Frontiers in Computer Science and Artificial Intelligence
ISSN: 2978-8048
DOI: 10.32996/fcsai
Journal Homepage: www.al-kindipublisher.com/index.php/fcsai

FCSAI
AL-KINDI CENTER FOR RESEARCH AND DEVELOPMENT

| RESEARCH ARTICLE

Artificial Intelligence for Sustainable and Climate-Resilient Apparel Supply Chains: A Narrative Review and Integrative Framework

Apurbaa Sarker[1], Mahmud Kamal Anamul Haque[2] and Zannatul Mouwa[3]
[1] *Manager, Product Development & Innovation, Brannerson Apparel Limited, Dhaka, Bangladesh*
[23] *Department of Environmental Science, Bangladesh Agricultural University, Mymensingh, Bangladesh*
Corresponding Author: Apurbaa Sarker, **E-mail**: apurbaa01@gmail.com

| ABSTRACT
This study examines the role of artificial intelligence (AI) in enhancing environmental sustainability and climate resilience in apparel supply chains. Although prior research has extensively explored sustainable supply chain management, circular economy practices, and AI-driven supply chain resilience, these streams remain largely fragmented. To address this gap, this paper adopts a narrative review approach, analyzing 25 peer-reviewed studies published between 2015 and 2021 across databases including Scopus, Web of Science, and Google Scholar. The findings reveal that apparel-specific research is strong in identifying sustainability challenges, such as environmental degradation, labor issues, and governance complexity, while AI and resilience studies provide advanced insights into predictive analytics, optimization, and risk management but are predominantly situated in general supply chain contexts. There is a clear lack of integration among AI capabilities, environmental sustainability, and climate resilience within apparel supply chains. This paper contributes by synthesizing these disconnected streams and proposing an integrated perspective that links AI technologies to supply chain functions, sustainability outcomes, and resilience capabilities. The study highlights that AI can serve as a bridging mechanism by improving forecasting, resource efficiency, and proactive risk management, while also identifying key barriers such as data limitations, lack of transparency, and organizational readiness. The findings have important implications for researchers, managers, and policymakers seeking to develop greener, more resilient apparel supply chains.

| KEYWORDS

Artificial Intelligence (AI); Apparel Supply Chains; Sustainable Supply Chain Management (SSCM); Climate Resilience; Circular Economy; Supply Chain Resilience; Environmental Sustainability

| ARTICLE INFORMATION

ACCEPTED: 03 May 2022 **PUBLISHED:** 25 May 2022 **DOI:** 10.32996/fcsai.2022.1.1.9x

1. Introduction

The textile and apparel industry is widely recognized as one of the most environmentally and socially impactful sectors in the global economy (Shen et al., 2017; Köksal et al., 2017). Characterized by resource-intensive production processes, complex multi-tier supply chains, and fast-changing consumption patterns, the industry faces significant sustainability challenges, including pollution, waste generation, and labor-related concerns (Bubicz et al., 2021; Palacios-Mateo et al., 2021). At the same time, apparel supply chains are increasingly exposed to climate-related disruptions such as extreme weather events, resource scarcity, and logistical uncertainties, which threaten operational continuity and long-term viability (Spieske & Birkel, 2021).

In response to these challenges, two major streams of research have evolved. The first focuses on sustainable supply chain management and circular economy practices, emphasizing environmental performance, social responsibility, and resource efficiency in textile and apparel systems (Touboulic & Walker, 2015; Rajeev et al., 2017; Jia et al., 2020). The second examines

supply chain resilience, highlighting the importance of risk management, adaptability, and recovery capabilities in the face of disruption. More recently, a third stream has emerged around AI and digital technologies, which offer advanced capabilities for forecasting, optimization, and decision-making in complex supply networks (Baryannis et al., 2019; Belhadi et al., 2021). Despite the progress in each of these domains, the existing literature remains fragmented. Sustainability research in apparel supply chains has largely focused on identifying environmental and social problems, while AI and resilience research has been developed primarily in general supply chain contexts with limited application to apparel-specific realities (Köksal et al., 2017; Bubicz et al., 2021). As a result, there is a lack of integrated understanding of how AI can simultaneously support environmental sustainability and climate resilience in apparel supply chains (Toorajipour et al., 2021; Pournader et al., 2021; Baryannis et al., 2019; Toorajipour et al., 2021)).

This study addresses this gap by conducting a narrative review of the literature published between 2015 and 2021. The objective is to synthesize existing research across sustainability, circular economy, AI, and resilience domains and to develop an integrated perspective on AI-driven transformation in apparel supply chains. Specifically, the paper aims to (1) identify key themes and research trends, (2) examine how AI capabilities relate to sustainability and resilience outcomes, and (3) highlight gaps and future research directions. By linking technological capabilities with sector-specific challenges, this study advances both theoretical understanding and the practical application of AI in sustainable, climate-resilient apparel supply chains.

2. Literature Review

2.1 Sustainable apparel supply chains as a research domain

The textile and apparel industry has become a prominent context for sustainable supply chain research due to its globally fragmented sourcing structures, short product life cycles, cost pressures, environmental burdens, and persistent social compliance issues. Reviews and sector syntheses show that sustainability problems in apparel supply chains span supplier selection, production systems, retailing, waste generation, labor conditions, and post-consumer disposal, making the sector especially suitable for integrated supply chain analysis (Shen et al., 2017; Köksal et al., 2017; Bubicz et al., 2021; Palacios-Mateo et al., 2021; Spieske & Birkel, 2021).

Within this domain, early- and mid-period studies from 2015 to 2021 focused primarily on the triple bottom line logic of sustainable supply chain management. Work in this stream examined theoretical foundations of SSCM, the evolution of sustainability research in supply chains, and apparel-specific topics such as sustainable retailing, green supplier evaluation, sustainable product strategy, firm performance after environmental management system adoption, and value-chain performance measurement in the textile and apparel industries. Together, these studies established that sustainability in apparel supply chains is not a single operational issue but a multi-level governance challenge involving suppliers, focal firms, retailers, regulators, and consumers.

Another important strand emphasized the social dimension of sustainability. Studies on apparel supply chains highlighted the persistence of labor-related risks, value conflicts between corporate sustainability rhetoric and practitioner realities, and the need for stronger collaboration and visibility across tiers. This literature is important for the present review because climate resilience and AI adoption in apparel cannot be treated as purely technical matters; they are embedded in wider organizational, ethical, and supplier-management systems (Touboulic & Walker, 2015; Rajeev et al., 2017; Jia et al., 2020; Baryannis et al., 2019; Belhadi et al., 2021; Köksal et al., 2017; Bubicz et al., 2021).

2.2 Environmental sustainability and circularity in textile and apparel chains

A second major stream from 2020 to 2021 examined the environmental footprint of textile and apparel systems more directly. These studies mapped pollution hotspots, waste generation, fiber and material choices, recycling options, and circular-economy practices. The literature shows that environmental burdens are distributed across the full chain, from raw materials and wet processing to logistics, use, washing, and end-of-life disposal, and that interventions therefore need to be systemic rather than factory-specific (Palacios-Mateo et al., 2021).

Research on circularity strengthened this systems view. Reviews and empirical studies found that circular economy implementation in the textile and clothing industries depends on organizational capabilities, technology, finance, collaboration, and consumer participation. They also showed that circular initiatives can improve economic, environmental, and social performance, but implementation barriers remain substantial, especially in emerging-economy production networks. This is

directly relevant to this review because climate resilience in apparel supply chains increasingly depends on resource efficiency, waste minimization, reuse, repair, and recycling capabilities (Jia et al., 2020; Memon et al., 2021).

2.3 Emergence of AI and digital intelligence in supply chains

The AI-focused literature during 2019–2021 broadened the discussion from conventional decision-support tools to machine learning, predictive analytics, sensing, and algorithmic decision-making. Systematic reviews concluded that AI applications in supply chain management were expanding but still fragmented across subfields and methods. A consistent finding is that AI can support forecasting, pattern recognition, risk identification, decision-making, and process optimization, yet the literature remains more mature in general supply chain settings than in apparel-specific contexts (Toorajipour et al., 2021; Pournader et al., 2021; Baryannis et al., 2019).

This gap matters for this topic. While apparel studies have long addressed supplier sustainability, power structures, and environmental performance, only a limited subset explicitly links these issues to AI, business intelligence, predictive analytics, or Industry 4.0. One notable textile/apparel-specific contribution is the work on business intelligence systems in the Industry 4.0 era, which suggests that digital intelligence can help firms address sustainability issues and competitiveness simultaneously. However, the broader literature still lacks a consolidated explanation of how AI specifically contributes to climate resilience and environmental sustainability in apparel supply chains.

2.4 AI, risk management, and supply chain resilience

The resilience literature provides the strongest conceptual bridge between AI and the management of climate-related disruption. Reviews on AI and supply chain risk management argue that intelligent systems can improve the identification, assessment, monitoring, and mitigation of risks through data-driven prediction and decision support. Parallel resilience studies show that digital technologies and Industry 4.0 tools enhance visibility, velocity, preparedness, and proactive risk management capabilities, which are especially relevant amid climate volatility and disruption.

Empirical research reinforces this link. Studies published in 2021 indicate that AI-enabled innovation can improve supply chain resilience and performance under dynamic conditions, while pandemic-era analyses show that AI and related digital technologies can support sensing, analysis, reconfiguration, and response during major disruptions. These insights are highly transferable to climate resilience in apparel chains, where firms face exposure to extreme weather, resource scarcity, transport interruptions, compliance shocks, and demand volatility.

2.5 Synthesis and research gap

Taken together (Table 1), the 2015–2021 literature (25 studies) suggests that the field developed along three partly disconnected streams. The first stream concentrated on sustainable apparel and textile supply chains, especially social and environmental issues. The second stream explored circularity and environmental intervention points in textile and clothing systems (Jia et al., 2020; Toorajipour et al., 2021; Pournader et al., 2021). The third stream focused on AI, analytics, and resilience largely in broader supply chain settings. Although each stream is well developed on its own, relatively few studies integrate all three dimensions, AI capability, environmental sustainability, and climate resilience, within the specific institutional and operational realities of apparel supply chains. This fragmentation creates a clear justification for the present narrative review. This paper can contribute by synthesizing how AI technologies may support greener, more adaptive, and more resilient apparel supply chains; identifying where existing studies remain technology-centric, sustainability-centric, or resilience-centric; and proposing an integrated agenda that connects AI applications to specific apparel supply chain functions and outcomes. Existing literature is fragmented across three streams—(1) sustainable apparel supply chains, (2) circular economy and environmental sustainability, and (3) AI-driven supply chain resilience—with limited integration of AI-driven approaches to simultaneously enhance environmental sustainability and climate resilience in apparel supply chains. The pie chart (Figure 1) illustrates the distribution of themes in the reviewed literature. Sustainability-focused studies dominate the field (44%), followed by studies addressing mixed or overlapping themes (20%). AI-driven resilience research accounts for 16%, while circular economy (12%) and AI-focused supply chain studies (8%) remain comparatively underrepresented. This distribution highlights a clear imbalance and fragmentation in the literature, with limited integration across sustainability, circular economy, and AI domains.

Table 1. Summary of 25 reviewed studies on AI, sustainability, resilience, and apparel supply chains (2015–2021).

Author (Year)	Context	Method	AI / Tech	Sustainability Focus	Resilience Focus	Supply Chain Stage	Key Findings	Research Gap
Touboulic & Walker (2015)	General SCM	Review	None	Triple bottom line	No	All	Established SSCM theories	Lack of tech integration
Rajeev et al. (2017)	General SCM	Review	None	Environmental + social	No	All	Evolution of SSCM	Limited sector focus
Shen et al. (2017)	Apparel	Conceptual	None	Environmental	No	Production	Identifies textile impacts	No AI integration
Köksal et al. (2017)	Apparel	Review	None	Social sustainability	No	Sourcing	Labor & ethics critical	No digital tools
Yang et al. (2017)	Fashion	Review	None	Retail sustainability	No	Retail	Sustainable consumption	Weak supply chain link
Guo et al. (2017)	Apparel	Quantitative	Decision tools	Environmental	No	Sourcing	Green supplier selection	Not AI-based
Yang & Dong (2017)	Apparel	Modeling	None	Environmental	No	Product design	Consumer-driven sustainability	No resilience focus
Li & Wu (2017)	Apparel	Empirical	None	Environmental	No	Production	EMS improves performance	No AI or resilience
Le & Wang (2017)	Textile	Quantitative	Analytics	Environmental	No	Value chain	Performance measurement	Limited AI depth
Niu et al. (2017)	Fashion	Modeling	None	Economic + environmental	No	Sourcing	Power impacts sustainability	No climate link
Shi et al. (2017)	Fashion	Modeling	None	Environmental	No	Production	Investment improves sustainability	No resilience
Oelze (2017)	Textile	Case study	None	Social + environmental	No	All	Barriers identified	No AI solutions
LoMonaco-Benzing (2016)	Apparel	Qualitative	None	Social	No	Management	Ethical conflicts	No digital role
Cai & Choi (2020)	Apparel	Conceptual	None	SDGs	Partial	All	Aligns apparel with SDGs	No AI focus
Bubicz et al. (2021)	Apparel	Review	None	Social	No	Sourcing	Social sustainability critical	Weak tech integration
Ahmad et al. (2020)	Textile	Empirical	BI / Industry 4.0	Environmental	Partial	Production	BI supports sustainability	Limited AI scope
Jia et al. (2020)	Apparel	Review	None	Circular economy	No	End-of-life	Circularity reduces impact	No AI integration
Saha et al. (2021)	Apparel	Empirical	None	Circular economy	Partial	All	CE improves sustainability	Implementation barriers
Palacios-	Apparel	Review	None	Environmenta	No	Full chain	Identifies	No resilience

Mateo (2021)				l			hotspots	
Memon et al. (2021)	Textile	Review	None	Circular economy	No	End-of-life	Recycling key strategy	Tech gap
Toorajipour et al. (2021)	General SCM	Review	AI/ML	Indirect	Yes	All	AI improves decisions	Not apparel-specific
Pournader et al. (2021)	General SCM	Review	AI	Indirect	Yes	All	AI taxonomy developed	Limited sustainability link
Baryannis et al. (2019)	General SCM	Review	AI	No	Yes	Risk mgmt	AI enhances risk prediction	No apparel context
Belhadi et al. (2021)	General SCM	Empirical	AI	Indirect	Yes	All	AI improves resilience	Weak sustainability focus
Spieske & Birkel (2021)	General SCM	Review	Industry 4.0	Indirect	Yes	All	Digitalization improves resilience	Apparel gap

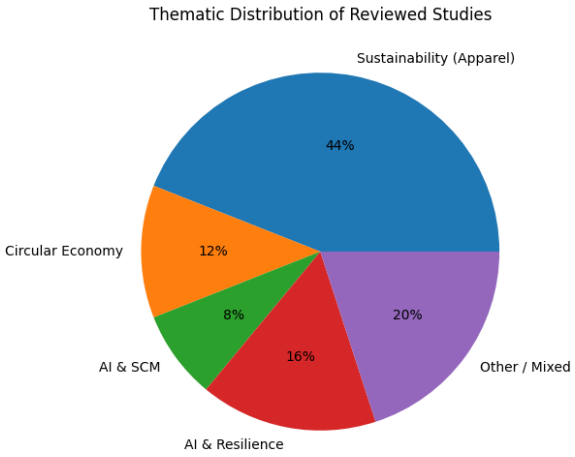

Figure 1: Thematic distribution of reviewed studies (2015–2021)

3. Methodology

3.1 Review design

This study adopts a narrative review design to synthesize and critically interpret the literature on AI-driven climate-resilient and environmentally sustainable apparel supply chains. This design is appropriate because the topic spans several partially disconnected streams, including sustainable textile and apparel supply chains, circular economy in textile/apparel systems, and AI-enabled supply chain management and resilience. Prior studies show that textile and apparel supply chains face severe environmental and social pressures, whereas AI and resilience research is more developed in general supply-chain settings than in apparel-specific contexts.

3.2 Search scope and sources

To improve transparency, the review uses a structured search process across Scopus, Web of Science, Google Scholar, and major publisher databases, including Elsevier, Springer Nature, Wiley, Nature portfolio journals, and MDPI. The search focused on peer-reviewed journal articles published in English between 2015 and 2021. Keyword combinations covered four concept groups: artificial intelligence/digital technologies, supply chain management, sustainability/resilience/climate-related adaptation,

and apparel/textile/fashion. This scope reflects evidence that apparel supply chains are sustainability-critical, while AI reviews identify forecasting, learning, and decision-support as major capabilities relevant to supply-chain transformation.

3.3 Search strings and selection criteria

The search strings combined terms such as "artificial intelligence," "machine learning," "predictive analytics," "business intelligence," "industry 4.0," "supply chain," "resilience," "risk management," "sustainab*," "circular economy," "climate resilience," "apparel," "textile," "fashion," and "garment." Studies were included if they met at least one of the following conditions:

(a) focused on environmental or social sustainability in apparel/textile supply chains;
(b) examined circular economy practices in textile/apparel systems;
(c) investigated AI or analytics applications in supply chain management; or
(d) addressed supply chain resilience or risk management in ways relevant to climate-related disruption.

Studies were excluded if they were outside the 2015–2021 period, were not peer-reviewed journal articles, lacked supply-chain relevance, or were purely technical AI studies without managerial or supply-chain implications. This logic is consistent with the literature: textile/apparel sustainability work emphasizes environmental and social complexity, circular-economy work identifies supply-chain-wide drivers and barriers, and AI reviews highlight the need to connect techniques with managerial SCM contexts.

3.4 Screening and coding process

The review followed four practical stages: identification, deduplication, title/abstract screening, and full-text assessment. Each retained paper was coded into a review matrix using the following fields: author, year, journal, context, method, AI/technology, sustainability focus, resilience focus, supply-chain stage, key findings, and research gap. This coding structure was chosen because the literature is fragmented. For example, apparel studies strongly emphasize sustainability challenges, circular-economy studies focus on environmental interventions, and AI studies emphasize sensing, learning, decision-making, and risk management.

3.5 Analytical approach

After coding, the studies were synthesized thematically. The analysis organized the literature into four main clusters:

1. sustainable apparel and textile supply chains;
2. circular economy and environmental intervention points;
3. AI applications in supply chain management; and
4. AI-enabled resilience and risk management.

This thematic approach enabled the development of an integrative conceptual framework linking AI capabilities to supply-chain functions, environmental sustainability outcomes, and climate resilience outcomes. The need for such integration is clear, as apparel sustainability research identifies persistent sector-specific problems, while AI/SCM reviews show a growing but still fragmented application of intelligent technologies across supply-chain subfields.

4. Thematic Analysis

The reviewed studies reveal that the literature between 2015 and 2021 can be organized into five major themes: (1) sustainability challenges in apparel supply chains, (2) circular economy and environmental intervention strategies, (3) AI and digital technologies in supply chain decision-making, (4) AI-driven resilience and risk management, and (5) barriers to integration in apparel supply chains. Across these themes, an important pattern emerges: apparel-specific studies are relatively strong in identifying sustainability problems and environmental interventions, whereas AI-oriented studies are more developed in general supply chain contexts and only weakly connected to apparel-specific realities. This fragmentation creates an important opportunity for integrated research.

The keyword network (Figure 1) reveals four major clusters: (1) AI and digital technologies (e.g., artificial intelligence, machine learning, Industry 4.0), (2) supply chain and resilience (e.g., supply chain, risk management, climate resilience), (3) sustainability

and circular economy, and (4) apparel domain terms (e.g., textile, fashion, garment). The central position of "supply chain," "artificial intelligence," and "sustainability" indicates their integrative role in connecting technological, environmental, and sector-specific research streams. Table 2 presents a "traffic-light matrix" summarizing the extent to which the 25 reviewed studies address five key themes. The matrix reveals a clear fragmentation in the literature, with sustainability, circular economy, and AI-driven resilience largely developed in isolation and limited integration across themes, where ◍ represents "Strong Focus"; ◍ represents "Partial / Indirect"; ◍ represents "Not Addressed"

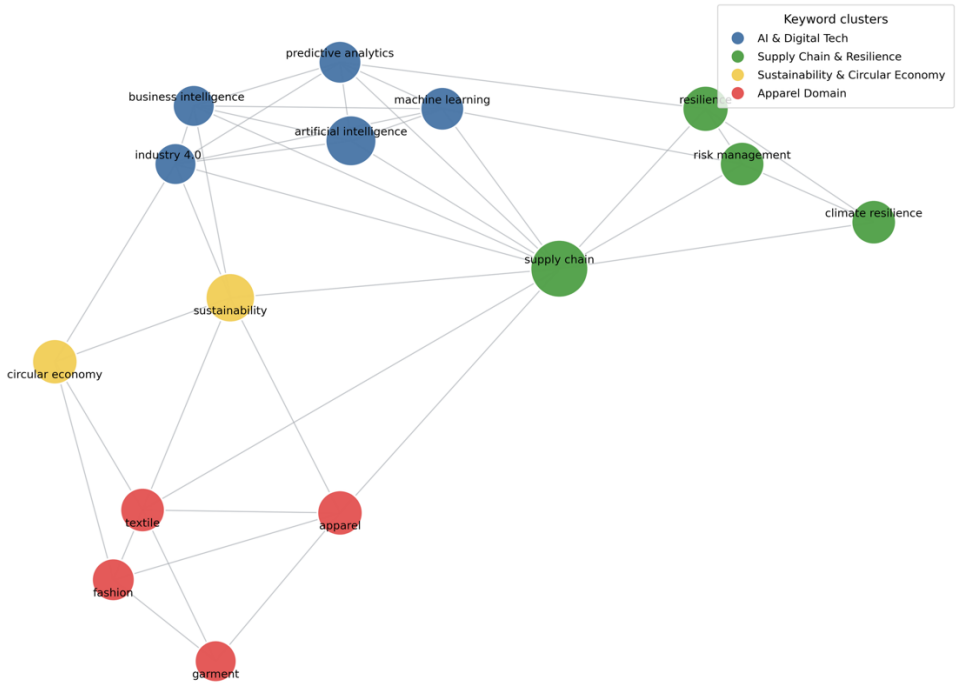

Figure 1: VOSViewer-Style Keyword Co-occurrence Network

Table 2: Traffic-light matrix summarizing the extent of five themes across 25 reviewed studies

Study	Sustainability Challenges	Circular Economy	AI & Decision-Making	AI-Driven Resilience	Integration Barriers
Touboulic & Walker (2015)	🟢	🔴	🔴	🔴	🟡
Rajeev et al. (2017)	🟢	🔴	🔴	🔴	🟡
Shen et al. (2017)	🟢	🔴	🔴	🔴	🔴
Köksal et al. (2017)	🟢	🔴	🔴	🔴	🟡
Yang et al. (2017)	🟡	🔴	🔴	🔴	🔴
Guo et al. (2017)	🟡	🔴	🟡	🔴	🔴
Yang & Dong (2017)	🟡	🔴	🔴	🔴	🔴
Li & Wu (2017)	🟡	🔴	🔴	🔴	🔴
Le & Wang (2017)	🟡	🔴	🟡	🔴	🔴
Niu et al. (2017)	🟢	🔴	🔴	🔴	🟡
Shi et al. (2017)	🟡	🔴	🔴	🔴	🟡
Oelze (2017)	🟢	🔴	🔴	🔴	🟢
LoMonaco-Benzing (2016)	🟢	🔴	🔴	🔴	🟡
Cai & Choi (2020)	🟡	🟡	🔴	🟡	🔴
Bubicz et al. (2021)	🟢	🔴	🔴	🔴	🟡
Ahmad et al. (2020)	🟡	🔴	🟢	🟡	🟡
Jia et al. (2020)	🟡	🟢	🔴	🔴	🟡
Saha et al. (2021)	🟡	🟢	🔴	🟡	🟢
Palacios-Mateo (2021)	🟢	🟢	🔴	🔴	🔴

Memon et al. (2021)	🟡	🟢	🔴	🔴	🟡
Toorajipour et al. (2021)	🔴	🔴	🟢	🟢	🔴
Pournader et al. (2021)	🔴	🔴	🟢	🟢	🔴
Baryannis et al. (2019)	🔴	🔴	🟢	🟢	🔴
Belhadi et al. (2021)	🔴	🔴	🟢	🟢	🟡
Spieske & Birkel (2021)	🔴	🔴	🟡	🟢	🔴

4.1 Sustainability challenges in apparel supply chains

A substantial part of the literature focuses on the sustainability burden of textile and apparel supply chains. These studies consistently show that the apparel sector is characterized by high environmental intensity, global production fragmentation, and multi-tier sourcing structures that complicate sustainability implementation. Shen et al. (2017) identified the apparel and textile industry as a major contributor to resource depletion, pollution, and waste generation, particularly through water-intensive production, chemical use, and fast-changing consumption cycles. Their work positions apparel supply chains as a critical domain for environmental sustainability research (Shen et al., 2017; Oelze, 2017). Shen et al. (2017).

The literature also shows that sustainability in apparel supply chains extends beyond environmental concerns. Köksal et al. (2017) and Bubicz et al. (2021) emphasized that social sustainability remains a central concern, particularly in relation to labor conditions, supplier monitoring, and ethical sourcing. These studies demonstrate that apparel sustainability is deeply embedded in supplier governance and inter-organizational coordination rather than only in technical production processes. LoMonaco-Benzing and Ha-Brookshire (2016) further added that apparel professionals often experience value conflicts between economic pressures and moral responsibility, suggesting that sustainability implementation is also shaped by organizational culture and managerial interpretation. Several studies also explored how sustainability is influenced by structural features of the fashion supply chain. Niu et al. (2017) and Shi et al. (2017) showed that power asymmetry, supplier behavior, and investment decisions significantly affect sustainability outcomes. Their findings suggest that sustainability performance cannot be understood independently from commercial relationships and governance structures. In other words, the sustainability of apparel supply chains is not simply a result of environmental awareness, but also of bargaining power, incentives, and strategic decision-making across the chain.

Overall, this stream of literature establishes that apparel supply chains face systemic sustainability problems involving environmental degradation, labor issues, and governance complexity (Figure 2). However, most studies in this group are descriptive, conceptual, or analytical rather than technologically oriented. As a result, they identify the urgency of transformation but offer limited insight into how advanced digital capabilities, such as AI, could help address these challenges.

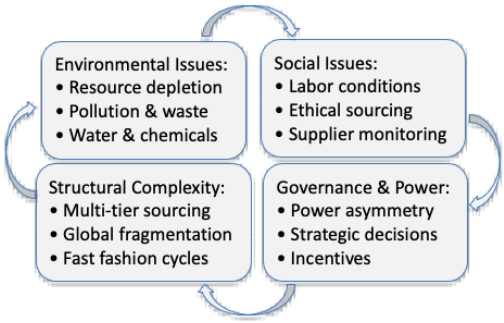

Figure 2: Depicts the barriers in the sustainable supply chain context

4.2 Circular economy and environmental intervention strategies

A second major theme focuses on circular economy practices and environmental intervention points in textile and apparel systems. This body of literature moves beyond identifying sustainability problems to examine practical strategies for reducing environmental burdens. Jia et al. (2020) provided one of the most important syntheses in this area by reviewing circular economy research in the textile and apparel industry. Their findings suggest that circularity offers a pathway to reduce waste, extend product life cycles, improve material efficiency, and lower overall environmental impacts. However, they also noted that circular implementation remains uneven and constrained by technological, organizational, and market barriers.

Similarly, Saha et al. (2021) found that implementing circular economy principles in textile and clothing supply chains requires stronger collaboration, supportive policy environments, investment in infrastructure, and business model innovation. Their study indicates that circular transition is not only a technical issue but also an ecosystem-level challenge involving producers, retailers, recyclers, and consumers. Palacios-Mateo et al. (2021) strengthened this systems view by mapping the polyester clothing value chain and identifying the most significant environmental intervention points. Their analysis suggests that sustainability gains require action across multiple stages, including material production, manufacturing, logistics, consumer use, and end-of-life management. Memon et al. (2021) further reinforced the importance of recycling, reuse, and closed-loop thinking for the textile and clothing industry. Collectively, these studies show that environmental sustainability in apparel supply chains is increasingly understood through a life-cycle and circular-economy lens. This is a significant development, because it shifts the literature away from isolated process improvements toward broader systemic redesign.

However, despite the value of circularity research, most studies in this stream remain weakly integrated with digital intelligence and predictive decision-making. They explain what environmental strategies are needed, but much less about how firms can use AI to support product recirculation, forecast returns, optimize reverse logistics, identify waste hotspots, or improve closed-loop coordination. Thus, the circular economy literature provides a strong environmental foundation for this review, but it also exposes a gap in digital implementation capability.

4.3 AI and digital technologies in supply chain decision-making

The reviewed studies collectively show that AI in supply chains has evolved from basic automation to advanced predictive and decision-support systems (Toorajipour et al., 2021; Pournader et al., 2021). Baryannis et al. (2019) demonstrated that AI enhances risk identification and prediction, while Ahmad et al. (2020) provided apparel-specific evidence that business intelligence systems improve sustainability and competitiveness. The reviewed studies (Table 3) collectively show that AI in supply chains has evolved from basic automation to advanced predictive and decision-support systems. While most contributions are developed in general supply chain contexts, emerging evidence in the textile and apparel sector suggests strong potential for AI to enhance forecasting, risk management, sustainability performance, and supplier evaluation.

Table 3: Reports the application of AI and digital technologies in the supply chain context.

Study and Context	AI / Technology Focus	Application Area	Key Contribution	Relevance to Apparel Supply Chains
Toorajipour et al. (2021) General SCM	AI / Machine Learning	Forecasting, demand planning, optimisation, decision support	Shows rapid growth of AI in supply chains and highlights its role in advanced coordination and predictive decision-making	Demonstrates how AI can address demand volatility and complex coordination challenges in apparel supply chains
Pournader et al. (2021) General SCM	AI	Pattern recognition, predictive analytics, decision support	Develops understanding of AI capabilities in supply chain analytics and decision-making	Indicates potential for AI to improve forecasting accuracy and operational efficiency in apparel systems
Baryannis et al. (2019) General SCM	AI in risk management	Risk identification, classification, prediction	Shows AI enhances supply chain risk management under uncertainty and complexity	Highly relevant for apparel sector facing demand uncertainty, supply disruptions, and multi-tier risks
Ahmad et al. (2020) Textile & Apparel	Business Intelligence / Industry 4.0	Process monitoring, visibility, decision-making	Demonstrates that digital intelligence systems improve sustainability and competitiveness	Provides direct evidence that data-driven systems can support sustainable apparel operations
Le & Wang (2017) Textile &	Analytical / Data-driven methods	Performance evaluation	Shows early adoption of analytical tools for assessing sustainability	Indicates readiness of apparel sector for AI-based performance

Apparel			and operational performance	optimization
Apparel manufacturing	Decision-support / Analytical models	Green supplier selection	Develops methods for evaluating suppliers based on environmental criteria	Highlights how AI can enhance supplier evaluation and sustainability decision-making

4.4 AI-driven resilience and risk management in supply chain decision making

Baryannis et al. (2019) argue that AI strengthens supply chain risk management by improving the ability to detect patterns, assess uncertainty, and generate predictive insights. This contributes directly to resilience because proactive risk identification is a prerequisite for effective response and adaptation. Belhadi et al. (2021) empirically found that AI-driven innovation can improve supply chain resilience and performance, particularly under dynamic, uncertain conditions. Their results indicate that AI is not merely a technical support tool but can become a strategic capability for coping with disruption. Spieske and Birkel (2021) further demonstrate that Industry 4.0 technologies can strengthen resilience through improved visibility, information processing, responsiveness, and reconfiguration capacity. Although their review is broader than AI alone, it supports the argument that digital technologies can improve adaptive capabilities in complex supply networks. For the apparel industry, such capabilities are especially important because supply chains are often geographically dispersed, highly outsourced, and vulnerable to logistics disruptions, climate shocks, and instability in raw-material supply.

The significance of this literature lies in its clear relevance to climate resilience, even when climate is not always explicitly named. Many of the resilience capabilities discussed in these studies, such as sensing, forecasting, flexibility, responsiveness, and recovery, are directly applicable to climate-related disruptions including floods, storms, heat stress, transport interruptions, and input shortages. In this sense, the resilience literature provides a conceptual pathway for connecting AI with climate adaptation in apparel supply chains. At the same time, an important limitation remains: the resilience literature is still predominantly general rather than apparel-specific. Very few studies explicitly examine how AI can help apparel firms manage sustainability-oriented climate risks while maintaining environmental performance. As a result, resilience research is strong on capability logic but weak on sector-specific sustainability integration.

4.5 Barriers to AI integration in apparel supply chains

The fifth theme concerns the barriers to integrating AI, sustainability, and resilience in apparel supply chains. Oelze (2017) identified a range of implementation barriers in the textile industry, including weak supplier collaboration, limited visibility, lack of internal alignment, and difficulties in translating sustainability goals into operational practice. These barriers remain highly relevant in the context of AI adoption because intelligent systems depend on reliable data, multi-tier transparency, and organizational coordination.

Several other studies indirectly reinforce this issue. Ahmad et al. (2020) indicate that digital intelligence systems require organizational readiness and technological capability. Saha et al. (2021) show that the implementation of the circular economy is often constrained by financial, infrastructural, and institutional barriers. Niu et al. (2017) and Shi et al. (2017) further suggest that power imbalances and strategic misalignments among supply chain actors can undermine sustainability-oriented investments. Taken together, these findings imply that the successful adoption of AI for environmental sustainability and climate resilience is likely to depend on a broader set of enabling conditions. These conditions include data availability, digital capability, supplier readiness, governance support, and regulatory pressure. In apparel supply chains, these barriers may be even more severe because many suppliers operate in developing countries with uneven access to technology, limited information systems, and cost-sensitive production environments. This makes the sector a challenging but important context for studying AI-enabled transformation. Therefore, the main contribution of this thematic stream is to show that the challenge is not only technological. Even if AI tools are available, their effectiveness depends on whether the surrounding supply chain system can support data sharing, organizational learning, and coordinated action. This suggests that future research should move beyond studying AI as an isolated technical tool and instead examine it as part of a socio-technical transformation process in apparel supply chains.

4.6 Cross-theme synthesis

When the five themes are considered together, three broader insights emerge. First, the apparel-specific literature is strongest in diagnosing sustainability problems, especially environmental burden, labor issues, governance complexity, and circular-economy challenges. This literature provides rich sectoral understanding but limited technological solutions. Second, the AI and resilience literature is strongest in identifying operational capabilities, such as prediction, optimization, sensing, and adaptation. However, this literature is often too general and rarely addresses the specific realities of textile and apparel supply chains. Third, there is a clear integration gap. Very few studies explicitly examine how AI can be used in apparel supply chains to achieve both environmental sustainability and climate resilience simultaneously. Most existing research addresses one or two of these dimensions, but not all three in a unified framework. This gap justifies the need for the present review and supports the conceptual framework proposed in this paper. By linking AI technologies with supply chain functions, sustainability outcomes, and resilience capabilities, the review contributes an integrated perspective that the existing literature has not yet sufficiently developed.

6. Discussion

This study provides an integrated understanding of how AI can contribute to environmental sustainability and climate resilience in apparel supply chains. The findings reveal that while significant progress has been made in each domain individually, their integration remains limited. This section discusses key insights derived from the thematic analysis and highlights theoretical, managerial, and policy implications.

6.1 Integration of sustainability and resilience through AI

One of the most important findings of this study is that AI can serve as a bridging mechanism between sustainability and resilience objectives**.** Traditionally, sustainability and resilience have been treated as separate domains. Sustainability research in apparel supply chains has primarily focused on environmental performance, circular economy practices, and social compliance, while resilience research has focused on disruption management, risk mitigation, and recovery capabilities (Köksal et al., 2017; Bubicz et al., 2021; Baryannis et al., 2019; Belhadi et al., 2021)). The reviewed literature suggests that AI enables integration by enhancing key supply chain capabilities such as forecasting, optimization, and real-time decision-making (Toorajipour et al., 2021). For example, AI-driven demand forecasting reduces overproduction and waste, thereby improving environmental sustainability, while enabling more responsive and adaptive supply chain operations and contributing to resilience. Similarly, AI-based risk analytics improves the ability to anticipate disruptions, which is critical for climate resilience, while also supporting efficient resource allocation. However, despite these potential synergies, the literature rarely addresses sustainability and resilience simultaneously. This indicates a conceptual gap and highlights the need for integrated frameworks that explicitly link AI capabilities to both environmental and resilience outcomes in apparel supply chains.

6.2 Trade-offs and tensions

The findings also reveal trade-offs among sustainability, resilience, and economic efficiency. Several studies suggest that investments in sustainability, such as cleaner production or circular economy practices, may increase operational costs in the short term. Similarly, building resilience through redundancy, flexibility, or supplier diversification may reduce efficiency and increase costs. AI has the potential to mitigate some of these trade-offs by improving decision accuracy and optimizing resource use. However, AI implementation itself requires significant investment in infrastructure, data systems, and organizational capabilities. In apparel supply chains, where cost pressure is high and margins are often low, these investments may be difficult to justify without clear short-term returns. Therefore, firms must carefully balance these competing objectives. The role of AI should not be viewed as eliminating trade-offs entirely, but rather as enabling more informed and optimized decision-making within existing constraints (Saha et al., 2021; Niu et al., 2017; Pournader et al., 2021).

A. 6.3 Sector-specific challenges in apparel supply chains

Another key insight is that **apparel supply chains present unique challenges for AI-driven transformation**. Unlike many other industries, apparel supply chains are characterized by:

- Multi-tier supplier networks
- High reliance on outsourcing

- Geographic dispersion
- Limited transparency and traceability

These characteristics create significant barriers to the implementation of AI. For example, AI systems require large volumes of high-quality data, but data availability and consistency are often limited in apparel supply chains, particularly in developing-country contexts. Furthermore, sustainability issues in apparel supply chains are often deeply embedded in social and institutional contexts, such as labor practices and regulatory environments. These issues cannot be fully addressed through technological solutions alone. As a result, AI must be integrated with broader governance mechanisms, including supplier collaboration, regulatory frameworks, and industry standards (Oelze, 2017; Bubicz et al., 2021; Ahmad et al., 2020).

B. 6.4 Managerial implications

From a managerial perspective, the findings suggest that apparel firms should adopt a holistic digital transformation strategy**.** Rather than implementing AI in isolated functions, firms should integrate AI across the supply chain, including forecasting, sourcing, production, and logistics. Managers should also focus on building data infrastructure and analytical capabilities**,** as these are critical enablers of AI adoption. In addition, collaboration with suppliers and technology providers is essential to ensure data sharing and system integration across the supply chain. Importantly, firms should align AI adoption with sustainability and resilience goals. This requires a strategic approach that prioritises long-term environmental and risk-related benefits over short-term cost reduction.

C. 6.5 Policy implications

The findings also have important implications for policymakers. Governments and industry organizations can play a key role in facilitating AI adoption by:

- Supporting digital infrastructure development
- Promoting data standardization and transparency
- Providing incentives for sustainable and resilient practices
- Encouraging collaboration across supply chain actors

In particular, policies that support circular economy initiatives and climate adaptation strategies can complement AI adoption and enhance overall supply chain sustainability.

7. Future Research Directions

The literature identifies four key research gaps:

- **Theoretical Development:** There is a need for integrated frameworks linking AI, sustainability, and resilience. Future studies should move beyond fragmented approaches and incorporate theories such as dynamic capabilities, socio-technical systems, and circular economy.
- **Methodological Advancement:** Existing research is largely conceptual. More empirical and quantitative studies (e.g., SEM, panel data, machine learning) are needed, along with case studies and longitudinal research to understand real-world AI implementation.
- **Contextual Expansion:** Research should focus more on developing countries and SMEs, where apparel supply chains are concentrated and face unique challenges, such as limited infrastructure and regulatory differences.
- **Technological Integration:** Future work should explore how AI can be combined with other digital technologies to enhance supply chain sustainability and resilience.

8. Conclusion

This study provides a comprehensive synthesis of the literature on AI, environmental sustainability, and climate resilience in apparel supply chains. The findings demonstrate that while each of these domains has developed significantly over the past decade, their integration remains limited. Apparel-focused studies have been effective in diagnosing sustainability challenges and identifying environmental intervention strategies, particularly through circular economy approaches. In contrast, AI and

resilience research has advanced the understanding of predictive, adaptive, and optimization capabilities, but has largely overlooked the specific institutional and operational characteristics of apparel supply chains. A key contribution of this study is the identification of a clear integration gap across three major research streams: sustainable apparel supply chains, circular economy practices, and AI-driven supply chain resilience. By synthesizing these streams, the paper highlights the potential of AI to act as a bridging mechanism that enhances both environmental performance and resilience capabilities. AI-enabled forecasting, optimization, and risk analytics can reduce waste, improve resource efficiency, and strengthen the ability of supply chains to anticipate and respond to climate-related disruptions. However, the study also emphasizes that technological potential alone is insufficient. The successful implementation of AI in apparel supply chains depends on broader enabling conditions, including data availability, digital infrastructure, supplier collaboration, and supportive governance frameworks. Structural characteristics of the apparel industry—such as multi-tier supplier networks, limited transparency, and cost pressures—pose additional challenges that must be addressed through coordinated efforts across firms, policymakers, and industry stakeholders. Overall, this study underscores the need for a holistic and integrated approach to supply chain transformation. Future research should focus on developing empirical evidence, exploring emerging digital technologies, and examining diverse geographical and organizational contexts. By advancing an integrated framework that connects AI capabilities with sustainability and resilience outcomes, this paper contributes to the development of more adaptive, efficient, and environmentally responsible apparel supply chains in an era of increasing climate uncertainty.

Funding: This research received no external funding.
Conflicts of Interest: The authors declare no conflict of interest.
Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers.

References:

[1]. Ahmad, S., Miskon, S., Alabdan, R., & Tlili, I. (2020). Role of business intelligence systems in textile sustainability. *Sustainability, 12*(7), 2632. https://doi.org/10.3390/su12072632
[2]. Baryannis, G., Validi, S., Dani, S., & Antoniou, G. (2019). AI in supply chain risk management. *International Journal of Production Research, 57*(7), 2179–2202. https://doi.org/10.1080/00207543.2018.1530476
[3]. Belhadi, A., Mani, V., Kamble, S. S., Khan, S. A. R., & Verma, S. (2021). AI-driven supply chain resilience. *Annals of Operations Research*. https://doi.org/10.1007/s10479-021-03956-x
[4]. Bubicz, M. E., Dias Barbosa-Póvoa, A. P. F., & Carvalho, A. (2021). Social sustainability management in apparel supply chains. *Journal of Cleaner Production, 280*, 124214. https://doi.org/10.1016/j.jclepro.2020.124214
[5]. Cai, Y. J., & Choi, T. M. (2020). A United Nations' SDGs perspective for sustainable textile and apparel supply chains. *Transportation Research Part E, 141*, 102010. https://doi.org/10.1016/j.tre.2020.102010
[6]. Guo, Z., Liu, H., Zhang, D., & Yang, J. (2017). Green supplier evaluation and selection in apparel manufacturing using a fuzzy multi-criteria decision-making approach. *Sustainability, 9*(4), 650. https://doi.org/10.3390/su9040650
[7]. Jia, F., Yin, S., Chen, L., & Chen, X. (2020). Circular economy in textile and apparel industry. *Journal of Cleaner Production, 259*, 120728. https://doi.org/10.1016/j.jclepro.2020.120728
[8]. Köksal, D., Strähle, J., Müller, M., & Freise, M. (2017). Social sustainable supply chain management in the textile and apparel industry: A literature review. *Sustainability, 9*(1), 100. https://doi.org/10.3390/su9010100
[9]. Le, T. N., & Wang, C. N. (2017). The integrated approach for sustainable performance evaluation in the textile and apparel industry. *Sustainability, 9*(3), 477. https://doi.org/10.3390/su9030477
[10]. Li, B., & Wu, K. (2017). Environmental management system adoption and the operational performance of firms in the textile and apparel industry. *Sustainability, 9*(6), 992. https://doi.org/10.3390/su9060992
[11]. LoMonaco-Benzing, R., & Ha-Brookshire, J. (2016). Sustainability as social contract. *Sustainability, 8*(12), 1278. https://doi.org/10.3390/su8121278
[12]. Memon, H., Wang, Y., Marriam, I., & Tebyetekerwa, M. (2021). Circular economy in textile industry. *Materials Circular Economy, 3*, 12. https://doi.org/10.1007/s42824-021-00026-2
[13]. Niu, B., Chen, L., & Zhang, J. (2017). Sustainability analysis of supply chains with fashion products under alternative power structures. *Sustainability, 9*(6), 995. https://doi.org/10.3390/su9060995
[14]. Oelze, N. (2017). Sustainable supply chain management implementation in the textile industry. *Sustainability, 9*(8), 1435. https://doi.org/10.3390/su9081435
[15]. Palacios-Mateo, C., van der Meer, Y., & Seide, G. (2021). Polyester clothing value chain analysis. *Environmental Sciences Europe, 33*, 2. https://doi.org/10.1186/s12302-020-00447-x
[16]. Pournader, M., Ghaderi, H., Hassanzadegan, A., & Fahimnia, B. (2021). Artificial intelligence applications in supply chains. *International Journal of Production Economics, 241*, 108250. https://doi.org/10.1016/j.ijpe.2021.108250

[17]. Rajeev, A., Pati, R. K., Padhi, S. S., & Govindan, K. (2017). Evolution of sustainability in supply chain management: A literature review. *Journal of Cleaner Production, 162*, 299–314. https://doi.org/10.1016/j.jclepro.2017.05.026

[18]. Saha, K., Dey, P. K., & Papagiannaki, E. (2021). Implementing circular economy in textile industry. *Business Strategy and the Environment, 30*(4), 1497–1530. https://doi.org/10.1002/bse.2670

[19]. Shen, B., Li, Q., Dong, C., & Perry, P. (2017). Sustainability issues in textile and apparel supply chains. *Sustainability, 9*(9), 1592. https://doi.org/10.3390/su9091592

[20]. Shi, X., Qian, Y., & Dong, C. (2017). Economic and environmental performance of fashion supply chains. *Sustainability, 9*(6), 961. https://doi.org/10.3390/su9060961

[21]. Spieske, A., & Birkel, H. (2021). Industry 4.0 and supply chain resilience. *Computers & Industrial Engineering, 158*, 107452. https://doi.org/10.1016/j.cie.2021.107452

[22]. Toorajipour, R., Sohrabpour, V., Nazarpour, A., Oghazi, P., & Fischl, M. (2021). Artificial intelligence in supply chain management. *Journal of Business Research, 122*, 502–517. https://doi.org/10.1016/j.jbusres.2020.09.009

[23]. Touboulic, A., & Walker, H. (2015). Theories in sustainable supply chain management: A structured literature review. *International Journal of Physical Distribution & Logistics Management, 45*(1/2), 16–42. https://doi.org/10.1108/IJPDLM-05-2013-0106

[24]. Yang, L., & Dong, S. (2017). Sustainable product strategy in apparel industry with consumer behavior consideration. *Sustainability, 9*(6), 920. https://doi.org/10.3390/su9060920

[25]. Yang, S., Song, Y., & Tong, S. (2017). Sustainable retailing in the fashion industry: A systematic literature review. *Sustainability, 9*(7), 1266. https://doi.org/10.3390/su9071266