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THE ROLE OF ARTIFICIAL INTELLIGENCE IN BUILDING RESILIENT AND SUSTAINABLE SUPPLY CHAINS: A MULTIPLE-CASE STUDY WITH AN EXTENSION TO PAKISTAN TEXTILE AND MANUFACTURING SECTOR

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Abstract

Purpose *This study examines how artificial intelligence (AI) contributes to building resilient and sustainable supply chains, investigating the mechanisms through which AI generates these outcomes and the organizational conditions that moderate their realization. The research extends its inquiry to Pakistan's textile and manufacturing sectors to assess how these mechanisms translate into resource-constrained emerging-market settings.*

Design/Methodology/Approach. *A qualitative, exploratory multiple-case study design was used to conduct this study.*

Findings. *The findings are striking in their consistency: optimization-driven AI cuts emissions or resource waste in 5 of 6 global cases, predictive analytics and digital twins compress disruption response time in half the sample, and the strongest performers achieve both outcomes at once, from a single system, rather than through separate initiatives. The Pakistan extension confirms the same mechanisms at the firm level, most vividly in a documented 30 percent reduction in material waste at a major textile exporter, but reveals a sharper constraint: infrastructure, energy, cost, and analytical-skills gaps concentrate these gains among a handful of well-resourced firms, with prescriptive analytics capability, not AI access alone, emerging as the true differentiator.*

Practical Implications. *From these findings, the study builds a three-layer framework, technology, data and infrastructure, and governance, that reframes AI investment decisions around a single question: which layer is constraining your resilience and sustainability outcomes? The paper closes with concrete, sequenced recommendations for Pakistani practitioners and policymakers seeking to close that gap.*

Originality/Value. *The study builds a three-layer framework technology, data and infrastructure, and governance reframing AI investment decisions around identifying the layer constraining resilience and sustainability outcomes. It provides sequenced recommendations for Pakistani practitioners and policymakers.*

Keywords: Artificial Intelligence; Supply Chain Resilience; Sustainable Supply Chain; Digital Twin; Pakistan Textile Industry

1. Introduction

Supply chains form the operational backbone of the global economy, and their disruption carries consequences that extend well beyond individual firms to entire regions and industries. Organizations have contended with an unusually dense sequence of shocks in recent years, including pandemic-driven shutdowns, port congestion, geopolitical conflict, trade restrictions, and extreme weather events, elevating supply chain resilience into a strategic priority (World Economic Forum, 2025; Deloitte Insights, 2026). Industry surveys report that supply chain professionals are increasingly prioritizing AI and generative AI investment as a decisive factor in technology planning (ABI Research, 2025), and market analysis projects the global AI-in-supply-chain sector to grow substantially over the remainder of the decade (MarketsandMarkets, 2025).

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Simultaneously, supply chains face mounting pressure to decarbonize and demonstrate credible environmental, social, and governance performance, as regulators, investors, and consumers converge on sustainability as a competitive requirement rather than a voluntary initiative (Nurkic, 2025).

1.1. Problem Statement

Organizations have historically pursued resilience and sustainability as separate, and at times competing, agendas. Artificial intelligence is frequently claimed to resolve this tension by enabling firms to forecast disruption and optimize operations simultaneously (Frontiers in Sustainability, 2025), yet the mechanisms through which this occurs, and the organizational conditions under which it does or does not occur, remain insufficiently documented through systematic case analysis. A further gap concerns context: most documented evidence originates from large, well-resourced multinational firms, leaving open the question of how these mechanisms translate into resource-constrained emerging-market settings such as Pakistan, where infrastructure, energy, and skills constraints differ substantially from the conditions under which most published case evidence was generated (ScienceDirect, 2025b).

2. Literature Review

2.1 Theoretical Framework

2.1.1 Organizational Information Processing Theory (OIPT). This holds that firms facing environmental uncertainty must expand their information-processing capacity to match the complexity of the environment in which they operate. Empirical work applying this lens to AI adoption shows that AI usage strengthens resilience by improving a firm's ability to gather, interpret, and act on dispersed information across a supply network (MDPI Sustainability, 2025).

2.1.2The Resource-Based View (RBV). RBV treats AI capability as a strategic resource that is valuable, difficult to imitate, and organizationally embedded. Panel-data research on manufacturing firms finds that AI strengthens resilience by improving information-processing efficiency and coordination of external resources (Guo, Chen, Xie, Wang, & Lei, 2025).

2.1.3 Technology- Organization- Environment (TOE) framework. In resource-constrained environments, research combining the Technology-Organization-Environment (TOE) framework with the RBV finds that technological readiness, meaning access to infrastructure, skilled personnel, and reliable data systems, has a strong, statistically significant effect on AI adoption among small and medium-sized enterprises (ScienceDirect, 2025b Drawing on OIPT, the RBV, the TOE framework, and the documented evolution of AI capability from descriptive to predictive to agentic analytics (Deloitte Insights, 2026; Supply Chain Management Review, 2026), five propositions were developed prior to case analysis to structure the investigation.

2.2 Empirical Evidence on AI and Supply Chain Resilience

Recent empirical studies have provided substantial evidence on the relationship between AI and supply chain resilience. Research on manufacturing firms has explored how AI can be leveraged to enhance supply chain resilience, drawing on OIPT to examine the mechanisms through which AI usage impacts resilience outcomes (Journal of Manufacturing Technology Management, 2025). Studies on emerging markets have found that enterprises' willingness to adopt artificial intelligence technology significantly impacts supply chain resilience and supply chain performance (MDPI Sustainability, 2022). Digital twin technology has emerged as a crucial enabler of resilience, enabling real-time assessment and dynamic optimization of supply chain resilience through synchronous mapping and continuous updating of multi-node supply chain states (IEEE, 2026). Research on digital twins demonstrates that multidimensional resilience metric systems covering robustness, recovery capability, and adaptability, complemented by real-time assessment algorithms, enable dynamic quantification of system resilience levels (IEEE, 2026).

2.3 AI and Supply Chain Sustainability

The literature on AI and supply chain sustainability has grown considerably. Research on AI-driven Internet of Things-based green supply chains for carbon reduction in sustainable manufacturing demonstrates how optimization-focused AI applications generate measurable sustainability outcomes (ScienceDirect, 2025a). Studies examining AI applications to low-carbon decision support systems for global supply chains

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provide evidence of AI's role in reducing emissions and resource waste (ScienceDirect, 2025c). Quasi-experimental evidence linking regional AI innovation to reduced manufacturing emissions further supports these findings (ScienceDirect, 2026). Systematic reviews of AI and robotics for reducing carbon emissions in supply chain management have documented applications across transportation and energy-intensive sectors (MDPI Logistics, 2025). Research on carbon-aware digital twin scheduling has demonstrated that integrated frameworks coupling digital twins with reinforcement learning and large language models can reduce carbon emissions by 18-32% while maintaining or improving service levels under disruption scenarios (IEEE, 2026). The literature also identifies that AI-enabled supply chain orchestration, as demonstrated by companies such as Maersk and Coca-Cola, can yield combined resilience and sustainability benefits (AI CERTs News, 2025).

2.4 AI Adoption in Emerging Markets and Pakistan

Research on AI adoption in emerging markets has highlighted the significant role of contextual moderators including firm size, industry type, and infrastructure development (Javaid et al., 2026). Studies on Pakistan's textile sector have examined AI-driven digital supply chain integration and found that prescriptive analytics capability mediates the relationship between AI adoption and supply chain performance (Journal of Management Science Research Review, 2026). Survey research on Pakistani textile and garment manufacturing employees has found a statistically significant positive relationship between AI use and demand forecasting, decision-making, and product delivery performance (ResearchGate, 2026a). Research on digital transformation barriers in Pakistani courier supply chains has identified poor road and port infrastructure, high fuel costs, regulatory hurdles, and inefficient customs clearance as persistent operational constraints that AI applications can partially mitigate but not eliminate (Alam et al., 2025). The literature on AI adoption in Pakistan in 2026 indicates an uneven readiness gap between large firms, which can access specialized talent, and SMEs, which often rely on generalist staff, compounded by a data-quality gap and misalignment between business decision-makers and technical teams (EmporionSoft, 2026).

2.5 Barriers to AI Adoption in Supply Chains

The broader literature on AI adoption in supply chain management identifies data quality, cost, organizational resistance, and a shortage of combined data-science and supply-chain expertise as recurring global barriers (Hangl et al., 2023; ResearchGate, 2024; Preprints.org, 2025), alongside unresolved questions of algorithmic transparency and fairness in AI-assisted decision-making (ResearchGate, 2025a). In the Pakistani context, technological readiness has been found to have a strong, statistically significant effect on AI adoption, with basic digital infrastructure often lacking (ScienceDirect, 2025b). Cost remains a disproportionate barrier for small and medium-sized enterprises, which face substantial upfront investment requirements for technology infrastructure, data acquisition, and skilled personnel (Pakistan Social Sciences Review, 2024). Case-based research on Industry 4.0 adoption among Pakistani firms found that change management and cost-related barriers were cited as the most significant obstacles by manufacturing managers, with Pakistani firms described as lagging behind international benchmarks in IT infrastructure readiness (FC College Journal of Business Innovation, n.d.).

2.6 Development Research Preposition

Drawing on OIPT, the RBV, the TOE framework, and the documented evolution of AI capability from descriptive to predictive to agentic analytics (Deloitte Insights, 2026; Supply Chain Management Review, 2026), five propositions were developed prior to case analysis to structure the investigation.

P1. Organizations deploying predictive analytics and digital twins exhibit a compressed interval between the emergence of a disruptive signal and the initiation of a corrective response, relative to organizations relying on descriptive analytics alone.

P2. Organizations deploying agentic or autonomous AI exhibit faster network reconfiguration during active disruption events than organizations using AI in a decision-support-only capacity.

P3. AI applications focused on route, load, and maintenance optimization generate measurable reductions in fuel consumption, emissions, or resource waste as a direct operational output.

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P4. Organizations that integrate multiple AI capability layers (forecasting, simulation, and optimization) realize resilience and sustainability benefits jointly from a shared system, whereas organizations deploying a single, isolated AI capability realize more fragmented benefits.

P5. The strength of realized resilience and sustainability benefits is moderated by the organization's data quality and governance maturity rather than by AI model sophistication alone.

These propositions were used as the coding frame for the global cross-case analysis in Section 5 and were subsequently applied, with attention to contextual moderators, to the Pakistan extension in Section 6.), a finding of particular relevance to the Pakistan extension in Section 6.

2.7. Research Objectives

The study is guided by the following objectives:

RO1. To identify the mechanisms through which AI contributes to resilience and sustainability in practice.

RO2. To determine whether these outcomes are generated jointly or independently within observed deployments; to identify the organizational conditions that moderate the strength of these effects

RO3. To assess how these mechanisms and moderators manifest within Pakistan supply chain sector specifically.

2.8 Research Questions

Correspondingly, the study poses four research questions:

RQ1. Through what observable mechanisms does AI strengthen supply chain resilience?

RQ2. Through what observable mechanisms does AI advance supply chain sustainability?

RQ3. What organizational conditions explain variation in outcomes across cases?

RQ4. How do these mechanisms and moderating conditions apply within Pakistan's supply chain sector, and with what implications for practitioners and policymakers?

3. Research Methodology

3.1 Research Design and Philosophical Orientation

This study adopts a qualitative, exploratory multiple-case study design, following established case study methodology in which cases are selected purposively to allow both literal replication and theoretical replication (Yin, 2018). The design is extended with a nested, context-specific case examination of Pakistan, treated as a theoretical replication opportunity: propositions developed from globally documented, well-resourced firms are tested against a resource-constrained emerging-market context where different outcomes would be theoretically expected under the TOE and RBV account in Section 2.2.

3.2 Population and Sampling

Six global cases were purposively selected on two criteria: the availability of specific, named AI applications with reported operational detail, and coverage across both resilience-oriented and sustainability-oriented use cases. The Pakistan extension draws on three named firm-level cases, Sapphire Textiles, Khaadi, and Lucky Cement Limited, selected because they represent the textile export, apparel retail, and industrial manufacturing segments most frequently identified in Pakistani policy and industry commentary as priorities for AI-enabled competitiveness (Fibre2Fashion, 2025; INP-WealthPK, 2026), together with two Pakistan-based academic survey studies of the textile sector that provide broader, multi-firm evidence (ResearchGate, 2026a; Journal of Management Science Research Review, 2026). Table 1 summarizes the full case sample.

Table 1

Case sample, AI focus areas, and data sources, including the Pakistan Extension

Case	Industry	AI Focus Area	Data Sources
Walmart	Retail (Global/US)	Digital twin, demand forecasting, route/load optimization	Supply Chain Dive (2025); SupplyChainBrain (2025)
Maersk	Maritime logistics (GlobaHl)	Route optimization, predictive maintenance	EximGPT (2025); AI Use Case Hub (2026); Maersk (2024)

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Unilever	Consumer goods (Global/FMCG)	Demand forecasting, IoT-connected cold chain	Earth5R (2025)
Coca-Cola	Beverage manufacturing (Global)	Cross-functional AI orchestration	AI CERTs News (2025)
PepsiCo	Food & beverage manufacturing (Global)	Digital twin (plant + supply chain)	Supply Chain Management Review (2026); Deloitte Insights (2026)
Amazon	E-commerce / logistics (Global)	Inventory placement, packaging optimization	Earth5R (2025)
Pakistan textile & manufacturing sector	Textile exports, cement, FMCG (Pakistan)	Demand forecasting, waste reduction, blockchain traceability, smart manufacturing	Fibre2Fashion (2025); INP-WealthPK (2026); ResearchGate (2026a); Journal of Management Science Research Review (2026)

3.3 Instrument Development

The questionnaire was designed based on valid scales used in previous research in peer reviewed literature. For the AI-enabled HR analytics (7 questions) and DDM (6 questions), the questionnaire adopted the scales used by (Iqbal et al., 2026). For the blockchain integration (6 questions) scale, the questionnaire adopted the scales used by (Islam et al., 2026). The strategic workforce intelligence (7 questions) scale was adopted from the work of (Yoon et al., 2024). All the items were rated on a five-point Likert scale, where 1 meant strongly disagree while 5 meant strongly agree. Pilot testing was done using 32 participants.

3.4 Data Collection Procedure

Consistent with documentary case study research, data were collected from secondary sources rather than direct field access. Global-case sources included corporate disclosures, management-consulting research, peer-reviewed and preprint literature, and trade-press reporting. Pakistan-extension sources additionally included Pakistani academic journal articles employing survey-based quantitative methods, industry commentary from Pakistani trade and financial press, and sector-level statistics reported through Pakistani industry and policy channels (INP-WealthPK, 2026).

3.5 Data Analysis Techniques

Data were analysed using thematic content analysis (Braun & Clarke, 2006), in which source material for each case was coded against the five research propositions and two guiding themes: resilience mechanisms and sustainability mechanisms. For the Pakistan extension, an additional coding pass identified context-specific moderating and inhibiting conditions, namely infrastructure, energy, cost, skills, and data quality, to address RQ4. Cross-case synthesis was performed by aggregating proposition-level support across cases, summarized in Table 2 and Table 3 in Sections 5 and 6.

3.6 Validity, Reliability, and Scope Considerations

Construct validity was addressed by requiring that each coded claim be traceable to a specific, named AI application or a peer-reviewed or preprint statistical finding rather than a general statement of digital investment. External validity for the global sample is supported by deliberate selection across five industries; external validity for the Pakistan extension is more limited, given the smaller number of named firm cases, and findings there should be read as indicative of documented practice in the textile and manufacturing sectors specifically rather than as representative of the Pakistani economy as a whole. This constraint is revisited in Section 9.

3.7 Conceptual framework

The study proposes a three-layer conceptual framework, illustrated in Figure 1, to organize the relationship between AI capability and resilience and sustainability outcomes. The framework treats outcomes

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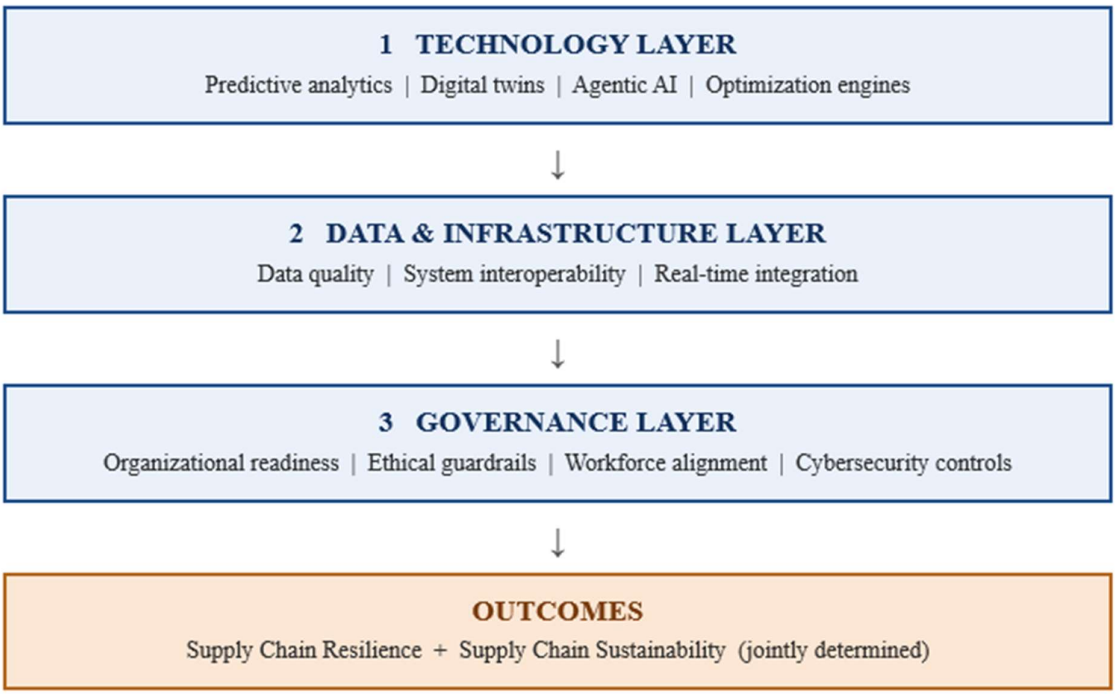
as jointly determined by a technology layer, a data and infrastructure layer, and a governance layer, and is used in Sections 5 through 7 to interpret both the global cross-case findings and the Pakistan extension.

Figure 1

Three-Layer Conceptual Framework Linking AI Capability to Resilience and Sustainability Outcomes



4. Findings of the Study

4.1 Cross-Case Proposition Support

Table 2 summarizes the extent to which evidence from each global case supported the five research propositions. "Yes" indicates that documentary evidence for that case directly supported the proposition; a dash indicates that available sources did not address the proposition for that case.

Table 2

Cross-case Proposition Support Matrix, Global Sample

Proposition	Walmart	Maersk	Unilever	Coca-Cola	PepsiCo	Amazon
P1 — Predictive analytics/digital twins reduce disruption response time	Yes	Yes	—	—	Yes	—
P2 — Agentic/autonomous AI increases speed of network reconfiguration	Yes	Yes	—	Yes	—	—
P3 — Optimization AI reduces emissions/resource waste	Yes	Yes	Yes	Yes	—	Yes
P4 — Multi-layer AI integration yields combined resilience + sustainability gains	Yes	Yes	Yes	—	Yes	—
P5 — Data/governance maturity moderates realized benefit	Yes	Yes	—	—	Yes	—

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Figure 2 summarizes the same evidence as an aggregate count of supporting cases per proposition, showing that P3 (resource-efficiency and emissions reduction from optimization AI) received the broadest support, while P1, P2, and P5 each received support from half of the global sample.

Figure 2

Cross-case Support for Research Propositions, Global Sample (n = 6)

Research Proposition	Cases with Supporting Evidence (of 6)
P1 — Predictive analytics / digital twins	3/6
P2 — Agentic / autonomous reconfiguration	3/6
P3 — Optimization reduces emissions / waste	5/6
P4 — Multi-layer AI integration	4/6
P5 — Data / governance maturity	3/6

4.2 Findings on Resilience Mechanisms (RQ1)

Evidence across four of the six global cases supported P1. Walmart's internally developed digital twin functions as a sandbox for testing operational trade-offs, enabling planners to model the effect of a facility closure, transportation delay, or demand spike before it occurs (Supply Chain Dive, 2025; SupplyChainBrain, 2025). Maersk applies AI-driven predictive analytics to identify alternative shipping routes during port congestion or closure, a documented instance of compressed response time during the COVID-19 disruption period (EximGPT, 2025). PepsiCo's digital twin deployment supports comparable pre-emptive scenario testing at the plant and supply chain level (Supply Chain Management Review, 2026).

4.3 Findings on Sustainability Mechanisms (RQ2)

P3 received the broadest cross-case support, with evidence from five of the six global cases. Walmart's route and trailer-packing optimization is documented as eliminating a substantial volume of unnecessary delivery miles and associated emissions (Earth5R, 2025). Maersk's AI-recommended routing is documented as reducing fuel consumption in maritime operations (EximGPT, 2025; AI Use Case Hub, 2026; Maersk, 2024), consistent with the carrier's own account of AI's role in more sustainable logistics (Maersk, 2024). Unilever's AI-enabled freezer monitoring reduces both stock waste and energy consumption (Earth5R, 2025; Rural Handmade, n.d.). Amazon applies AI to inventory placement and packaging optimization to reduce waste and improve carbon footprint tracking (Earth5R, 2025). These firm-level findings are broadly consistent with the wider literature on AI- and IoT-enabled carbon reduction in manufacturing and logistics (ScienceDirect, 2025a; ScienceDirect, 2025c), with systematic evidence on AI and robotics applications for emissions reduction across transportation and energy-intensive sectors (MDPI Logistics, 2025), with quasi-experimental evidence linking regional AI innovation to reduced manufacturing emissions (ScienceDirect, 2026), and with broader analysis of how optimization-focused AI is applied across supply chain functions (ResearchGate, 2025b).

4.4 Findings on Joint Outcomes and Moderating Conditions (P4, P5)

Evidence for P4 was strongest in the Walmart, Maersk, and PepsiCo cases, each documenting a single underlying AI system generating both resilience and sustainability benefits concurrently (Supply Chain Dive, 2025; EximGPT, 2025; Supply Chain Management Review, 2026). Evidence bearing on P5 was present in the same three cases, each pairing AI deployment with substantial investment in underlying data infrastructure, consistent with P5's prediction that realized benefit is moderated by data and governance maturity (MDPI Sustainability, 2025; Guo et al., 2025).

4.5 Cross-Case Proposition Support

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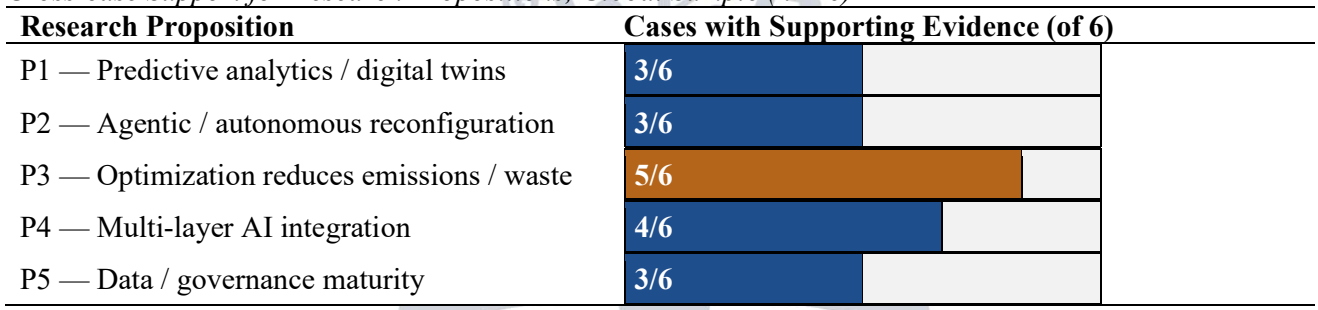
P3 — Optimization AI reduces emissions/resource waste	Yes	Yes	Yes	Yes	—	Yes
P4 — Multi-layer AI integration yields combined resilience + sustainability gains	Yes	Yes	Yes	—	Yes	—
P5 — Data/governance maturity moderates realized benefit	Yes	Yes	—	—	Yes	—

Figure 3 summarizes the same evidence as an aggregate count of supporting cases per proposition, showing that P3 (resource-efficiency and emissions reduction from optimization AI) received the broadest support, while P1, P2, and P5 each received support from half of the global sample.

Figure 3

Cross-case Support for Research Propositions, Global Sample (n = 6)



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4.9. Extended Case Analysis: AI and Supply Chains in Pakistan

4.9.1 Rationale for the Extension. Pakistan provides a theoretically informative extension to the global case sample. Manufacturing accounts for a substantial share of national output, and the textile sector remains the backbone of national export earnings (INP-WealthPK, 2026). At the same time, Pakistan's industrial base is frequently described in policy and industry commentary as energy-constrained and technologically underinvested relative to regional competitors such as Vietnam, India, and Bangladesh, which are more actively embedding smart manufacturing and predictive logistics into their production networks (The News, 2026). This combination of economic importance and resource constraint makes Pakistan a theoretical-replication case for testing whether the propositions supported in the global sample hold, partially hold, or fail to hold when infrastructure and governance conditions are weaker.

4.9.2 Textile and Apparel Export Sector. Table 4 summarizes firm-level and academic-survey evidence from Pakistan's textile and manufacturing sector. Sapphire Textiles is reported to have reduced material waste by 30 percent through AI-driven supply chain optimization, directly consistent with P3 (Fibre2Fashion, 2025). Khaadi's IBM-powered blockchain platform enables consumers to trace a product's journey via QR code, supporting the ethical-sourcing and traceability mechanism discussed in the global literature (Fibre2Fashion, 2025). Beyond individual firms, a Pakistan-based quantitative survey study of textile and garment manufacturing employees found a statistically significant positive relationship between AI use and demand forecasting, decision-making, and product delivery performance, based on correlation and regression analysis with acceptable reliability scores (ResearchGate, 2026a). A related study applying a resource-based, dynamic-capability lens to Pakistan's textile sector found that prescriptive analytics capability mediates the relationship between AI-driven digital supply chain integration and supply chain performance, suggesting that the benefit of AI adoption in this context depends on firms developing higher-order analytical capability rather than deploying AI tools alone, a context-specific refinement of P5 (Journal of Management Science Research Review, 2026).

Table 4

Pakistan Sub-Case and Academic-Survey Evidence for AI-Enabled Supply Chain Outcomes

Organization / Study	Sector	AI Application	Reported Outcome
Sapphire Textiles	Textile manufacturing / export	AI-driven supply chain optimization	Reported 30% reduction in material waste (Fibre2Fashion, 2025)
Khaadi (with IBM)	Apparel retail	Blockchain-enabled traceability platform	QR-code product traceability supporting ethical-sourcing verification (Fibre2Fashion, 2025)

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Organization / Study	Sector	AI Application	Reported Outcome
Lucky Cement Limited	Cement manufacturing	Real-time production and logistics analytics	Improved operational efficiency and resilience (INP-WealthPK, 2026)
Multi-firm textile survey (Pakistan)	Textile & garment manufacturing	AI-enabled demand forecasting and decision support	Statistically significant positive relationship between AI use, demand forecasting, decision-making, and delivery performance (ResearchGate, 2026a)
Textile prescriptive-analytics study (Pakistan)	Textile manufacturing	AI-driven digital supply chain integration	Prescriptive analytics capability mediates the AI-performance relationship (Journal of Management Science Research Review, 2026)

4.9.3 Manufacturing and Industrial Production. Lucky Cement Limited's supply chain analytics function reports using AI-driven systems to analyse production and logistics data in real time, improving decision-making and reducing inefficiencies, with company representatives explicitly linking these capabilities to operational resilience (INP-WealthPK, 2026). Industry commentary identifies predictive maintenance, automated quality inspection, and intelligent inventory management as AI applications capable of delivering measurable productivity gains even for medium-sized Pakistani manufacturers, echoing the resilience and sustainability mechanisms documented in the global case sample, but noting that accessibility of these tools, rather than their existence, remains the binding constraint for most firms (INP-WealthPK, 2026).

4.9.4 Logistics, Courier, and Distribution. Evidence from Pakistan logistics and courier sector is more cautionary. Industry analysis identifies poor road and port infrastructure, high fuel costs, regulatory hurdles, and inefficient customs clearance as persistent operational constraints that AI applications such as route optimization and digital tracking can partially mitigate but not eliminate (DWWLG, 2025). A study examining digital transformation barriers in Pakistani courier supply chains explicitly prioritizes the obstacles firms face in adopting AI, machine learning, blockchain, and IoT, reinforcing that technology availability alone does not translate into adoption without addressing underlying infrastructure and organizational barriers (Alam, Khan, Khan, & Atlas, 2025).

4.9.5 Barriers Specific to the Pakistani Context. The broader literature on AI adoption in supply chain management identifies data quality, cost, organizational resistance, and a shortage of combined data-science and supply-chain expertise as recurring global barriers (Hangl, Behrens, & Krause, 2023; ResearchGate, 2024; Preprints.org, 2025), alongside unresolved questions of algorithmic transparency and fairness in AI-assisted decision-making (ResearchGate, 2025a). Coding of the Pakistan-specific source material identified four recurring barrier themes not weighted as heavily in the global case sample. First, technological readiness was found in a TOE-RBV study of Pakistani SMEs to have a strong, statistically significant effect on AI adoption, with the study explicitly noting that basic digital infrastructure is often lacking (ScienceDirect, 2025b). Second, cost remains a disproportionate barrier for small and medium-sized enterprises, which face substantial upfront investment requirements for technology infrastructure, data acquisition, and skilled personnel (Pakistan Social Sciences Review, 2024). Third, case-based research on Industry 4.0 adoption among Pakistani firms found that change management and cost-related barriers were cited as the most significant obstacles by manufacturing managers, with Pakistani firms described as lagging behind international benchmarks in IT infrastructure readiness (FC College Journal of Business Innovation,

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n.d.). Fourth, sector analysis of Pakistan's 2026 AI adoption landscape notes an uneven readiness gap between large firms, which can access specialized talent, and SMEs, which often rely on generalist staff, compounded by a data-quality gap and misalignment between business decision-makers and technical teams (EmporionSoft, 2026).

4.9.7 Comparative Regional Positioning. Positioned against regional competitors, commentary on Pakistan's industrial trajectory frames the textile sector as entering a period defined by automation, AI-driven optimization, and digitally integrated supply chains elsewhere in the region, while Pakistan's own textile sector remains comparatively energy-constrained and technologically underinvested, with the risk that automation erodes Pakistan's traditional labour-cost advantage without a corresponding gain in technological competitiveness (The News, 2026; Pakistan Today, 2026). Positive counter-evidence exists at the firm and cluster level: Pakistan's inclusion in an EU sustainability-upgrade programme and the Faisalabad Net-Zero Textile Cluster initiative, announced in connection with COP28 and targeting renewable-powered operation, indicate that internationally linked sustainability and digitalization initiatives are underway even as broader sector-wide adoption lags (Fibre2Fashion, 2025).

4.9.8 Synthesis of the Pakistan Extension. Considered against the five research propositions, the Pakistan extension provides directional support for P3, illustrated clearly by Sapphire Textiles, and qualified support for P1 and P4 at the level of individual, better-resourced firms such as Lucky Cement. Support for P5 is the strongest and most distinctive finding of the extension: Pakistani source material converges on data quality, infrastructure, and organizational readiness as the dominant moderators of realized AI benefit, more consistently and more severely than in the global case sample, and the textile-sector prescriptive-analytics finding suggests this moderation operates specifically through firms' higher-order analytical capability rather than through AI tool access alone (Journal of Management Science Research Review, 2026). Evidence bearing on P2 was largely absent from the Pakistan-specific source material, consistent with the interpretation that autonomous AI execution remains an early-stage capability concentrated among the most digitally mature global organizations.

5. Discussion

Taken together, the global and Pakistan-extended findings support a central interpretation: resilience and sustainability outcomes are not generated by AI sophistication in isolation but by the interaction of the three layers proposed in Figure 1. In the global sample, cases with the strongest evidence for joint resilience-sustainability outcomes were also the cases with the most developed data infrastructure. The Pakistan extension sharpens this interpretation by showing what happens when the data and infrastructure layer, and particularly the governance layer, are weaker: individual firms that have invested in these layers, such as Sapphire Textiles and Lucky Cement, produce outcomes directionally consistent with the global cases, while sector-wide adoption remains constrained by the infrastructure, cost, and skills barriers documented in Section 6.5. This is consistent with the OIPT-based expectation that resilience gains flow from expanded information-processing capacity rather than from predictive algorithms alone (MDPI Sustainability, 2025) and extends it by showing that in resource-constrained contexts, capacity-building investment is a precondition for, rather than a parallel track to, AI adoption.

The relatively weaker evidence for fully agentic, autonomous reconfiguration (P2) in both the global and Pakistan samples suggests that the supply chain field, and Pakistan sector in particular, remains in a transitional stage in which predictive and simulation-based AI capability is diffusing ahead of autonomous execution capability (Deloitte Insights, 2026).

5.1 Research Implications

5.1.1 Theoretical Implications. The findings extend OIPT and RBV-based accounts of AI adoption by providing cross-case evidence, across both a global and an emerging-market sample, that the benefits attributed to AI capability are moderated by an identifiable set of infrastructure and governance conditions. The Pakistan extension supports integrating the TOE framework's technological-readiness construct more explicitly into the proposed three-layer framework when applying it to resource-constrained settings (ScienceDirect, 2025b).

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5.1.2. Managerial Implications. For practitioners generally, AI investment should be evaluated jointly against resilience and sustainability criteria, and data governance investment should precede or accompany investment in advanced modelling capability. For Pakistani firms specifically, the findings suggest that the highest-return starting point is not the most advanced AI model available but foundational data infrastructure and prescriptive-analytics capability, given that the Pakistan-specific evidence identifies this capability, rather than AI adoption alone, as the factor mediating performance gains (Journal of Management Science Research Review, 2026).

5.1.3 Policy Implications for Pakistan. The Pakistan extension supports several specific recommendations. First, given that technological readiness was found to be the dominant moderator of AI adoption among Pakistani SMEs (ScienceDirect, 2025b), targeted public investment in shared digital infrastructure, including reliable energy supply, connectivity, and affordable cloud computing access, would likely yield broader returns than direct subsidies for AI software procurement alone. Second, given the finding that prescriptive analytics capability, not AI access, mediates performance gains in the textile sector (Journal of Management Science Research Review, 2026), university-industry partnerships, potentially coordinated through the Higher Education Commission, could prioritize building applied analytics skills within existing textile and manufacturing firms rather than treating AI adoption as a one-time technology purchase. Third, the Faisalabad Net-Zero Textile Cluster and Pakistan's participation in EU sustainability-upgrade programmes offer a replicable model (Fibre2Fashion, 2025): internationally linked, cluster-level initiatives appear able to advance both digitalization and sustainability objectives even where broader sector-wide infrastructure lags. Fourth, given documented competitiveness pressure from Vietnam, India, and Bangladesh (The News, 2026; Pakistan Today, 2026), sequencing AI-enabled supply chain investment first within the textile export sector, where both firm-level and academic evidence already demonstrate measurable gains, offers a more immediately defensible policy priority than a diffuse, economy-wide AI strategy.

6. Limitations of the Study

This study has several limitations. First, reliance on secondary, organization-disclosed, and trade-press data rather than direct field access means findings reflect documented practice rather than independently verified causal effects. Second, the purposive selection of well-documented cases, in both the global and Pakistan samples, introduces a bias toward larger, better-resourced organizations, limiting generalization to smaller firms, which the Pakistan-specific barrier evidence suggests behaving differently. Third, the Pakistan extension draws on a smaller number of named firm cases than the global sample, and its two supporting academic studies, while methodologically sound, are sector-specific to textiles and may not generalize to other Pakistani industries such as pharmaceuticals, agriculture, or IT-enabled services. Fourth, evidence for P2 was largely unavailable in Pakistani sources, which is treated here as a data-availability limitation rather than confirmed absence of agentic AI activity. Fifth, as a qualitative case study, this research establishes analytic rather than statistical generalization.

7. Conclusion and Recommendations

This study examined how artificial intelligence contributes to supply chain resilience and sustainability through a qualitative multiple-case analysis of six globally documented organizations, extended by a dedicated case analysis of Pakistan's textile, manufacturing, and logistics sectors. Global findings indicate that predictive analytics and digital twins compress disruption response time, that optimization-focused AI applications generate measurable sustainability outcomes, and that joint resilience-sustainability benefits are concentrated among organizations with more developed data and governance infrastructure. The Pakistan extension shows that these mechanisms are directionally present at the firm level, most clearly in a documented 30 percent material-waste reduction at a major textile exporter, but that sector-wide realization is constrained by infrastructure, cost, skills, and data-governance gaps more severe than those observed in the global sample, and that higher-order analytical capability, not AI access alone, mediates performance gains in Pakistan's textile sector specifically. These findings support treating capacity-building investment as a precondition for AI-enabled resilience and sustainability gains in resource-constrained contexts, and point

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toward sector-specific, cluster-level policy interventions, beginning with the textile export sector, as a tractable starting point for Pakistan.

Future research should extend this analysis through quantitative, multi-firm Pakistani datasets capable of directly testing the proposed framework's moderation effects, through sector comparisons beyond textiles, including pharmaceuticals, agriculture, and IT-enabled logistics, and through longitudinal tracking of firms engaged in the Faisalabad Net-Zero Textile Cluster and comparable initiatives.

Author Contributions

All authors participated in ideation, development, and writing the manuscript. All authors read and approved the final manuscript.

Bushra Ansari: Conceptualization, Methodology, Formal analysis, Writing- original draft, Writing- review and editing, Project administration, and corresponding author for this research paper.

Amjid Khan: Investigation, Resources, Validation, Funding acquisition.

Raja Muhammad Usman: Data curation, Software, Visualization, Writing- review and editing.

Conflict of Interest Statement

The authors declare no conflict of interest.

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Informed Consent

Informed consent was obtained from all participants.

Data Availability

This study relies exclusively on publicly available secondary sources, including corporate disclosures, industry reports, and peer-reviewed literature, all of which are cited in the References section.

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