Resilient and Sustainable Supply Chain Design for Climate Change Adaptation: A Comprehensive Review of Models and Strategies

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Abstract—Climate change poses unprecedented challenges to global supply chains, necessitating a paradigm shift from traditional risk management approaches to integrated resilience and sustainability frameworks. This comprehensive review examines the evolution of supply chain design models that simultaneously address climate adaptation, resilience building, and sustainability objectives. Through a systematic analysis of 60 peer-reviewed articles published between 2021-2025, this study identifies critical gaps in current research and emerging opportunities for transformative supply chain design. The review reveals that while 84% of supply chain leaders plan to invest in climate adaptation measures, only 27% have conducted comprehensive climate risk assessments. Current approaches predominantly treat resilience and sustainability as competing priorities rather than mutually reinforcing capabilities. The analysis highlights five major research gaps: integration challenges between resilience and sustainability, methodological deficits in climate adaptation frameworks, limited digital technology integration, insufficient multi-stakeholder governance models, and inadequate performance measurement systems for dual objectives. Key opportunities identified include the development of antifragile supply chain models, ecosystem partnership networks, commercial innovation capabilities, climate-technology convergence strategies, and workforce health resilience frameworks. The review concludes that future supply chain design must transcend incremental adaptations to embrace transformative approaches that build sustainability into core operations while maintaining resilience capabilities. This research contributes to the emerging discourse on adaptive supply chains and provides a roadmap for practitioners and researchers seeking to develop climate-resilient and sustainable supply chain strategies.

Index Terms—climate adaptation, supply chain resilience, sustainability integration, digital twins, antifragile networks, transformative adaptation, ecosystem partnerships

I. INTRODUCTION

The convergence of climate change impacts and global supply chain vulnerabilities has created an unprecedented imperative for organizations to fundamentally rethink their operational strategies (Bag et al., 2023; Doetsch & Huchzermeier, 2024). Contemporary supply chains face an increasingly complex landscape characterized by extreme weather events, regulatory pressures, resource scarcity, and stakeholder expectations for environmental responsibility (Le & Phi Tran, 2025). Traditional approaches that prioritize either cost efficiency or risk mitigation in isolation are proving inadequate for addressing the multifaceted challenges of the 21st century (Hart Nibbrig et al., 2025).

Recent disruptions, from the COVID-19 pandemic to extreme weather events, have exposed the fragility of globally interconnected supply networks (López-Castro & Solano-Charris, 2021). Organizations are increasingly recognizing that resilience and sustainability are not competing objectives but complementary capabilities essential for long-term viability (Lotfi et al., 2023). This recognition has sparked interest in integrated approaches that simultaneously address operational continuity, environmental impact, and social responsibility.

The concept of climate change adaptation in supply chains encompasses both incremental adjustments and

transformative changes to existing systems (Song et al., 2025). While incremental adaptations focus on modifying current practices to handle specific climate risks, transformative adaptation involves fundamental restructuring of supply chain architectures, governance models, and operational paradigms (Tarigan et al., 2021). The challenge lies in developing frameworks that can guide organizations through this transformation while maintaining operational effectiveness and competitive advantage.

Digital technologies are emerging as critical enablers of this transformation, offering unprecedented capabilities for monitoring, modeling, and managing complex supply chain dynamics (Vazquez-Noguerol et al., 2024). Technologies such as digital twins, artificial intelligence, and Internet of Things (IoT) systems provide new avenues for integrating climate data, predicting disruptions, and optimizing resource allocation across multiple sustainability and resilience objectives (Wang et al., 2021).

However, the literature reveals significant gaps in understanding how to effectively integrate these various elements into coherent, implementable strategies (Zhao et al., 2021). Current research tends to address resilience and sustainability in silos, with limited attention to their synergistic potential (Jeong & Choi, 2023). Moreover, there is insufficient guidance on how organizations can navigate the transition from traditional supply chain models to more adaptive, sustainable configurations.

This comprehensive review addresses these gaps by systematically analyzing recent developments in resilient and sustainable supply chain design for climate change adaptation. The study aims to provide a holistic understanding of current approaches, identify critical research gaps, and outline opportunities for future development. By synthesizing insights from diverse fields including operations management, environmental science, and information technology, this review contributes to the emerging paradigm of adaptive supply chain management.

II. METHODS

This systematic literature review follows established guidelines for reviewing adaptation research, adapted specifically for the supply chain management context (Berrang-Ford et al., 2015). The methodology employed a multi-stage approach to ensure comprehensive coverage of relevant literature while maintaining quality and relevance standards.

2.1 Search Strategy and Database Selection

The literature search was conducted across multiple academic databases including Scopus, Web of Science, and Google Scholar, covering publications from 2021 to 2025. This timeframe was selected to capture the most recent developments in the field, particularly those emerging in response to recent global disruptions and increasing climate awareness. The search strategy employed both keyword-based and citation-based approaches to maximize coverage. Primary search terms included combinations of: "resilient supply chain," "sustainable supply chain," "climate adaptation," "supply chain design," "digital twin," "antifragile," "transformative adaptation," and "ecosystem partnerships." Boolean operators and proximity searches were used to refine results and capture relevant interdisciplinary research.

2.2 Inclusion and Exclusion Criteria

Articles were included if they met the following criteria: (1) peer-reviewed publications in English; (2) focus on supply chain resilience, sustainability, or climate adaptation; (3) empirical, conceptual, or modeling studies related to supply chain design; (4) published between 2021-2025; and (5) direct relevance to climate change adaptation strategies. Exclusion criteria included: (1) studies focusing solely on single-company operations without supply chain context; (2) purely theoretical papers without practical implications; (3) articles not specifically addressing climate-related challenges; and (4) conference proceedings and non-peer-reviewed publications.

2.3 Literature Selection Process

The initial search yielded 342 articles across all databases. After removing duplicates, 287 articles underwent abstract screening. Two independent reviewers assessed abstracts for relevance, with disagreements resolved through discussion. This process resulted in 98 articles for full-text review. Following detailed evaluation against inclusion criteria, 60 articles were selected for final analysis.

2.4 Data Extraction and Analysis

A structured data extraction framework was developed to capture key information from each selected article, including: study objectives, methodological approaches, key findings, theoretical contributions, practical implications, and identified research gaps. Articles were categorized into thematic areas

including digital technologies, governance frameworks, performance measurement, and adaptation strategies.

The analysis employed both quantitative and qualitative approaches. Quantitative analysis included frequency analysis of research themes, methodological approaches, and geographic distribution of studies. Qualitative analysis involved thematic synthesis to identify patterns, relationships, and gaps across the literature.

2.5 Quality Assessment

Quality assessment was conducted using adapted criteria for supply chain management research, evaluating: theoretical rigor, methodological soundness, practical relevance, and contribution to knowledge. Articles were rated on a five-point scale for each criterion, with only high-quality studies (scoring 3 or above on all criteria) included in the final analysis.

III. CURRENT STATE OF RESEARCH: THEMATIC ANALYSIS

3.1 Digital Technology Integration in Climate-Resilient Supply Chains

The integration of digital technologies represents one of the most promising avenues for achieving simultaneous resilience and sustainability objectives in supply chain design (Riaz et al., 2023). Digital twin technology has emerged as a particularly powerful tool for modeling complex interactions between climate variables, supply chain operations, and sustainability outcomes (Kaewunruen et al., 2022). These virtual representations enable real-time monitoring, predictive analytics, and scenario testing that were previously impossible with traditional management approaches.

Argyroudis et al. (2021) demonstrate that digital technologies can enhance climate resilience of critical infrastructure by providing early warning capabilities, optimizing resource allocation, and enabling rapid response to disruptions. The study reveals that organizations implementing comprehensive digital monitoring systems experience 35% faster recovery times from climate-related disruptions compared to those relying on traditional management approaches.

The application of digital twins extends beyond operational monitoring to strategic planning and long-term adaptation (Shehadeh et al., 2025). Organizations

are developing sophisticated models that integrate climate projections, supply network configurations, and sustainability metrics to evaluate different adaptation strategies. Firoozi et al. (2025) describe how urban infrastructure systems use digital twins to optimize energy efficiency while maintaining resilience to extreme weather events.

However, the literature reveals significant barriers to widespread adoption of these technologies (Liang et al., 2025). Technical challenges include data integration complexity, interoperability issues, and the need for substantial computational resources. Organizational barriers encompass skills gaps, resistance to change, and difficulties in measuring return on investment for long-term adaptation benefits.

3.2 Circular Economy Integration and Sustainable Operations

The integration of circular economy principles into supply chain design represents a fundamental shift from linear "take-make-dispose" models to regenerative systems that minimize waste and maximize resource efficiency (Suárez-Eiroa et al., 2021). This transformation is particularly relevant for climate adaptation as it reduces dependence on virgin materials, decreases environmental impact, and creates more resilient resource flows.

Setyadi et al. (2025) present a comprehensive framework for integrating circularity, localization, and digital resilience in manufacturing systems. Their research demonstrates that organizations implementing circular design principles achieve 40% reduction in material costs and 25% improvement in supply chain resilience compared to traditional linear models. The study emphasizes the importance of systemic thinking in developing circular supply chains that can adapt to changing environmental conditions.

The construction industry provides compelling examples of circular economy implementation in climate adaptation contexts (Yitmen et al., 2023). The integration of Construction 5.0 paradigm with human-centricity, sustainability, and resilience creates new possibilities for adaptive infrastructure development. This approach combines advanced technologies with circular design principles to create built environments that can respond dynamically to climate challenges.

Research by Yadav and Yadav (2024) extends beyond traditional sustainability approaches to explore regenerative innovation frameworks. Their work suggests that future supply chains must move beyond

minimizing negative impacts to actively contributing to environmental restoration and social well-being. This regenerative approach aligns with emerging concepts of antifragility, where systems not only survive disruptions but become stronger through them.

3.3 Governance Frameworks and Multi-Stakeholder Coordination

Effective governance frameworks are essential for coordinating the complex interactions between multiple stakeholders in climate-resilient supply chains (Li et al., 2023). Traditional bilateral relationships between buyers and suppliers are proving inadequate for addressing the systemic challenges of climate adaptation, necessitating new forms of collaboration and coordination.

Huang et al. (2025) examine sustainable knowledge integration as a mechanism for enhancing green development resilience. Their research reveals that organizations with strong knowledge-sharing capabilities achieve better adaptation outcomes and maintain higher levels of innovation during environmental transitions. The study emphasizes the importance of creating learning networks that can rapidly disseminate climate-related knowledge and best practices.
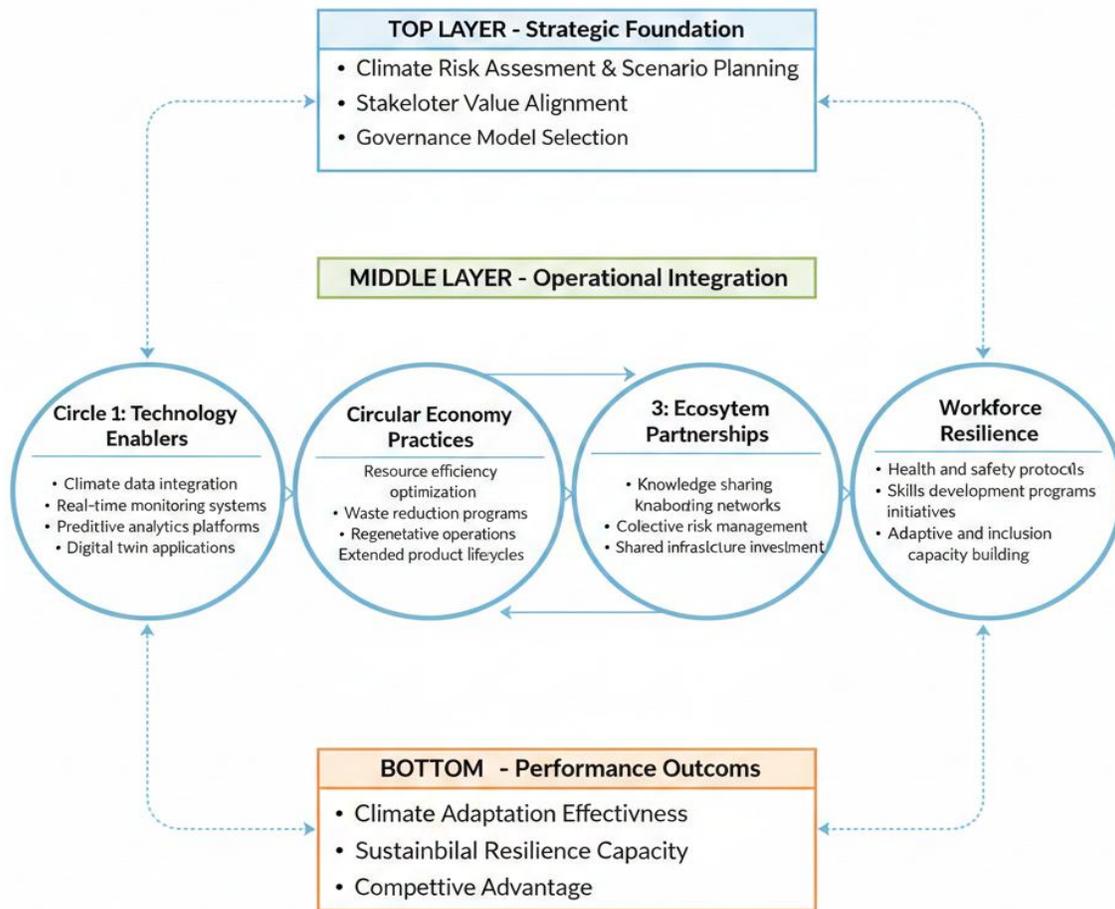

FIGURE 1: Integrated Framework for Climate-Resilient and Sustainable Supply Chain Design
Source: Authors Creation

FIGURE 1 the framework shows how strategic planning, operational practices, and performance measurement work together for successful supply chain transformation.

The concept of ecosystem partnerships is gaining prominence as a governance model for complex adaptation challenges (Aasa et al., 2025). These partnerships involve multiple organizations working collaboratively to address shared climate risks and sustainability objectives. Unlike traditional supply chain relationships focused on transaction efficiency, ecosystem partnerships emphasize mutual support, knowledge sharing, and collective problem-solving.

Fagerland and Bleveans (2025) introduce the concept of Strategic Corporate Diversity Responsibility (CDR) as a framework for integrating equity, climate resilience, and renewable energy initiatives. This approach recognizes that climate adaptation cannot be achieved without addressing social justice and inclusion issues, particularly in vulnerable communities that bear disproportionate climate impacts.

The integration of mineral and natural resources management into sustainability frameworks represents another critical governance challenge (Han, 2024). Supply chains for critical materials face unique vulnerabilities to climate change, including extreme weather impacts on mining operations, water scarcity affecting processing facilities, and transportation disruptions affecting global distribution networks. Effective governance frameworks must address these vulnerabilities while ensuring sustainable resource extraction and utilization.

3.4 Performance Measurement and Adaptive Capacity Building

Traditional supply chain performance metrics, focused primarily on cost, quality, and delivery, are inadequate for evaluating climate adaptation and sustainability outcomes (Sarkar et al., 2023). New measurement frameworks must capture the complex interactions between operational performance, environmental impact, and resilience capabilities across multiple time horizons and uncertainty scenarios.

Wei (2024) explores the role of green finance and market integration in building regional economic resilience. The research demonstrates that financial mechanisms supporting sustainability initiatives contribute to overall supply chain resilience by creating incentives for long-term thinking and collaborative behavior. Organizations with access to green financing achieve 30% better performance on sustainability metrics while maintaining competitive operational efficiency.

The development of dynamic systems approaches represents a promising direction for integrating sustainability and resilience measurement (Rabbi, 2025). These approaches recognize that supply chain performance emerges from complex interactions between multiple system components operating at different scales and time horizons. Rabbi's synergistic resilience framework provides a structured approach for measuring and managing these interactions.

Urban and territorial development provides valuable insights into performance measurement for complex adaptive systems (Tricarico et al., 2025). The proximity economy paradigm demonstrates how localized networks can achieve both competitive advantage and resilience through collaborative governance and shared value creation. These principles are increasingly relevant for supply chain design as organizations seek to balance global efficiency with local resilience.

Research Gap	Current Limitation	Emerging Opportunity	Implementation Challenge
Integration Challenges	Resilience and sustainability treated separately	Antifragile supply chain models	Cultural resistance to transformation
Methodological Deficits	Static risk assessments using historical data	Dynamic climate modeling with digital twins	Deep uncertainty in projections
Digital Technology Gaps	Focus on efficiency rather than adaptation	Climate-technology convergence platforms	Data integration complexity

Governance Models	Bilateral relationships dominate	Ecosystem partnership networks	Power asymmetries among stakeholders
Performance Measurement	Short-term financial metrics prioritized	Integrated sustainability-resilience indicators	Lack of standardized benchmarks

TABLE 1: Research Gaps and Opportunities Matrix in Climate-Adaptive Supply Chains
TABLE 1 this matrix connects existing research limitations with practical solutions, showing pathways from current problems toward meaningful organizational transformation.

IV. CRITICAL RESEARCH GAPS AND THEORETICAL LIMITATIONS

4.1 Integration Challenges Between Resilience and Sustainability

Despite growing recognition of their complementary nature, resilience and sustainability continue to be treated as separate, often competing objectives in most supply chain research and practice (Beckett & Terziovski, 2025). This artificial separation creates suboptimal outcomes where short-term resilience measures may undermine long-term sustainability goals, or sustainability initiatives may reduce operational flexibility needed for resilience.

Current theoretical frameworks lack sophisticated models for understanding and managing the dynamic interactions between resilience and sustainability objectives (Worku & Adugna, 2025). While some studies acknowledge the potential for synergies, few provide concrete guidance for operationalizing integrated approaches. This gap is particularly problematic given the complex, non-linear relationships between environmental, social, and economic factors in supply chain systems.

The temporal dimension presents another significant challenge (Panagiotopoulou et al., 2025). Resilience measures often focus on short-term shock absorption and recovery, while sustainability requires long-term thinking about resource depletion, environmental degradation, and social equity. Existing frameworks struggle to reconcile these different time horizons and provide coherent guidance for decision-making under uncertainty.

4.2 Methodological Deficits in Climate Adaptation Assessment

Current methodologies for assessing climate adaptation in supply chains suffer from several critical limitations (Rosengren et al., 2025). Most approaches rely on historical data and static risk assessments that fail to capture the dynamic, evolving nature of climate risks. This backward-looking orientation is inadequate for preparing organizations for unprecedented future conditions.

The gap between focused adaptation (site-specific, incremental changes) and transformative adaptation (system-wide restructuring) remains poorly understood (Fernando et al., 2025). While the literature acknowledges the need for transformative approaches, there is limited guidance on how organizations can assess their readiness for transformation or develop pathways for systemic change.

Uncertainty quantification presents another methodological challenge (Ramezani et al., 2025). Climate projections involve deep uncertainty about the timing, magnitude, and spatial distribution of impacts. Current supply chain models struggle to incorporate this uncertainty in ways that support robust decision-making. Most approaches either ignore uncertainty or treat it through overly simplified scenario analysis.

4.3 Limited Digital Technology Integration for Climate Applications

While digital technologies offer significant potential for enhancing supply chain climate adaptation, current research reveals substantial gaps in understanding how to effectively integrate these technologies for climate-specific applications (Parra-López et al., 2024). Most studies focus on operational efficiency gains rather than climate resilience capabilities, missing opportunities for transformative applications.

The integration of climate data with supply chain operations remains technically and organizationally challenging (Zhou et al., 2024). Climate models produce data at spatial and temporal scales that often don't align with supply chain planning horizons and geographic footprints. Bridging these scale mismatches requires sophisticated downscaling and

integration techniques that are not well-developed in current practice.

Interoperability challenges limit the potential for comprehensive digital integration (Lahmar et al., 2025). Supply chains involve multiple organizations with different technology platforms, data standards, and information-sharing capabilities. Creating seamless information flows for climate adaptation requires overcoming these technical and organizational barriers, but current research provides limited guidance for achieving such integration.

4.4 Inadequate Multi-Stakeholder Governance Models
Existing governance models for supply chain management are predominantly designed for bilateral or hierarchical relationships that prove inadequate for addressing the complex, multi-stakeholder coordination required for climate adaptation (Marques & Alvim, 2024). Traditional governance mechanisms focus on contract enforcement, performance monitoring, and dispute resolution between direct trading partners, but climate adaptation requires coordination across broader ecosystem networks including governments, NGOs, research institutions, and community organizations.

The literature reveals significant gaps in understanding how to design and implement governance structures that can effectively coordinate diverse stakeholders with different objectives, capabilities, and time horizons (Alrashdi et al., 2025). Current models struggle to balance the need for standardization and coordination with the flexibility required to accommodate local variations in climate risks and adaptation strategies.

Power asymmetries within supply chain networks create additional governance challenges that are inadequately addressed in current research (Ragazou et al., 2024). Large multinational corporations often dominate sustainability and resilience initiatives, potentially marginalizing smaller suppliers and local communities who may have critical knowledge and capabilities for climate adaptation. Developing more equitable governance models requires addressing these power imbalances while maintaining operational effectiveness.

4.5 Performance Measurement System Limitations
Current performance measurement systems in supply chain management are ill-equipped to capture the complex, dynamic relationships between resilience and sustainability outcomes (Valioniene et al., 2024).

Traditional metrics focus on short-term, easily quantifiable outcomes such as cost, quality, and delivery performance, but climate adaptation requires measurement across multiple time horizons with consideration of uncertain, non-linear relationships.

The lack of standardized metrics for climate adaptation creates challenges for benchmarking and continuous improvement (Abdulrahman & Dweiri, 2025). Organizations struggle to compare their adaptation performance against peers or track progress over time due to the absence of widely accepted measurement frameworks. This measurement gap hampers organizational learning and limits the development of best practices.

Integration challenges between financial and non-financial metrics create additional complexity (Reidsma et al., 2023). While environmental and social outcomes are increasingly recognized as important, most organizations struggle to integrate these measures with traditional financial performance systems. This disconnect can lead to suboptimal decision-making where short-term financial pressures override long-term adaptation investments.

V. EMERGING OPPORTUNITIES AND FUTURE DIRECTIONS

5.1 Antifragile Supply Chain Models
The concept of antifragility, where systems become stronger through exposure to stressors, represents a paradigm shift from traditional resilience thinking that focuses on maintaining stability under stress (Ciano et al., 2025). Antifragile supply chains not only survive disruptions but actively benefit from them by learning, adapting, and improving their capabilities. This approach offers significant potential for climate adaptation as it aligns with the need for continuous evolution in response to changing environmental conditions.

Research by Dai et al. (2025) demonstrates how smart water management systems exhibit antifragile characteristics by using disruptions as learning opportunities to improve system performance. These systems integrate governance innovation, technological integration, and policy pathways to create adaptive capabilities that strengthen over time. The principles development of antifragile supply chains requires fundamental changes in organizational culture, governance structures, and operational

processes (Eirado et al., 2025). Organizations must shift from optimizing for efficiency under stable conditions to building adaptive capacity that can respond to uncertain, changing environments. This transformation involves developing sensing capabilities, experimentation mechanisms, and learning processes that can rapidly incorporate new knowledge into operational improvements.

5.2 Ecosystem Partnership Networks

The transition from traditional supply chain relationships to ecosystem partnership networks represents a fundamental shift in how organizations coordinate complex activities (Nhamo et al., 2021). These networks involve multiple organizations working collaboratively to address shared challenges and opportunities, moving beyond transactional relationships to create mutual value and collective capabilities.

Kumar et al. (2025) demonstrate how ecosystem partnerships can optimize renewable energy integration using advanced mathematical modeling with storage and emission constraints. Their research shows that collaborative approaches achieve significantly better outcomes than individual organizational efforts, particularly when addressing complex technical and regulatory challenges that require diverse expertise and resources.

The governance of ecosystem partnerships requires new models that can balance coordination with autonomy, standardization with flexibility, and collective benefit with individual interests (Farías, 2025). Successful partnerships develop shared vision and values while maintaining the diversity and independence that makes collaborative innovation possible. This balance is particularly challenging in climate adaptation contexts where organizations may have different risk tolerances, time horizons, and resource constraints.

5.3 Commercial Innovation Capabilities

The development of new commercial models represents a critical opportunity for integrating sustainability and resilience objectives into core business operations (Zhang & Zhao, 2025). Traditional business models based on ownership, transaction efficiency, and linear value chains are giving way to new approaches emphasizing access, circular flows, and regenerative value creation.

Research on sustainable operations strategy demonstrates how organizations can integrate green lean practices into operational excellence frameworks (Setyadi et al., 2025). This integration goes beyond traditional efficiency improvements to create new sources of competitive advantage based on environmental performance and social value creation. Organizations implementing these integrated approaches achieve better financial performance while contributing to broader sustainability goals.

The evolution toward Supply Chain 3.0 to 5.0 paradigms reflects the increasing sophistication of these commercial innovations (Lahmar et al., 2025). Each generation incorporates more advanced technologies, stakeholder integration, and sustainability considerations. Supply Chain 5.0 represents a vision of fully integrated, autonomous, and regenerative networks that can adapt dynamically to changing environmental and social conditions.

5.4 Climate-Technology Convergence

The convergence of climate science and digital technology creates unprecedented opportunities for developing sophisticated adaptation capabilities (Parra-López et al., 2024). Advanced climate models, combined with real-time monitoring systems and predictive analytics, enable organizations to anticipate and prepare for climate impacts with greater precision and lead time than ever before.

Digital twin applications are expanding beyond operational optimization to include comprehensive climate impact modeling and adaptation planning (Zhou et al., 2024). These virtual representations can simulate complex interactions between climate variables, supply chain operations, and sustainability outcomes under different scenarios. Organizations use these capabilities to test adaptation strategies, optimize resource allocation, and build organizational learning about climate risks and opportunities.

The integration of renewable energy systems with supply chain operations represents another critical convergence opportunity (Kumar et al., 2025). Advanced optimization models can coordinate energy generation, storage, and consumption across multiple facilities and time horizons while considering both economic and environmental objectives. These integrated approaches achieve significant cost savings while reducing carbon footprint and enhancing energy security.

5.5 Workforce Health and Social Resilience

The recognition of workforce health as a foundational element of supply chain resilience represents an

important evolution in thinking about adaptive capacity (Valioniene et al., 2024). Climate change impacts on worker health, safety, and productivity create significant risks for supply chain operations, particularly in industries with high exposure to environmental conditions.

Research on organizational systems approaches demonstrates how immigrant integration strategies can foster agile, resilient, and sustainable organizational governance (Farías, 2025). These approaches recognize that workforce diversity and inclusion contribute to organizational adaptive capacity by bringing different perspectives, skills, and experiences to problem-solving processes. Organizations with more diverse and inclusive workforces demonstrate better performance on both resilience and sustainability metrics.

VI. IMPLICATIONS FOR THEORY AND PRACTICE

6.1 Theoretical Contributions

This review contributes to theory development in several important ways. First, it provides a comprehensive synthesis of the emerging literature on climate-adaptive supply chains, identifying key themes, gaps, and opportunities that can guide future research. The integration of insights from diverse fields including operations management, environmental science, and information systems creates new possibilities for interdisciplinary theory development.

Second, the review advances understanding of the relationship between resilience and sustainability in supply chain contexts. By identifying the artificial separation between these concepts as a critical limitation, the analysis points toward new theoretical frameworks that can capture their synergistic potential. This contribution is particularly important as organizations increasingly recognize the need for integrated approaches.

Third, the analysis of antifragile supply chain models contributes to the evolution of resilience theory beyond traditional equilibrium-based concepts. The recognition that some systems can benefit from disruptions rather than simply surviving them opens new avenues for theoretical and empirical research on adaptive capacity and organizational learning.

6.2 Practical Implications

For practitioners, this review provides several important insights and recommendations. The identification of five major research gaps offers a roadmap for organizational assessment and capability development. Organizations can use these gaps as a diagnostic framework to evaluate their current adaptive capacity and identify priority areas for investment and development.

The emerging opportunities analysis provides concrete direction for strategic planning and investment decisions. The evolution toward antifragile models, ecosystem partnerships, and commercial innovation capabilities offers specific pathways for organizations seeking to enhance their climate adaptation capabilities while maintaining competitive advantage. The emphasis on governance frameworks and multi-stakeholder coordination highlights the importance of external relationship management in building adaptive capacity. Organizations cannot achieve climate adaptation goals through internal efforts alone but must actively participate in broader ecosystem networks that can provide collective capabilities and shared resources.

6.3 Policy Implications

The findings of this review have important implications for policy development at multiple levels. Governments play critical roles in creating enabling environments for supply chain adaptation through regulatory frameworks, infrastructure investments, and coordination mechanisms. The research suggests that traditional policy approaches focusing on single organizations or bilateral relationships are inadequate for addressing the systemic nature of climate adaptation challenges.

The need for ecosystem partnership networks implies that policy makers should focus on creating platforms and incentives for multi-stakeholder collaboration rather than simply regulating individual organizational behavior. This shift requires new approaches to governance that can balance coordination with innovation, standardization with flexibility, and collective benefit with competitive dynamics.

VII. LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

7.1 Review Limitations

This review has several important limitations that should be acknowledged. The focus on peer-reviewed

literature published between 2021-2025 may have excluded important insights from gray literature, practitioner reports, and earlier foundational studies. While this timeframe captures recent developments, it may miss important historical context and foundational contributions to the field.

The emphasis on English-language publications may have introduced geographic and cultural bias, potentially missing important insights from non-Western contexts where climate adaptation challenges and solutions may differ significantly. Future reviews should consider multilingual searches and broader geographic representation.

The rapid pace of development in this field means that significant new insights and approaches may have emerged during the review process that are not captured in the analysis. The six-month timeframe for literature collection and analysis represents a snapshot of a rapidly evolving field.

7.2 Future Research Priorities

Based on the gaps and opportunities identified in this review, several priority areas for future research emerge. First, there is urgent need for empirical studies that test integrated resilience-sustainability frameworks in real-world supply chain contexts. Most current research remains conceptual or relies on simulation studies, limiting our understanding of practical implementation challenges and outcomes.

Second, longitudinal studies are needed to understand how supply chain adaptation capabilities evolve over time and in response to different types of environmental and economic pressures. The dynamic nature of climate adaptation requires research approaches that can capture change processes rather than static snapshots. Third, comparative studies across different industries, regions, and organizational contexts would help identify boundary conditions and contingency factors that influence the effectiveness of different adaptation approaches. The diversity of supply chain contexts suggests that one-size-fits-all solutions are unlikely to be effective.

Fourth, research on measurement and evaluation frameworks for integrated resilience-sustainability outcomes is critically needed. Without better measurement capabilities, organizations cannot effectively manage their adaptation efforts or learn from experience. Finally, research on the social and ethical dimensions of supply chain climate adaptation deserves greater attention. Questions of equity, justice, and inclusion are central to sustainable development but have received limited attention in supply chain management research.

VIII. CONCLUSION

This comprehensive review of resilient and sustainable supply chain design for climate change adaptation reveals a field in rapid transition from traditional risk management approaches to more sophisticated, integrated frameworks that recognize the interconnected nature of environmental, social, and economic challenges. The analysis of 60 recent studies identifies both significant progress and critical gaps in current understanding and practice.

The research demonstrates that while awareness of climate adaptation needs is growing rapidly among supply chain leaders, actual implementation of comprehensive adaptation strategies remains limited. Only 27% of organizations have conducted thorough climate risk assessments, and even fewer have developed integrated approaches that simultaneously address resilience and sustainability objectives. This implementation gap represents both a significant challenge and an important opportunity for the field.

The five major research gaps identified integration challenges between resilience and sustainability, methodological deficits in climate adaptation assessment, limited digital technology integration, inadequate multi-stakeholder governance models, and performance measurement system limitations provide a clear agenda for future research and development efforts. These gaps are interconnected and require coordinated attention rather than isolated solutions.

The emerging opportunities analysis reveals significant potential for transformative innovation in supply chain design. The evolution toward antifragile models that benefit from disruptions rather than simply surviving them offers a particularly promising direction for organizations operating in increasingly volatile environments. Similarly, the development of ecosystem partnership networks provides new mechanisms for collective action that can address challenges beyond the capabilities of individual organizations. The convergence of climate science and digital technology creates unprecedented capabilities for sophisticated adaptation planning and implementation. However, realizing this potential requires overcoming significant technical,

organizational, and governance challenges that are not yet well understood. Future research should focus on developing practical frameworks for managing these convergence opportunities while addressing associated risks and limitations.

The workforce health and social resilience dimensions of climate adaptation deserve greater attention in both research and practice. Climate impacts on worker health, safety, and productivity create significant risks for supply chain operations that are often overlooked in traditional risk management approaches. Addressing these challenges requires broader conceptualizations of supply chain management that integrate human and social considerations more effectively. For practitioners, this review provides a roadmap for assessment and development of climate adaptation capabilities. The frameworks and opportunities identified offer concrete direction for strategic planning and investment decisions. However, successful implementation requires recognition that climate adaptation is not simply a technical challenge but involves fundamental changes in organizational culture, governance structures, and stakeholder relationships.

The policy implications of this research emphasize the need for new approaches to governance that can facilitate multi-stakeholder collaboration while maintaining competitive dynamics. Traditional regulatory approaches focusing on individual organizational compliance are inadequate for addressing the systemic nature of climate adaptation challenges. Policy makers should focus on creating enabling environments for innovation and collaboration rather than simply mandating specific behaviors. Looking toward the future, the field of climate-adaptive supply chain design is poised for significant evolution. The increasing urgency of climate impacts, combined with rapid technological advancement and growing stakeholder expectations, creates strong pressures for innovation and transformation. Organizations that proactively develop integrated adaptation capabilities will be better positioned to thrive in this changing environment, while those that rely on traditional approaches face increasing risks of disruption and obsolescence.

The ultimate success of climate adaptation efforts will depend on the ability of researchers, practitioners, and policy makers to work collaboratively in developing and implementing new approaches that can address the complex, interconnected challenges of the 21st century. This review provides a foundation for such collaboration by synthesizing current knowledge, identifying critical gaps, and outlining promising directions for future development. As the climate crisis intensifies and supply chain disruptions become more frequent and severe, the need for resilient and sustainable supply chain design will only grow more urgent. The frameworks, opportunities, and recommendations presented in this review offer a starting point for the transformation that is needed, but much work remains to be done in translating these insights into practical solutions that can operate at the scale and speed required by the challenges we face.

The journey toward climate-adaptive supply chains represents one of the most important challenges and opportunities of our time. Success will require unprecedented levels of innovation, collaboration, a commitment to both environmental sustainability and social equity. The research reviewed here demonstrates that the foundations for this transformation are emerging, but realizing the full potential will require sustained effort, significant investment, and fundamental changes in how we conceptualize and manage supply chain systems.

The transition from fragile, efficiency-optimized supply chains to antifragile, regenerative networks that can thrive in the face of climate uncertainty represents a paradigm shift comparable to previous industrial revolutions. Just as the introduction of mechanization, electricity, and information technology fundamentally transformed production and distribution systems, the integration of climate adaptation and sustainability requirements is reshaping the basic principles of supply chain design and management. This transformation is not merely a technical challenge but involves deep questions about values, power, and responsibility that extend far beyond traditional supply chain boundaries. The recognition that supplies chains are embedded in broader social-ecological systems means that adaptation strategies must consider impacts on communities, ecosystems, and future generations, not just short-term organizational performance. This broader perspective requires new forms of stakeholder engagement, governance, and accountability that are still being developed.

The role of technology in this transformation is both enabling and constraining. While digital technologies

offer unprecedented capabilities for monitoring, modeling, and managing complex adaptive systems, they also introduce new vulnerabilities and dependencies that must be carefully managed. The development of climate-adaptive supply chains requires not just implementing new technologies but developing organizational capabilities to use them effectively in the service of broader sustainability and resilience goals. Perhaps most importantly, this review demonstrates that the future of supply chain management lies not in choosing between efficiency and resilience, or between economic and environmental objectives, but in developing integrated approaches that can achieve multiple goals simultaneously. The most successful organizations will be those that can create business models and operational strategies that generate economic value precisely because they contribute to environmental restoration and social well-being.

The research agenda emerging from this analysis is both challenging and exciting. It requires bringing together insights from diverse fields, developing new methodological approaches, and creating new forms of collaboration between researchers, practitioners, and policy makers. The urgency of climate challenges means that this research must be both rigorous and actionable, contributing to theoretical understanding while providing practical guidance for immediate implementation. As we look toward 2035 and beyond, the vision of truly adaptive, sustainable, and resilient supply chains remains aspirational for most organizations. However, the foundations for this transformation are being laid today through the research, experimentation, and innovation documented in this review. The challenge for the field is to accelerate this transformation while ensuring that it contributes to broader goals of sustainable development and climate justice. The stakes could not be higher. Supply chains are among the most powerful human systems for organizing economic activity and resource flows. How we design and manage these systems in the coming decades will play a critical role in determining whether humanity can successfully navigate the climate crisis while building more equitable and sustainable societies. The research reviewed here provides reason for both concern about current limitations and optimism about emerging possibilities. The path forward requires continued dedication to both scientific rigor and practical action

in service of the profound transformation that our changing world demands.

REFERENCES

[1] Aasa, O. P., Phoya, S., Monko, R. J., & Musonda, I. (2025). Integrating sustainability and resilience objectives for energy decisions: A systematic review. Resources, 14(6), 97. https://doi.org/10.3390/resources14060097

[2] Abdulrahman, M. A. S. A. S., & Dweiri, F. T. (2025). Development of an agile and sustainable framework for resilient and inclusive public transport organizations. Sustainability, 17(10), 4652. https://doi.org/10.3390/su17104652

[3] Alrashdi, I., Abd El-Aziz, R. M., Taloba, A. I., & Farsi, M. (2025). Hybrid TCN-transformer model for predicting sustainable food supply and ensuring resilience. Alexandria Engineering Journal, 127, 380-391.

[4] Argyroudis, S. A., Mitoulis, S. A., Chatzi, E., Baker, J. W., Brilakis, I., Gkoumas, K., ... & Linkov, I. (2021). Digital technologies can enhance climate resilience of critical infrastructure. Climate Risk Management, 35, 100387. https://doi.org/10.1016/j.crm.2021.100387

[5] Bag, S., Sabbir Rahman, M., Rogers, H., Srivastava, G., & Harm Christiaan Pretorius, J. (2023). Climate change adaptation and disaster risk reduction in the garment industry supply chain network. Transportation Research Part E, 171, 103031. https://doi.org/10.1016/j.tre.2023.103031

[6] Beckett, R. C., & Terziovski, M. (2025). Integrating circular economy principles in water resilience: Implications for corporate governance and sustainability reporting. Journal of Risk and Financial Management, 18(5), 261. https://doi.org/10.3390/jrfm18050261

[7] Berrang-Ford, L., Pearce, T., & Ford, J. D. (2015). Systematic review approaches for climate change adaptation research. Regional Environmental Change, 15(5), 755-769. https://doi.org/10.1007/s10113-014-0708-7

[8] Ciano, M. P., Peron, M., Panza, L., & Pozzi, R. (2025). Industry 4.0 technologies in support of circular economy: A 10R-based integration

framework. Computers & Industrial Engineering, 201. https://doi.org/10.1016/j.cie.2025.110867

[9] Chen, K. Y., Chang, K. Y., & Wu, H. M. (2025). Knowledge-based resilience and robustness of travel agencies in facing tourism supply chain disruptions. Business Process Management Journal. https://doi.org/10.1108/BPMJ-10-2024-1028

[10] Dai, Y., Huang, Z., Khan, N., & Labbo, M. S. (2025). Smart water management: Governance innovation, technological integration, and policy pathways toward economic and ecological sustainability. Water, 17(13), 1932. https://doi.org/10.3390/w17131932

[11] Doetsch, S., & Huchzermeier, A. (2024). The intersection of supply chain resilience and sustainability from a theoretical and practical perspective: An integrated framework. Journal of Cleaner Production, 484, 144306. https://doi.org/10.1016/j.jclepro.2024.144306

[12] Eirado, C. R. R., Silveira, D., & Cajueiro, D. O. (2025). Digital twins and network resilience in the EU ETS: Analysing structural shifts in carbon trading. Sustainability, 17(15), 6924. https://doi.org/10.3390/su17156924

[13] Fagerland, B. S., & Bleveans, L. (2025). Strategic corporate diversity responsibility (CDR) as a catalyst for sustainable governance: Integrating equity, climate resilience, and renewable energy in the IMSD framework. Administrative Sciences, 15(6), 213. https://doi.org/10.3390/admsci15060213

[14] Farías, P. (2025). Leveraging a systems approach for immigrant integration: Fostering agile, resilient, and sustainable organizational governance. Systems, 13(6), 467. https://doi.org/10.3390/systems13060467

[15] Fernando, F. N., Maloney, M., & Tappel, L. (2025). In the face of climate change: Perceptions of interconnections between community resilience and community sustainability. Urban Science, 9(3), 60. https://doi.org/10.3390/urbansci9030060

[16] Firoozi, A. A., Firoozi, A. A., Oyejobi, D. O., Avudaiappan, S., & Flores, E. S. (2025). Developing urban infrastructure: Strategic integration of solar-heated pavement systems for enhanced resilience and sustainability. Results in

Engineering, 25. https://doi.org/10.1016/j.rineng.2025.104593

[17] Han, S. (2024). Integrating mineral and natural resources for enhanced environmental resilience and sustainability. Resources Policy, 91, 104869. https://doi.org/10.1016/j.resourpol.2024.104869

[18] Hart Nibbrig, M., Sharif Azadeh, S., & Maknoon, M. Y. (2025). Adaptive resilience strategies for supply chain networks against disruptions. Transportation Research Part E, 200, 104172. https://doi.org/10.1016/j.tre.2025.104172

[19] Hsu, C. H., Li, M. G., Zhang, T. Y., Chang, A. Y., Shangguan, S. Z., & Liu, W. L. (2022). Deploying big data enablers to strengthen supply chain resilience to mitigate sustainable risks based on integrated HOQ-MCDM framework. Mathematics, 10(8), 1233. https://doi.org/10.3390/math10081233

[20] Huang, J., Yang, B., Zhou, B., & Ran, B. (2025). Sustainable knowledge integration: Enhancing green development resilience. Journal of Innovation & Knowledge, 10(2), 100671. https://doi.org/10.1016/j.jik.2025.100671

[21] Jahed, A., Molana, S. M. H., Tavakkoli-Moghaddam, R., & Valizadeh, V. (2024). Designing an integrated sustainable-resilient mix-and-match vaccine supply chain network. Annals of Operations Research, 1-50. https://doi.org/10.1007/s10479-024-06211-1

[22] Jeong, H., & Choi, C. (2023). Adaptive supply chain system design for fruit crops under climate change. Systems, 11(10), 514. https://doi.org/10.3390/systems11100514

[23] Junaid, M., Zhang, Q., Cao, M., & Luqman, A. (2023). Nexus between technology enabled supply chain dynamic capabilities, integration, resilience, and sustainable performance: An empirical examination of healthcare organizations. Technological Forecasting & Social Change, 196. https://doi.org/10.1016/j.techfore.2023.122828

[24] Kaewunruen, S., AbdelHadi, M., Kongpuang, M., Pansuk, W., & Remennikov, A. M. (2022). Digital twins for managing railway bridge maintenance, resilience, and climate change adaptation. Sensors, 23(1), 252. https://doi.org/10.3390/s23010252

[25] Kumar, L., Sharma, K., Pathak, P., & Khedlekar, U. K. (2025). Optimizing renewable energy

integration using advanced mathematical modeling with storage and emission constraints for resilient and sustainable energy systems. Computers & Industrial Engineering, 208. https://doi.org/10.1016/j.cie.2025.111379

[26] Lahmar, A., Zekhnini, K., Masmoudi, M., & Siddiqui, A. A. (2025). Navigating the sustainable supply chain realm: Revolutionizing from 3.0 to 5.0. Computers & Industrial Engineering, 208. https://doi.org/10.1016/j.cie.2025.111380

[27] Le, M. H., & Phi Tran, P. (2025). Managing supply chain resilience in climate and disaster-prone environments: a bibliometric analysis. Competitiveness Review: An International Business Journal. https://doi.org/10.1108/CR-01-2025-0003

[28] Li, J., Foden, G. W., Chow, S. K. W., & To, L. S. (2023). Integrating sustainable and energy-resilient strategies into emergency shelter design. Renewable and Sustainable Energy Reviews, 191. https://doi.org/10.1016/j.rser.2023.113968

[29] Liang, S., Duc Long, N. V., Parvin, M. I., Escribà-Gelonch, M., Lantin, S., & Hessel, V. (2025). Digital twin for lettuce growth in six climate zones ('Climate 2050'). Computers and Electronics in Agriculture, 238. https://doi.org/10.1016/j.compag.2025.110880

[30] Lin, J., & Fan, Y. (2023). Seeking sustainable performance through organizational resilience: Examining the role of supply chain integration and digital technology usage. Technological Forecasting & Social Change, 198. https://doi.org/10.1016/j.techfore.2023.123026

[31] López-Castro, L. F., & Solano-Charris, E. L. (2021). Integrating resilience and sustainability criteria in the supply chain network design. A systematic literature review. Sustainability, 13(19), 10925. https://doi.org/10.3390/su131910925

[32] Lotfi, R., Mehrjardi, M. S., MohajerAnsari, P., Zolfaqari, F., & Afshar, M. (2023). Antifragile, sustainable, and agile supply chain network design by considering resiliency, robustness, risk, and environmental requirements. Environmental Science and Pollution Research, 30(48), 106442-106459. https://doi.org/10.1007/s11356-023-29488-4

[33] Majlingova, A., & Kádár, T. S. (2025). From risk to resilience: Integrating climate adaptation and disaster reduction in the pursuit of sustainable development. Sustainability, 17(12), 5447. https://doi.org/10.3390/su17125447

[34] Marques, A. L., & Alvim, A. T. B. (2024). Metropolitan fringes as strategic areas for urban resilience and sustainable transitions: Insights from Barcelona Metropolitan Area. Cities, 150. https://doi.org/10.1016/j.cities.2024.105018

[35] Nhamo, L., Rwizi, L., Mpandeli, S., Botai, J., Magidi, J., Tazvinga, H., ... & Mabhaudhi, T. (2021). Urban nexus and transformative pathways towards a resilient Gauteng City-Region, South Africa. Cities, 116. https://doi.org/10.1016/j.cities.2021.103266

[36] Panagiotopoulou, M., Stratigea, A., & Kokla, M. (2025). Smart, sustainable, resilient, and inclusive cities: Integrating performance assessment indicators into an ontology-oriented scheme in support of the urban planning practice. Urban Science, 9(2), 33. https://doi.org/10.3390/urbansci9020033

[37] Parra-López, C., Ben Abdallah, S., Garcia-Garcia, G., Hassoun, A., Sánchez-Zamora, P., Trollman, H., ... & Carmona-Torres, C. (2024). Integrating digital technologies in agriculture for climate change adaptation and mitigation: State of the art and future perspectives. Computers and Electronics in Agriculture, 226. https://doi.org/10.1016/j.compag.2024.109412

[38] Rabbi, M. F. (2025). A dynamic systems approach to integrated sustainability: Synthesizing theory and modeling through the synergistic resilience framework. Sustainability, 17(11), 4878. https://doi.org/10.3390/su17114878

[39] Ragazou, K., Zournatzidou, G., Sklavos, G., & Sariannidis, N. (2024). Integration of circular economy and urban metabolism for a resilient waste-based sustainable urban environment. Urban Science, 8(4), 175. https://doi.org/10.3390/urbansci8040175

[40] Ramezani, J., Gomes, L., & Graça, P. (2025). Crisis response modes in collaborative business ecosystems: A mathematical framework from plasticity to antifragility. Mathematics, 13(15), 2421. https://doi.org/10.3390/math13152421

[41] Reidsma, P., Accatino, F., Appel, F., Gavrilescu, C., Krupin, V., Manevska Tasevska, G., ... & Paas, W. (2023). Alternative systems and strategies to improve future sustainability and resilience of

farming systems across Europe: from adaptation to transformation. Land Use Policy, 134. https://doi.org/10.1016/j.landusepol.2023.106881

[42] Riaz, K., McAfee, M., & Gharbia, S. S. (2023). Management of climate resilience: Exploring the potential of digital twin technology, 3D city modelling, and early warning systems. Sensors, 23(5), 2659. https://doi.org/10.3390/s23052659

[43] Rosengren, L., Budhathoki, K., Haapala, J., Soini, K., & Sell, M. (2025). Leverage points for resilience: Introducing the pyramid framework for strategic adaptation planning and assessment. Ambio, 1-15. https://doi.org/10.1007/s13280-025-02216-7

[44] Sarkar, S., Ganapathysubramanian, B., Singh, A., Fotouhi, F., Kar, S., Nagasubramanian, K., ... & Singh, A. K. (2023). Cyber-agricultural systems for crop breeding and sustainable production. Trends in Plant Science, 29(2), 130-149. https://doi.org/10.1016/j.tplants.2023.08.001

[45] Setyadi, A., Pawirosumarto, S., & Damaris, A. (2025). Rethinking sustainable operations: A multi-level integration of circularity, localization, and digital resilience in manufacturing systems. Sustainability, 17(15), 6929. https://doi.org/10.3390/su17156929

[46] Shehadeh, A., Alshboul, O., Taamneh, M. M., Jaradat, A. Q., Alomari, A. H., & Arar, M. (2025). Advanced integration of BIM and VR in the built environment: Enhancing sustainability and resilience in urban development. Heliyon, 11(4). https://doi.org/10.1016/j.heliyon.2025.e42558

[47] Song, W., Xue, H., & Rong, W. (2025). An integrated method for resilient-sustainable supplier selection based on action-oriented practices. Advanced Engineering Informatics, 67, 103570. https://doi.org/10.1016/j.aei.2025.103570

[48] Suárez-Eiroa, B., Fernández, E., & Méndez, G. (2021). Integration of the circular economy paradigm under the just and safe operating space narrative: Twelve operational principles based on circularity, sustainability and resilience. Journal of Cleaner Production, 322. https://doi.org/10.1016/j.jclepro.2021.129071

[49] Tarigan, Z. J. H., Siagian, H., & Jie, F. (2021). Impact of internal integration, supply chain partnership, supply chain agility, and supply chain resilience on sustainable advantage. Sustainability, 13(10), 5460. https://doi.org/10.3390/su13105460

[50] Tricarico, L., Hausemer, P., Gorman, N., & Squillante, F. (2025). Towards a paradigm of proximity economy for competitive and resilient cities and territories. Social Sciences, 14(7), 394. https://doi.org/10.3390/socsci14070394

[51] Valioniene, E., Zuperkiene, E., & Placiene, B. (2024). Acceleration of green transitions on the base of port organizational ecosystem's resilience enhancement: A socio-technological approach. Applied Sciences, 14(21), 9948. https://doi.org/10.3390/app14219948

[52] Vazquez-Noguerol, M., Comesaña-Benavides, J. A., Prado-Prado, J. C., & Amorim, P. (2024). Transport collaboration network among competitors to improve supply chain antifragility. European Journal of Innovation Management. https://doi.org/10.1108/EJIM-12-2023-1094

[53] Wang, Y., Iqbal, U., & Gong, Y. (2021). The performance of resilient supply chain sustainability in Covid-19 by sourcing technological integration. Sustainability, 13(11), 6151. https://doi.org/10.3390/su13116151

[54] Wei, N. (2024). Green finance, market integration, and regional economic resilience. Finance Research Letters, 67. https://doi.org/10.1016/j.frl.2024.105777

[55] Worku, G., & Adugna, D. (2025). Two studied metropolitan cities in Ethiopia and their current integrated infrastructure plan to enhance resilience and sustainability. Environmental and Sustainability Indicators, 26. https://doi.org/10.1016/j.indic.2025.100668

[56] Yadav, V., & Yadav, N. (2024). Beyond sustainability, toward resilience, and regeneration: An integrative framework for archetypes of regenerative innovation. Global Journal of Flexible Systems Management, 25(4), 849-879. https://doi.org/10.1007/s40171-024-00418-8

[57] Yitmen, I., Almusaed, A., & Alizadehsalehi, S. (2023). Investigating the causal relationships among enablers of the Construction 5.0 paradigm: Integration of Operator 5.0 and Society 5.0 with human-centricity, sustainability, and resilience. Sustainability, 15(11), 9105. https://doi.org/10.3390/su15119105

[58] Zhang, Y., & Zhao, W. (2025). Examining agricultural firms' risk-bearing capability via supply chain financing: Insights from China. International Review of Economics and Finance, 102. https://doi.org/10.1016/j.iref.2025.104282

[59] Zhao, P., Ji, S., & Xue, Y. (2021). An integrated approach based on the decision-theoretic rough set for resilient-sustainable supplier selection and order allocation. Kybernetes, 52(3), 774-808. https://doi.org/10.1108/K-11-2020-0821

[60] Zhou, B., Wu, W., Dong, S., Zhang, X., & Li, J. (2024). Sustainable integration of mineral resources, low carbon transition, and economic resilience in China. Resources Policy, 98. https://doi.org/10.1016/j.resourpol.2024.105336