which organizations reduce the environmental impacts of their activities and supply chain relationships. Relevant dimensions include greenhouse gas emissions, energy consumption, water use, material efficiency, waste generation, air and water pollution, and resource conservation. The relationship between GSCM and environmental performance has received considerable attention in empirical research. Zhu et al. (2008) examined green supply chain management practices and performance among Chinese manufacturing enterprises, identifying important relationships between environmental management practices and organizational performance. Green et al. (2012) also demonstrated that green supply chain management practices can improve environmental performance through the integration of environmental considerations into internal operations and external supply chain relationships.

The broader empirical evidence generally supports a positive relationship between environmental supply chain practices and organizational performance. Golicic and Smith (2013), through a meta-analysis of environmentally sustainable supply chain management research, identified positive relationships with market-based, operational, and accounting-based performance. These findings suggest that environmental improvements can result from coordinated interventions rather than isolated operational initiatives. For example, green procurement may reduce

the environmental impacts of purchased materials, cleaner production may reduce manufacturing emissions, and green logistics may lower transportation-related emissions. However, environmental performance should be evaluated using both absolute and relative indicators. A reduction in emissions per unit of production does not necessarily imply a reduction in total emissions if production volumes increase. Similarly, improvements in energy efficiency may not translate into lower total energy consumption when increased production offsets efficiency gains. Therefore, organizations should evaluate the environmental consequences of green supply chain practices across relevant life-cycle stages and geographical boundaries.

5.2. Supply chain decarbonization and greenhouse gas emissions reduction

Supply chain decarbonization is an increasingly important component of corporate climate strategies. It involves reducing greenhouse gas emissions across procurement, production, transportation, distribution, product use, and end-of-life activities. The Greenhouse Gas Protocol Corporate Accounting and Reporting Standard distinguishes between three categories of corporate emissions. Scope 1 emissions arise from sources owned or controlled by an organization, Scope 2 emissions originate from purchased electricity, steam, heating, and cooling, and Scope 3 emissions include other indirect emissions occurring throughout the value chain (WRI and WBCSD, 2004; WRI and WBCSD, 2011). Scope 3 emissions are particularly important for supply chain management because they include upstream activities such as purchased goods, capital goods, fuel- and energy-related activities, and transportation, as well as downstream activities such as product distribution, use, and end-of-life treatment. Reducing these emissions requires coordination between organizations and their supply chain partners. Important strategies include supplier engagement, low-carbon material substitution, renewable energy procurement, transportation optimization, energy-efficient manufacturing, and circular product design. Organizations can also establish science-based emissions reduction targets and integrate carbon accounting into procurement and investment decisions. The Science Based Targets initiative provides guidance for companies seeking to align emissions reduction targets with climate science, including value-chain considerations. However, Scope 3 accounting remains challenging because organizations frequently depend on supplier-specific information, industry emission factors, estimates, and secondary datasets. Differences in reporting boundaries, data quality, and calculation methods can limit comparability across organizations.

5.3. Resource efficiency, pollution prevention, and waste reduction

Resource efficiency is another important dimension of supply chain environmental performance. It involves reducing the quantity of materials, energy, and water required to deliver products and services while maintaining or improving operational functionality. Organizations can improve resource efficiency through cleaner production, eco-design, preventive maintenance, production optimization, and material recovery. These practices may reduce production costs and environmental impacts simultaneously. Water efficiency is especially important for industries that depend on water-intensive manufacturing processes, agricultural inputs, and industrial cooling. Water recycling, wastewater treatment, process optimization, and rainwater harvesting can reduce freshwater demand and improve operational continuity in water-stressed regions.

Waste reduction is similarly important. Organizations can minimize waste through improved inventory management, packaging optimization, material substitution, product durability, and industrial symbiosis. Industrial symbiosis enables organizations to use by-products and waste streams from other industries as production inputs, thereby reducing demand for virgin materials. Nevertheless, resource efficiency should be assessed within an appropriate life-cycle boundary. An intervention that reduces water use in manufacturing may

increase energy consumption through additional treatment requirements. Likewise, substituting one material for another may transfer environmental impacts to different stages of the supply chain. Life-cycle assessment provides an important means of identifying these potential trade-offs (ISO, 2006a, 2006b).

5.4. Organizational resilience as a pathway to environmental sustainability

Organizational resilience can contribute to environmental sustainability by enabling supply chains to maintain and improve their environmental performance under disruptive conditions. A resilient supply chain is not simply one that restores operations quickly after a disruption. It should also be capable of learning from disturbances, adjusting operational configurations, and improving its long-term adaptability. For example, organizations exposed to recurring water shortages may invest in water-efficient technologies, alternative production processes, and supplier diversification. Such measures can improve both climate adaptation and resource efficiency. Similarly, organizations experiencing repeated transportation disruptions may develop alternative distribution networks, improve shipment consolidation, and invest in lower-carbon logistics. These strategies can strengthen operational continuity while reducing emissions, provided that alternative routes and modes are evaluated for their environmental consequences.

Ivanov and Dolgui (2020) emphasize the importance of understanding interconnected supply chain structures and the propagation of disruptions. Their perspective suggests that resilience strategies should consider the dependencies among suppliers, production facilities, logistics providers, and customers. Nevertheless, the relationship between resilience and environmental performance is conditional. Maintaining additional inventory, developing redundant production facilities, or diversifying transportation networks may increase resource consumption and emissions. Consequently, resilience strategies should be designed to minimize unnecessary environmental burdens.

5.5. Measuring environmental performance in sustainable supply chains

Effective environmental performance measurement requires a combination of quantitative indicators, standardized methodologies, and reliable data collection systems. Organizations should establish performance indicators that reflect their most significant environmental impacts and relevant supply chain activities. These indicators should be aligned with organizational sustainability objectives, industry-specific environmental characteristics, and applicable reporting standards. Important environmental performance indicators are presented in Table 2.

Environmental indicators should be interpreted in relation to operational scale and supply chain boundaries. For example, emissions intensity can be measured per unit of product, production volume, revenue, or another relevant functional unit. Absolute emissions should also be reported to determine whether improvements in efficiency translate into reductions in overall environmental impacts. Furthermore, organizations should distinguish between actual emissions reductions, avoided emissions, and carbon removals. These concepts are not interchangeable and should be accounted for transparently to prevent overstating environmental performance.

Digital monitoring technologies can improve the availability and accuracy of environmental data. IoT sensors, automated energy monitoring, supplier reporting platforms, and digital traceability systems can support continuous measurement. However, data verification, methodological consistency, and independent assurance remain essential.

Table 2. Relationships between sustainable supply chain practices, organizational resilience, and environmental performance

Performance dimension	Representative indicators	Relevant green practices	Expected contribution
Carbon performance	Absolute GHG emissions; emissions intensity; Scope 1, 2, and 3 emissions	Renewable energy, green procurement, low-carbon logistics	Reduced climate footprint
Energy performance	Energy consumption; renewable energy share; energy intensity	Cleaner production, efficient equipment, renewable energy	Lower energy demand and fossil-fuel dependence
Water performance	Water withdrawal; water consumption; water intensity; wastewater reuse	Water recycling, efficient processing, sustainable sourcing	Reduced freshwater pressure
Material efficiency	Virgin material consumption; recycled material share; material productivity	Eco-design, recycling, remanufacturing, material substitution	Reduced resource extraction
Waste performance	Waste generation; landfill disposal; recycling and recovery rates	Circular economy, reverse logistics, waste prevention	Reduced waste and improved resource recovery
Pollution performance	Air pollutant emissions; wastewater quality; hazardous waste generation	Cleaner production, chemical substitution, pollution prevention	Lower environmental pollution
Biodiversity and ecosystem impacts	Land-use change; habitat disturbance; ecosystem-related impacts	Sustainable sourcing, responsible land management, supplier monitoring	Reduced ecosystem degradation
Climate resilience	Disruption frequency; recovery time; supplier concentration; climate-risk exposure	Supplier diversification, climate adaptation, digital monitoring	Improved preparedness and continuity

Source: Synthesized from WRI and WBCSD (2004, 2011), ISO (2006a, 2006b), Zhu et al. (2008), Golicic and Smith (2013), and environmental supply chain management literature.

5.6. Institutional, stakeholder, and governance influences

The implementation of sustainable supply chain management is influenced by external stakeholders, institutional pressures, and governance arrangements. Regulatory requirements, investor expectations, customer preferences, environmental standards, and civil society organizations can encourage businesses to adopt greener supply chain practices. Stakeholder theory suggests that organizations must consider the interests and expectations of groups that influence or are affected by their activities (Freeman, 1984). In supply chains, these stakeholders include suppliers, employees, customers, regulators, investors, local communities, and environmental organizations.

Institutional theory also provides an explanation for the adoption of environmental practices. Organizations may respond to coercive pressures arising from regulations, normative pressures associated with professional standards, and mimetic pressures resulting from the adoption of practices by competitors and industry leaders (DiMaggio and Powell, 1983). These pressures can encourage environmental certification, supplier audits, carbon

reporting, and sustainability-oriented procurement. However, formal adoption does not necessarily guarantee actual environmental improvements. Organizations may adopt environmental policies primarily to maintain legitimacy or satisfy stakeholder expectations without implementing substantive operational changes. Therefore, effective governance should combine formal environmental requirements with measurable performance targets, transparent reporting, supplier engagement, independent verification, and continuous improvement.

6. Challenges, research gaps, and future research directions

6.1. Financial, technological, and organizational barriers

Despite the potential environmental and resilience benefits of sustainable supply chain management, its implementation remains challenging. One major barrier is the financial investment required for cleaner production technologies, renewable energy systems, digital monitoring, sustainable materials, and circular infrastructure. These investments may be particularly difficult for small and medium-sized enterprises (SMEs), which frequently operate with limited financial resources, technical expertise, and bargaining power. SMEs may also depend on larger customers that impose environmental requirements without providing sufficient technical or financial support. Technological limitations represent another important constraint. The availability of accurate supplier data, digital monitoring infrastructure, emissions measurement systems, and advanced environmental technologies varies considerably across industries and geographical regions. Organizational resistance can further delay implementation. Employees and managers may prioritize short-term financial objectives, production efficiency, and delivery reliability over environmental improvements. The adoption of sustainable practices may also require changes in procurement policies, supplier relationships, production systems, and organizational culture.

6.2. Supplier coordination and supply chain complexity

Global supply chains often involve multiple tiers of suppliers, subcontractors, logistics providers, and distributors. This complexity creates difficulties in collecting environmental information and monitoring compliance beyond direct suppliers. Organizations may have detailed environmental information about their immediate suppliers but limited visibility into second-, third-, and lower-tier suppliers. This problem is particularly important for Scope 3 emissions accounting and the assessment of upstream environmental impacts.

Supplier resistance may arise when environmental requirements increase operational costs or require technological changes. Differences in environmental regulations, certification systems, and reporting practices can further complicate cross-border supply chain coordination. Vachon and Klassen (2008) highlight the importance of environmental collaboration and monitoring in improving supply chain environmental management. Their findings suggest that collaborative approaches can be more effective than relying exclusively on compliance requirements. Future research should therefore examine how organizations can establish effective multi-tier supplier engagement mechanisms, particularly when suppliers operate in countries with different institutional and technological conditions.

6.3. Conflicts between efficiency, resilience, and sustainability

An important challenge is the potential conflict between operational efficiency, organizational resilience, and environmental sustainability. Traditional lean supply chain strategies often emphasize minimizing inventories,

reducing costs, and maximizing asset utilization. Although these approaches may improve efficiency, they can increase vulnerability when supply chains experience unexpected disruptions.

Conversely, resilience strategies such as maintaining additional inventory, developing alternative production facilities, and diversifying transportation routes may increase material consumption, energy use, and emissions. Similarly, geographically diversified sourcing may improve resilience but increase transportation distances. Local sourcing may reduce transportation requirements but create dependence on regional suppliers that are vulnerable to the same climate-related hazards. These trade-offs indicate that environmental sustainability and resilience cannot be evaluated independently. Organizations need integrated decision-making approaches that consider carbon emissions, resource efficiency, operational continuity, recovery capacity, and long-term costs.

6.4. Climate risk assessment and uncertainty

Climate risk assessment presents methodological challenges because climate-related hazards vary across geographical locations, industries, time horizons, and supply chain configurations. Organizations may lack sufficient information about the climate exposure of suppliers, transportation corridors, manufacturing facilities, and critical resource sources. Climate hazards may also interact with economic and geopolitical disruptions, increasing uncertainty.

Future research should investigate how climate scenario analysis, geographic information systems, remote sensing, digital twins, and artificial intelligence can improve supply chain risk assessment. Particular attention should be given to distinguishing between acute and chronic climate risks. Organizations should also examine how climate-related hazards may affect different supply chain tiers and how disruptions can propagate through interconnected production and distribution networks.

6.5. Research gaps and future research priorities

Although research on sustainable supply chain management has expanded considerably, several important knowledge gaps remain. First, the relationship between green supply chain practices and organizational resilience requires further empirical investigation. Many studies examine environmental performance or resilience independently, limiting understanding of their interaction. Second, additional research is needed to distinguish between the mitigation and adaptation outcomes of sustainable supply chain strategies. For example, renewable energy adoption primarily contributes to emissions reduction, whereas climate risk screening and infrastructure protection primarily contribute to adaptation.

Third, the environmental consequences of resilience strategies require more systematic assessment. Supplier diversification, redundant capacity, and strategic inventories may improve continuity but can also increase environmental impacts. Fourth, research should examine the role of digital technologies in integrating carbon accounting, supplier monitoring, climate risk prediction, and environmental performance measurement. Fifth, the challenges faced by SMEs and suppliers in developing economies require greater attention. Much of the literature focuses on large organizations with relatively advanced environmental management systems.

Finally, the development of standardized and comparable environmental and resilience indicators remains essential for evaluating sustainable supply chain performance across different industries and geographical contexts. The principal research gaps and proposed priorities are summarized in Table 3.

Table 3. Key research gaps and future research priorities in climate-resilient sustainable supply chain management

Research gap	Current limitation	Recommended future research direction
Integration of green practices and resilience	Environmental sustainability and resilience are frequently examined separately	Develop integrated empirical models linking green practices, resilience capabilities, and environmental outcomes
Climate mitigation and adaptation	Limited differentiation between emissions reduction and climate risk reduction	Examine the combined effects of mitigation and adaptation strategies
Scope 3 emissions accounting	Supplier data limitations and inconsistent accounting boundaries	Develop standardized multi-tier carbon accounting and verification approaches
Digital technologies	Limited evidence on the combined use of AI, IoT, blockchain, and digital twins	Investigate digital technologies for real-time environmental monitoring and climate risk prediction
Sustainability–resilience trade-offs	Limited understanding of the environmental costs of redundancy and diversification	Develop multi-objective models integrating emissions, cost, and resilience
SME participation	Limited financial and technological capacity among smaller suppliers	Investigate collaborative financing, technology transfer, and accessible environmental management systems
Circular supply chain resilience	Uncertainty regarding the environmental and operational benefits of recovery systems	Evaluate closed-loop supply chains using life-cycle and resilience indicators
Long-term environmental performance	Many studies rely on cross-sectional data and short-term indicators	Conduct longitudinal studies to assess persistent environmental improvements
Climate-related supply chain governance	Differences in environmental regulations and supplier requirements	Examine institutional coordination, accountability, and independent verification

Source: Authors' synthesis based on Seuring and Müller (2008), Carter and Rogers (2008), and Ivanov and Dolgui (2020).

6.6. Future research roadmap

Future research should move beyond examining individual green supply chain practices and develop integrated frameworks that explain how environmental strategies, organizational capabilities, institutional pressures, and climate-related risks interact. One priority is the development of quantitative models that simultaneously evaluate environmental performance and organizational resilience. Such models could integrate carbon emissions, resource efficiency, disruption probability, recovery time, supplier concentration, and operational costs.

Another important direction concerns the application of digital technologies to supply chain environmental governance. Artificial intelligence and advanced analytics could support climate risk prediction, supplier screening, emissions estimation, and real-time resource monitoring. However, research should also examine the reliability, transparency, cybersecurity, and environmental footprint of these technologies. Longitudinal and comparative studies are also necessary to establish whether green supply chain practices generate sustained

environmental improvements. Research should compare different industries, geographical regions, organizational sizes, and regulatory environments. Finally, greater attention should be given to the role of public policy and collaborative governance. Environmental regulations, carbon pricing, sustainability standards, green finance, and technical assistance can encourage organizations to adopt climate-resilient and environmentally responsible supply chain strategies.

Figure 3 identifies major research priorities and illustrates how interdisciplinary research can support the development of climate-resilient and environmentally sustainable supply chain systems. The proposed roadmap emphasizes the need to combine technological innovation, organizational capabilities, environmental assessment, and collaborative governance. Such integration can help move sustainable supply chain management from fragmented operational interventions toward more comprehensive climate-responsive strategies.

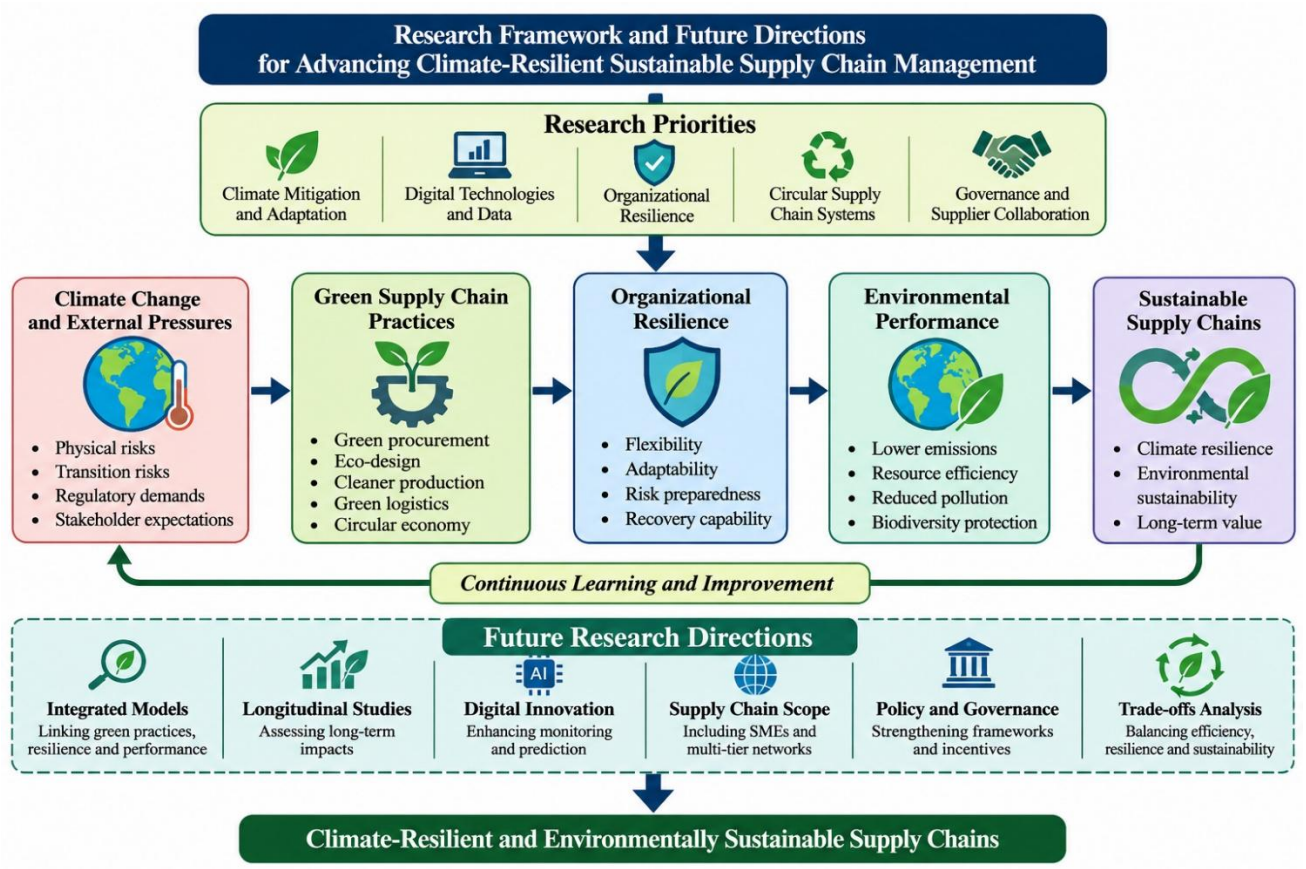


Figure 3. Research framework and future directions for advancing climate-resilient sustainable supply chain management

7. Conclusions and implications

Sustainable supply chain management has become an important strategic approach for addressing the interconnected challenges of climate change, environmental degradation, resource scarcity, and operational uncertainty. This review demonstrates that green supply chain practices, organizational resilience, and environmental performance are closely related dimensions of sustainable supply chain development. Green procurement, sustainable supplier management, eco-design, cleaner production, low-carbon logistics, circular economy strategies, and digital technologies provide important mechanisms for reducing environmental impacts

throughout supply chains. These practices can improve resource efficiency, reduce greenhouse gas emissions, minimize waste, and strengthen environmental accountability. Existing empirical research and meta-analyses generally support positive relationships between green supply chain practices and environmental performance.

The review also highlights the importance of organizational resilience in responding to climate-related disruptions. Supplier diversification, supply chain visibility, resource efficiency, digital monitoring, climate risk assessment, and collaborative governance can improve preparedness, adaptability, and recovery capacity. However, environmental sustainability and resilience do not always produce mutually reinforcing outcomes. Strategies such as additional inventory, redundant production capacity, and geographically diversified sourcing may increase environmental impacts if they are not carefully designed. Consequently, organizations should adopt integrated decision-making approaches that consider both environmental and operational objectives.

Several implementation challenges remain, including financial limitations, technological barriers, supplier coordination difficulties, inconsistent environmental standards, and inadequate Scope 3 emissions data. Addressing these challenges requires stronger collaboration among organizations, suppliers, policymakers, technology providers, and research institutions. From a managerial perspective, companies should integrate climate risk assessments into procurement and supply chain planning, establish measurable environmental targets, strengthen supplier engagement, and adopt reliable carbon accounting and environmental monitoring systems. Policymakers can support this transition through consistent environmental regulations, technical assistance, climate-related disclosure requirements, and incentives for low-carbon technologies and circular business models.

From a research perspective, greater attention should be directed toward integrated models linking green practices, climate adaptation, organizational resilience, and environmental performance. Longitudinal research, cross-industry comparisons, quantitative assessments, and digital monitoring applications are particularly important for advancing the field.

Overall, the transition toward climate-resilient sustainable supply chains requires moving beyond isolated environmental initiatives toward coordinated strategies that combine climate mitigation, adaptation, resource efficiency, organizational flexibility, and transparent environmental governance. Such an approach can contribute to long-term organizational competitiveness while supporting broader environmental sustainability and climate objectives.

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