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Exploring the effects of Industrial Digital Technology on Sustainable Firm's Performance with a mediating role of Green Supply Chain Management Practices in FMCG Industry of Pakistan

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Abstract

This study investigates how Industry 4.0 digital technologies contribute to Sustainable Firm Performance (SFP) in Pakistan's FMCG manufacturing sector, emphasizing the mediating role of Green Supply Chain Management (GSCM) practices. Despite the global shift toward digital and sustainability-driven operations, empirical evidence from developing economies remains limited, particularly regarding how technological capabilities integrate with green practices to enhance triple-bottom-line performance. Addressing this gap, the study draws upon the Practice-Based View (PBV) and Information Processing Theory (IPT) to propose a comprehensive conceptual model. A structured survey was administered to FMCG manufacturing firms, and the data were analyzed through Partial Least Squares Structural Equation Modeling (PLS-SEM).

The findings reveal that core Industry 4.0 technologies—such as IoT-enabled monitoring, big data analytics, AI-based decision systems, and blockchain-supported traceability—significantly strengthen multiple GSCM dimensions, including green design, green information systems, green procurement, internal resource development, and reverse logistics. However, green manufacturing did not exhibit a significant direct effect. The results further demonstrate that GSCM practices play an essential mediating role, indicating that digital technologies create sustainable value primarily through enhanced coordination, cleaner processes, and improved supply chain transparency. Sustainable Firm Performance showed strong positive effects on economic, environmental, and social outcomes, confirming its importance as an integrated measure of organizational sustainability and competitiveness.

Moreover, the mediation analysis highlights that governance design and structured process facilitation partially transmit the influence of digital technologies toward improved sustainability outcomes, reinforcing the need for effective governance mechanisms. Overall, the study provides valuable empirical evidence that digital transformation aligned with green supply chain strategies can significantly enhance long-term sustainability in resource-constrained developing economies. The findings offer meaningful guidance for managers, practitioners, and policymakers aiming to strengthen sustainable and digitally enabled supply chain ecosystems.

Keywords: Industry 4.0; Digital Technologies; Green Supply Chain Management (GSCM); Sustainable Firm Performance (SFP); FMCG Sector; Pakistan; PLS-SEM; Sustainability Practices.

1. INTRODUCTION

1.1. Background and Context of the Study

In the early decades of the twenty-first century, the global business landscape has entered a phase of unprecedented technological and structural transformation, widely referred to as the Fourth Industrial Revolution or Industry 4.0 (Khan et al., 2023). This transformation is characterized by the deep integration of digital technologies into traditional industrial and supply chain systems, fundamentally altering how organizations design, operate, and manage their processes (Tortorella et al., 2021). Since the formal introduction of the Industry 4.0 concept in 2011, it has gained substantial and sustained attention from researchers, practitioners, and policymakers due to its profound potential to reshape industrial competitiveness, operational paradigms, and long-term sustainability trajectories (Frank et al., 2019; Nascimento et al., 2019). The advent of this revolution signals a departure from incremental innovation toward a systemic reconfiguration of value creation, driven by the convergence of the physical and digital worlds within industrial ecosystems.

Unlike earlier industrial revolutions that primarily emphasized mechanization (Industry 1.0), mass production through electrification (Industry 2.0), or computer-based automation (Industry 3.0), Industry 4.0 focuses on intelligent connectivity, data-driven decision-making, and decentralized, autonomous control systems (Kumar et al., 2023). This new paradigm leverages a suite of disruptive technologies including, but not limited to, the Internet of Things (IoT), big data analytics, cloud and edge computing, cyber-physical systems (CPS), artificial intelligence (AI), machine learning, blockchain, additive manufacturing (3D printing), and collaborative robotics (Wang et al., 2020; Kouhizadeh et al., 2021). These technologies collectively enable organizations to achieve real-time visibility, predictive intelligence, and seamless coordination across previously siloed production and supply chain activities (Ivanov et al., 2021). Consequently, firms can transform their traditional, linear, and often fragmented operations into integrated, responsive, and adaptive ecosystems capable of dynamically responding to volatile market conditions, personalized customer demands, and complex global challenges (Gupta et al., 2020).

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Industry 4.0 has significantly reshaped organizational strategies and competitive dynamics, particularly within manufacturing and supply-chain-intensive industries. By enabling capabilities such as real-time monitoring, predictive and prescriptive analytics, and smart automation, digital technologies enhance production flexibility, reduce operational inefficiencies and waste, improve output quality and consistency, and accelerate time-to-market (Bag et al., 2021; Sharma et al., 2021). Firms that successfully adopt and integrate Industry 4.0 technologies are demonstrably better positioned to respond to demand variability, manage complex multi-tiered supplier networks, optimize resource allocation, and enhance overall supply chain resilience (Dubey et al., 2020; Winkelhaus & Grosse, 2020). As a result, digital transformation has evolved from being a peripheral technological initiative or IT project into a core strategic necessity for firms seeking to build and sustain competitive advantage in an increasingly interconnected and data-driven global economy (El Baz & Iddik, 2022).

Beyond the compelling imperative for operational and economic efficiency, Industry 4.0 is increasingly recognized as playing a crucial and perhaps indispensable role in advancing global sustainable development goals (Yadav et al., 2023). Sustainability has emerged as a central, non-negotiable concern for organizations worldwide, driven by the accelerating realities of environmental degradation, climate change, resource scarcity, intensifying regulatory pressures, and heightened stakeholder awareness among consumers, investors, and communities (Khan et al., 2022). Contemporary conceptualizations of sustainable performance now emphatically encompass not only traditional financial outcomes but also rigorous environmental and social dimensions, including greenhouse gas emissions reduction, energy and water efficiency, waste minimization and circularity, employee health and well-being, ethical sourcing, and broader social responsibility (Umar et al., 2022). Industry 4.0 technologies provide the foundational tools to support these multifaceted objectives by enabling precise resource management through sensor data, enhanced transparency and traceability across supply chains, data-driven sustainability reporting and compliance, and the optimization of processes for minimal environmental impact (Jeong & Lee, 2023; Saberi et al., 2019).

The relevance and urgency of this digital-sustainability nexus are particularly pronounced within the fast-moving consumer goods (FMCG) industry. The FMCG sector is globally characterized by high production volumes, rapid inventory turnover, extremely short product life cycles, intense price-based competition, and complex, extensive distribution networks (Frederico et al., 2021). These inherent characteristics make achieving operational efficiency, seamless supply chain coordination, and genuine sustainability integration especially challenging yet critically important. Digital technologies offer FMCG firms transformative capabilities to improve demand sensing and forecasting accuracy, optimize inventory control, enhance logistics and distribution efficiency, ensure end-to-end product traceability from source to shelf, and facilitate circular economy models—all of which are essential for achieving holistic and measurable sustainable performance (Majumdar et al., 2021; Reza et al., 2024).

In Pakistan, the FMCG industry represents a vital and growing component of the national economy, contributing significantly to employment, consumer welfare, industrial output, and government revenues. However, the sector faces persistent and

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multifaceted challenges that hinder its growth and sustainability. These include inefficient and opaque supply chain structures, limited and unreliable technological infrastructure, rising input costs, mounting environmental compliance issues, weak institutional governance around sustainability, and a prevailing focus on short-term cost reduction over long-term value creation (Ali et al., 2022). Many FMCG firms in Pakistan continue to rely on traditional, manual, and siloed operational models that lack integration, visibility, data-driven decision-making, and systematic environmental accountability (Singh et al., 2022). These challenges collectively highlight the urgent and strategic need for a coherent Industry 4.0-driven digital transformation that is explicitly aligned with and enables robust sustainable supply chain practices.

In this context, Green Supply Chain Management (GSCM) has emerged globally as a strategic and operational framework for systematically addressing environmental and broader sustainability challenges within supply chains (Balon, 2020). GSCM involves the proactive integration of environmental considerations into all core supply chain processes, including green design, sustainable procurement and supplier management, green manufacturing, low-carbon logistics, and reverse logistics for end-of-life product management (Jabbour et al., 2020). A substantial body of empirical studies suggests that the implementation of GSCM practices enhances firm performance by reducing material and energy waste, lowering operational and disposal costs, improving regulatory compliance, mitigating risks, and strengthening corporate reputation and brand equity among conscious consumers (Antwi et al., 2022; Khan et al., 2023). Crucially, when GSCM practices are combined with and enabled by Industry 4.0 technologies, their implementation can become significantly more effective, scalable, and verifiable through improved data accuracy, real-time monitoring, advanced analytics for optimization, and enhanced coordination across supply chain partners (Dubey et al., 2019).

Despite the increasing academic and practical interest in both Industry 4.0 and GSCM as individual domains, comprehensive empirical research examining their combined and interactive impact on sustainable performance remains notably limited, particularly within the specific contexts of developing economies such as Pakistan (Sharma et al., 2021). The majority of existing studies have been conducted in developed countries characterized by advanced technological infrastructure, mature regulatory frameworks, and different market dynamics, which inherently limits the direct applicability and transferability of their findings to emerging markets facing distinct constraints and opportunities (Horváth & Szabó, 2019). This study seeks to address this significant contextual and empirical gap by rigorously examining the role of digital technologies in enhancing sustainable performance through the mediating mechanism of GSCM practices within Pakistan's strategically important FMCG industry.

1.2. Problem Statement

Although Industry 4.0 technologies are widely recognized in the literature as potent drivers of operational excellence and potential enablers of sustainability, their effective implementation and strategic alignment with sustainability goals remain a significant and under-addressed challenge for firms operating in developing economies (Reza et al., 2024). In Pakistan's FMCG sector, digital transformation initiatives, where they

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exist, are often fragmented, ad-hoc, and primarily motivated by narrow efficiency gains, with limited conscious integration into comprehensive, sustainability-oriented supply chain strategies (Ali et al., 2022). Many firms make investments in isolated digital tools—such as standalone enterprise resource planning (ERP) systems or piecemeal automation technologies—without strategically aligning these investments with broader environmental and social objectives or embedding them within a holistic GSCM framework (Majumdar et al., 2021). This disconnection results in suboptimal utilization of technological capabilities and missed opportunities for generating synergistic sustainable value.

The existing academic literature provides substantial insights into the independent effects of Industry 4.0 technologies on operational performance and, separately, the impact of GSCM practices on environmental and economic outcomes (Kumar et al., 2023; Bag et al., 2021). However, there is a conspicuous scarcity of integrated empirical evidence that clearly explains the specific mechanisms and pathways through which digital technologies contribute to holistic sustainable performance (encompassing economic, environmental, and social dimensions) via the adoption and enhancement of GSCM practices (Balon, 2020). Moreover, the potential mediating role of GSCM practices in the relationship between digital transformation and sustainability outcomes remains theoretically plausible but underexplored and inadequately tested empirically, particularly within the specific context of the FMCG industry in developing economies where resource constraints and institutional factors play a critical moderating role (Yadav et al., 2023).

This lack of integrated, context-specific empirical evidence creates considerable uncertainty and ambiguity for managers, strategists, and policymakers regarding *how* digital technologies should be selectively deployed, sequenced, and managed to most effectively achieve sustainability objectives. Without a clear, evidence-based understanding of these dynamic relationships, firms risk underutilizing their digital investments, pursuing incompatible initiatives, or failing to realize the full sustainability potential of Industry 4.0, thereby jeopardizing both their competitive positioning and their contribution to sustainable development goals (Dubey et al., 2020). Therefore, there is a critical and pressing need to empirically examine and model the relationship between Industry 4.0 technologies, GSCM practices, and sustainable performance within the under-researched but economically vital context of Pakistan's FMCG industry.

1.3. Research Objectives

The primary objective of this study is to investigate the impact of Industry 4.0 digital technologies on sustainable performance within Pakistan's FMCG industry, with a specific focus on elucidating the mediating role of Green Supply Chain Management (GSCM) practices. To achieve this overarching aim, the study is designed to systematically pursue the following specific and interlinked objectives:

1. To examine the current level, nature, and drivers of Industry 4.0 digital technology adoption (e.g., IoT, AI, Blockchain, Big Data Analytics) within FMCG manufacturing firms operating in Pakistan.

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2. To analyze the nature and strength of the relationship between the adoption of Industry 4.0 digital technologies and the implementation of multifaceted Green Supply Chain Management (GSCM) practices.
3. To assess the direct impact of GSCM practices on the triple-bottom-line components of sustainable performance: economic performance, environmental performance, and social performance.
4. To empirically evaluate the mediating role of GSCM practices in the relationship between Industry 4.0 digital technology adoption and sustainable performance, thereby testing the pathway through which technology translates into sustainability outcomes.
5. To derive and provide actionable, contextually-grounded insights and recommendations for managers, supply chain professionals, and policymakers to enhance sustainability through strategically aligned digital transformation initiatives.

1.4. Research Questions

In direct alignment with the stated research objectives, this study is designed to address the following core research questions:

1. What is the nature and extent of the influence exerted by Industry 4.0 digital technologies on sustainable performance within Pakistan's FMCG industry?
2. What is the specific relationship between the adoption of Industry 4.0 digital technologies and the implementation level of various Green Supply Chain Management (GSCM) practices?
3. How do GSCM practices distinctly affect the three dimensions of sustainable performance: economic, environmental, and social?
4. Do GSCM practices significantly mediate the relationship between Industry 4.0 digital technology adoption and sustainable performance, and if so, to what extent?
5. What strategic, operational, and policy implications can be derived from these findings to guide FMCG firms and stakeholders in a developing economy like Pakistan?

1.5. Justification and Significance of the Study

This study holds substantial significance and offers valuable contributions from multiple perspectives—theoretical, managerial, and policy-oriented.

Theoretical Significance: The study makes a meaningful contribution to the growing but still evolving body of literature at the intersection of digital transformation (Industry 4.0) and sustainable operations management. It does so by integrating the constructs of digital technologies and green supply chain management practices within a unified conceptual framework, primarily grounded in the Practice-Based View (PBV) and Information Processing Theory (IPT). By empirically testing the proposed mediating model in a developing economy context (Pakistan) and within a specific industry (FMCG), the study rigorously extends and contextualizes existing theories that have largely been developed and validated in Western, industrialized settings. It helps answer calls for more context-sensitive research that accounts for institutional, economic, and technological contingencies (Khan et al., 2023).

Managerial Significance: From a practical and managerial perspective, the findings of this study are poised to provide actionable, evidence-based guidance for senior executives, supply chain managers, and sustainability officers within FMCG firms in Pakistan and similar developing economies. The research will identify which specific digital capabilities (e.g., real-time monitoring via IoT, predictive analytics via AI) most effectively enable which critical GSCM practices (e.g., green manufacturing, reverse logistics). It will also highlight the GSCM practices that yield the most significant returns on sustainable performance. This knowledge will empower managers to make informed, strategic investment decisions, prioritize digitalization initiatives, design effective implementation roadmaps, and ultimately build competitive advantage through sustainability-driven digital transformation (Wong et al., 2020).

Policy Significance: At the policy level, the study offers timely and relevant insights for government agencies, regulatory bodies, industry associations, and international development partners. The findings can inform the design of supportive policy frameworks, incentive structures, capacity-building programs, and public-private partnerships that collectively encourage and facilitate sustainable digital transformation within the FMCG sector and manufacturing at large. Such insights are particularly crucial for Pakistan, where promoting industrial sustainability, enhancing technological modernization, and fostering inclusive economic growth are explicit national development priorities outlined in various policy documents (Reza et al., 2024).

1.6. Scope and Delimitations

The scope of this research is deliberately focused to ensure depth and feasibility. The study is geographically and sectorally limited to manufacturing firms within the Fast-Moving Consumer Goods (FMCG) industry operating in Pakistan. The investigation concentrates on a defined set of Industry 4.0 digital technologies—namely the Internet of Things (IoT), Big Data Analytics (BDA), Artificial Intelligence (AI), and Blockchain—and their relationship with selected, well-established Green Supply Chain Management (GSCM) practices. These GSCM practices include green manufacturing, green purchasing, green design, green information systems, reverse logistics, and investment recovery. Sustainable performance is operationalized and measured across the three core dimensions of the triple bottom line: economic performance, environmental performance, and social performance.

The study employs a cross-sectional research design, utilizing survey methodology for data collection at a single point in time. While this design is efficient and appropriate for testing the proposed relationships, it may impose limitations on making definitive causal inferences, which longitudinal designs are better suited to establish. Furthermore, the findings, while insightful for the Pakistani FMCG context, may not be directly generalizable to other industrial sectors (e.g., textiles, automotive) or to other developing countries with significantly different institutional environments, market structures, or levels of technological maturity.

1.7. Structure of the Thesis

This thesis is structured into five comprehensive chapters to ensure logical coherence and systematic presentation of the research.

Chapter One (Introduction): This chapter has presented the background and context of the study, articulated the specific research problem, outlined the primary and specific research objectives and questions, justified the significance of the study from theoretical, managerial, and policy perspectives, and defined the scope and delimitations of the research.

Chapter Two (Literature Review and Hypotheses Development): This chapter will provide a comprehensive and critical review of the extant literature related to Industry 4.0 technologies, Green Supply Chain Management (GSCM), and sustainable performance. It will elaborate on the theoretical foundations (Practice-Based View and Information Processing Theory), synthesize existing empirical findings, identify research gaps, and formally develop the conceptual framework and testable research hypotheses.

Chapter Three (Research Methodology): This chapter will detail the research philosophy, approach, and design. It will explicitly describe the measures and instrumentation for all constructs (digital technologies, GSCM practices, sustainable performance), the target population and sampling procedure, data collection methods, and the planned statistical techniques for data analysis, including tests for reliability, validity, and hypothesis testing (e.g., Structural Equation Modeling).

Chapter Four (Data Analysis and Results): This chapter will present the empirical findings of the study. It will include descriptive statistics of the sample, results of the measurement model assessment (confirmatory factor analysis, reliability, validity), and the results of the structural model testing to examine the direct and mediating relationships posited in the hypotheses.

Chapter Five (Discussion, Conclusion, and Implications): This final chapter will discuss the key findings in relation to the existing literature and the proposed theoretical framework. It will present the conclusions of the study, elaborate on the theoretical, managerial, and policy implications, acknowledge the limitations of the research, and suggest pertinent directions for future scholarly inquiry.

2. LITERATURE REVIEW

2.1. Digital Technologies in Industry 4.0: Conceptual Evolution and Sectoral Application

The concept of Industry 4.0 has matured significantly in recent years, now understood as a comprehensive digital ecosystem that integrates advanced technologies to create intelligent, connected, and autonomous production and supply chain systems. This fourth industrial revolution is characterized by the seamless convergence of operational technology (OT) and information technology (IT), enabling real-time data exchange, predictive analytics, and automated decision-making across manufacturing and distribution networks. Core technologies underpinning this transformation include the Internet of Things (IoT) for connecting physical assets, cloud computing for scalable data storage and processing, artificial intelligence (AI) and machine learning for pattern recognition and optimization, and blockchain for secure, transparent transaction

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recording (Frank, Dalenogare, & Ayala, 2019). These technologies collectively enable what researchers term "smart manufacturing" or "digital supply chains," where systems can self-monitor, self-diagnose, and self-optimize with minimal human intervention.

From a theoretical perspective, the evolution of Industry 4.0 aligns closely with advancements in **Information Processing Theory**, which has expanded beyond its original organizational design focus to encompass how digital systems process vast information flows in real-time. Contemporary applications of this theory emphasize how digital technologies transform information from a passive resource into an active asset that drives continuous improvement and innovation (Li, Wu, Cao, & Wang, 2021). This theoretical lens helps explain why firms that effectively leverage digital information flows achieve superior operational performance and faster adaptation to market changes compared to those with less sophisticated information processing capabilities.

In the global FMCG sector, digital transformation has accelerated dramatically, driven by converging trends including rising consumer expectations for transparency, increasing regulatory pressures for traceability, and growing competitive intensity requiring operational excellence. Recent implementations showcase sophisticated applications: AI-powered demand forecasting systems that incorporate hundreds of variables including weather patterns, social media trends, and economic indicators; blockchain-based traceability platforms that provide end-to-end visibility from farm to shelf; IoT-enabled quality monitoring that tracks products throughout distribution networks; and augmented reality (AR) systems for remote equipment maintenance and operator training (Sharma, Jabbour, & Lopes de Sousa Jabbour, 2021). These technologies address persistent FMCG challenges including short product lifecycles, complex global supply networks, stringent quality and safety requirements, and thin profit margins that demand operational efficiency.

The **Pakistani FMCG sector** presents a distinctive context for digital technology adoption, characterized by what scholars term "frugal innovation" – achieving substantial outcomes with limited resources through creative adaptation. Between 2020 and 2024, leading Pakistani FMCG companies have implemented targeted digital solutions addressing specific local challenges. **Engro Foods**, for instance, deployed an IoT-based cold chain monitoring system across its dairy logistics network, addressing Pakistan's infrastructure limitations where inconsistent refrigeration during transportation causes significant product spoilage. This system utilizes low-cost sensors with extended battery life and offline data storage capabilities, syncing information when connectivity becomes available rather than requiring constant internet access (Khan & Abbas, 2024). Similarly, **Nestlé Pakistan** implemented an AI-enhanced demand planning system specifically calibrated for Pakistan's unique consumption patterns, which fluctuate dramatically during Ramadan, Eid festivals, and seasonal changes. This system outperforms traditional forecasting methods by 22% in accuracy by incorporating localized variables including regional precipitation patterns affecting agricultural outputs, electricity load-shedding schedules impacting production, and social media sentiment analysis gauging brand perception shifts (SECP, 2023).

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Despite these advancements, substantial barriers constrain more comprehensive digital transformation across Pakistan's FMCG sector, particularly for small and medium enterprises that comprise approximately 85% of industry participants. Infrastructure limitations remain significant, with unreliable electricity supply disrupting automated production lines and inadequate internet connectivity in rural sourcing regions limiting cloud-based applications. Cybersecurity vulnerabilities have escalated as digital adoption increases, with a 2023 survey revealing that 68% of Pakistani FMCG firms experienced at least one significant cyber incident in the previous year, ranging from ransomware attacks to data breaches (Pakistan Cybersecurity Report, 2024). Human capital constraints persist, with shortages of technicians capable of maintaining advanced equipment and managers capable of leveraging analytics for strategic decision-making. Financial barriers are particularly acute, as many firms operate with narrow margins that limit investment capacity, while financial institutions often perceive technology investments as high-risk with uncertain returns.

Digital technology adoption patterns in Pakistan's FMCG sector reveal several distinctive characteristics. First, implementation typically follows a "problem-first" rather than "technology-first" approach, where specific operational challenges drive technology selection rather than adopting the latest innovations. Second, solutions emphasize robustness and simplicity over sophistication, prioritizing systems that function reliably despite infrastructure constraints. Third, hybrid models combining digital and manual processes are common, recognizing that full automation may not be feasible or economically justified. Fourth, partnerships with technology providers often include substantial knowledge transfer components, building internal capabilities alongside system implementation. These patterns reflect pragmatic adaptation to local conditions rather than wholesale adoption of international best practices designed for different contexts.

The theoretical implications of these sectoral patterns align with contemporary developments in **Practice-Based View (PBV)**, which emphasizes how competitive advantage derives from effectively implementing practices rather than merely possessing resources. In Pakistan's FMCG context, this perspective explains why some firms achieve superior outcomes with relatively basic technologies through excellent implementation practices, including thorough needs assessment, careful change management, continuous training, and systematic performance measurement. This theoretical alignment redirects attention from technology acquisition to technology integration – how digital tools become embedded in organizational routines and capabilities that deliver sustained value.

2.2. Green Supply Chain Management Practices: Contemporary Frameworks and Implementation in Emerging Markets.

Green Supply Chain Management (GSCM) has evolved from a peripheral environmental initiative to a core strategic imperative for FMCG companies worldwide, driven by regulatory pressures, consumer expectations, resource constraints, and competitive dynamics. Contemporary GSCM frameworks emphasize circular economy principles that minimize waste and maximize resource utilization through closed-loop systems. The six-dimensional framework examined in this study –

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encompassing green manufacturing, green purchasing, green design, green information systems, reverse logistics, and investment recovery – represents a comprehensive approach that addresses environmental impacts across the entire product lifecycle (Umar, Khan, Yusliza, Ali, & Yu, 2022). Recent research demonstrates that integrated implementation across multiple dimensions creates synergistic benefits exceeding the sum of individual practice impacts, highlighting the importance of holistic rather than piecemeal approaches to environmental management.

Green Manufacturing (GM) practices have advanced substantially through integration with Industry 4.0 technologies that enable precise monitoring and optimization of environmental parameters. Modern GM implementations utilize IoT sensors for real-time tracking of energy, water, and raw material consumption; AI algorithms for optimizing production parameters to minimize waste generation; and digital twins for simulating process changes before physical implementation (Lai, Feng, & Zhu, 2023). These technologies transform environmental management from periodic reporting to continuous optimization, identifying inefficiencies invisible through conventional monitoring approaches. In Pakistan's FMCG sector, water-intensive industries like beverages and dairy have made particularly significant GM investments, driven by both environmental responsibility and operational necessity in a water-scarce country. **Coca-Cola Pakistan** implemented a comprehensive water stewardship program between 2020 and 2024 that reduced water usage ratio by 23% through multiple interventions: membrane filtration systems that purify and recycle process water, optimized cleaning procedures that reduce water consumption while maintaining hygiene standards, and community water replenishment projects that balance operational water usage through watershed restoration initiatives (Sustainable Development Report, 2024). Similarly, **Shezan International** completed a phased transition to renewable energy between 2021 and 2024, achieving 72% renewable energy usage through rooftop solar installations, solar thermal systems for process heating, and power purchase agreements with dedicated solar farms. This transition reduced both carbon emissions and energy costs while providing insulation from Pakistan's volatile electricity prices and frequent grid outages (Khan & Abbas, 2024).

Green Purchasing (GP) has evolved from basic supplier screening to collaborative capability-building programs that enhance environmental performance throughout supply networks. Contemporary GP practices include digital platforms for assessing supplier environmental performance, blockchain systems for verifying sustainable sourcing claims, and shared investment models for financing environmental improvements with strategic partners (Kouhizadeh & Sarkis, 2020). These approaches recognize that significant environmental impacts occur upstream in supply chains and that buying organizations must extend their influence beyond immediate suppliers to create meaningful change. In Pakistan's agricultural supply chains, which provide critical inputs for FMCG products, GP implementation faces distinctive challenges including fragmented smallholder production, limited farmer awareness of environmental practices, and inadequate infrastructure for implementing sustainable agriculture at scale. **Tapal Tea** addressed these challenges through a multi-faceted program launched in 2021: a digital traceability system that connects cultivation

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practices to final products, enabling verification of sustainable farming methods; training programs for tea growers on integrated pest management, soil conservation, and water efficiency; and premium pricing incentives for farmers achieving certification under recognized sustainability standards (Haque & Rauf, 2024). This program demonstrates how digital technologies can enhance GP implementation even in challenging contexts by providing transparent, verifiable data on supply chain environmental performance.

Green Design (GD) approaches have transformed through advances in materials science, digital design tools, and circular economy business models. Modern GD utilizes lifecycle assessment software to evaluate environmental impacts during design phases, simulation tools to predict product performance under various usage scenarios, and collaborative platforms that integrate input from multiple stakeholders including material scientists, manufacturing engineers, marketing specialists, and sustainability experts (Habib et al., 2021). This cross-functional approach ensures that environmental considerations are embedded throughout the design process rather than treated as an afterthought. In Pakistan's packaging-intensive FMCG sector, GD innovations focus particularly on reducing material usage, enhancing recyclability, and eliminating hazardous substances. **Packages Limited**, a major packaging supplier to FMCG companies, introduced several notable GD innovations between 2020 and 2024: lightweight glass bottles with improved structural design that reduces material usage by 18% while maintaining strength; mono-material flexible packaging that enhances recyclability by eliminating mixed-material laminates; and water-based printing inks that eliminate volatile organic compound emissions during production (SECP, 2023). These innovations address Pakistan's specific waste management challenges where limited recycling infrastructure makes design for recyclability particularly important, and where air quality regulations are increasingly restricting industrial emissions.

Green Information Systems (GIS) have advanced from standalone environmental management software to integrated platforms that connect sustainability metrics with core business processes. Modern GIS implementations include IoT sensor networks for automated data collection, cloud-based analytics for identifying improvement opportunities, and interactive dashboards for communicating performance to diverse stakeholders (Qu & Liu, 2020). These systems transform environmental management from a compliance-oriented administrative function to a strategic capability that drives operational excellence and competitive advantage. In Pakistan's FMCG sector, GIS implementation varies significantly by company size and multinational affiliation. **Engro Foods** implemented an integrated environmental management platform in 2022 that consolidates data from 200+ monitoring points across manufacturing and distribution facilities, providing real-time visibility into energy, water, and emissions performance. The system includes automated alerts when performance deviates from established benchmarks, predictive analytics that identify potential issues before they occur, and standardized reporting templates that streamline compliance with multiple regulatory requirements (Khan & Abbas, 2024). **Unilever Pakistan** developed a supplier sustainability portal in 2023 that enables agricultural suppliers to input environmental data directly through mobile applications, reducing

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reporting burdens while improving data accuracy and timeliness. The portal includes gamification elements that encourage friendly competition among suppliers to improve environmental performance, and knowledge-sharing features that disseminate best practices across the supply network (Pakistan Business Council, 2024).

Reverse Logistics (RL) systems have evolved through technological innovations that improve collection efficiency, sorting accuracy, and value recovery from post-consumer materials. Contemporary RL implementations include mobile applications for convenient consumer returns, AI-powered sorting systems that identify materials for optimal recycling, and blockchain platforms for tracking material flows through complex recovery networks (Butt, Ali, & Govindan, 2023). These technologies address persistent RL challenges including low collection rates, contamination of recyclable streams, and difficulty tracing materials through multiple processing stages. In Pakistan's institutional context, formal RL systems remain underdeveloped due to multiple barriers: inadequate collection infrastructure in most cities, limited processing capacity for certain materials, low consumer awareness about proper disposal, and weak economic incentives for recovery. However, innovative partnerships are emerging that leverage Pakistan's extensive informal waste sector, which already recovers substantial value from post-consumer materials through highly efficient though often environmentally problematic methods. **Packages Limited** collaborated with waste picker cooperatives in Karachi and Lahore to establish standardized PET bottle collection systems that improved recovery rates by 40% through guaranteed pricing, dedicated collection containers placed in high-traffic areas, and basic safety equipment for collectors (Pakistan Climate Change Ministry, 2023). This partnership exemplifies how hybrid formal-informal approaches can enhance RL effectiveness in emerging markets by combining the efficiency of informal networks with the quality standards and safety protocols of formal systems.

Investment Recovery (IR) practices have advanced through digital marketplaces that connect material sellers with buyers, advanced analytics for identifying optimal recovery options, and verification systems that ensure material quality and provenance. Contemporary IR approaches treat waste streams as revenue opportunities rather than disposal costs, aligning environmental and economic objectives through circular business models (Kouhizadeh & Sarkis, 2020). Effective IR requires systems to identify recoverable materials across operations, evaluate alternative recovery options based on market conditions, execute recovery transactions efficiently, and measure both financial and environmental outcomes. Pakistani FMCG firms practice IR primarily through informal channels and focused initiatives rather than comprehensive programs. **Engro Foods** established a dedicated byproducts division in 2022 that commercializes whey protein from cheese production for multiple applications: premium whey protein concentrate for sports nutrition products, basic whey powder for animal feed, and lactose derivatives for pharmaceutical applications. This initiative transformed what was previously a disposal challenge into a $3.2 million annual revenue stream while reducing organic load in wastewater by 65% (Khan & Abbas, 2024). **Nestlé Pakistan** implemented a comprehensive production scrap recovery program in 2023 that increased aluminum recovery rates by 45% through improved

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sorting at source and dedicated partnerships with specialized recyclers. The program includes digital tracking of material flows from generation point to final recovery, enabling precise measurement of both economic value and environmental benefits (Sustainable Development Report, 2024).

2.3. Sustainable Performance: Contemporary Measurement Frameworks and Management Approaches

Sustainable performance assessment has evolved significantly in recent years, moving beyond the basic triple bottom line framework to incorporate more sophisticated measurement methodologies, enhanced assurance processes, and greater integration with core business management systems. Contemporary sustainable performance frameworks emphasize the interconnectedness of economic, environmental, and social dimensions, recognizing that optimization in one domain often creates trade-offs or synergies in others that must be explicitly managed (Rehman Khan & Yu, 2021). This holistic perspective aligns with the United Nations Sustainable Development Goals (SDGs), which provide a comprehensive framework for assessing corporate contributions to global sustainability challenges. For FMCG companies, relevant SDGs include SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action), each with specific targets and indicators that guide performance measurement and reporting.

Economic Performance in sustainable business contexts has expanded to include circular economy metrics that capture value creation from waste reduction and resource productivity, in addition to traditional financial indicators. Modern economic performance assessment for sustainability includes measures such as revenue per unit of water consumed, cost savings from energy efficiency investments, percentage of materials from recycled or renewable sources, and risk-adjusted returns accounting for environmental liabilities and transition risks (Khuntia, Saldanha, Mithas, & Sambamurthy, 2018). These expanded metrics acknowledge that financial outcomes increasingly depend on efficient resource utilization as scarcity drives up input costs and regulations internalize environmental externalities. For Pakistani FMCG firms, this connection between resource efficiency and financial performance is particularly direct, as savings from reduced energy, water, and material consumption flow directly to the bottom line without requiring price increases or market share gains. Digital technologies contribute to economic performance through multiple pathways: route optimization algorithms that reduce fuel costs in extensive distribution networks; predictive maintenance systems that minimize expensive equipment downtime and repair costs; data analytics that improve demand forecasting accuracy, reducing inventory carrying costs and stockouts; and automation that enhances production consistency, reducing quality-related waste and rework (Li, Dai, & Cui, 2020). These technologies are particularly valuable in Pakistan's challenging operating environment where infrastructure constraints and supply chain disruptions elevate the economic returns from operational efficiency improvements.

Environmental Performance measurement has advanced through several key developments including widespread adoption of the Greenhouse Gas Protocol for

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emissions accounting, increasing use of water footprint assessment methodologies, growing emphasis on scope 3 emissions that capture supply chain impacts, and development of science-based targets that align corporate environmental goals with planetary boundaries (Dubey et al., 2019). Modern environmental performance management utilizes digital monitoring systems for real-time data collection, geospatial analysis for assessing ecosystem impacts, predictive modeling for forecasting future environmental risks under climate change scenarios, and blockchain systems for verifying environmental claims across complex supply chains. Pakistan's environmental regulations have strengthened significantly, with provincial governments implementing plastic bag bans, federal authorities developing extended producer responsibility frameworks, courts taking stricter enforcement actions against polluting industries, and the Securities and Exchange Commission of Pakistan (SECP) introducing mandatory sustainability reporting requirements for listed companies (Ministry of Climate Change, 2024). These regulatory developments create both compliance obligations and competitive opportunities for FMCG firms demonstrating environmental leadership. **Packages Limited** reduced water consumption by 35% between 2020 and 2024 through multiple interventions: closed-loop systems that recycle process water, rainwater harvesting that supplements municipal supply, and efficiency improvements that reduce water usage per unit of production (Pakistan Climate Change Ministry, 2023). **Coca-Cola Pakistan** achieved carbon neutrality for its manufacturing operations in 2023 through a combination of renewable energy investments, energy efficiency improvements, and verified carbon offsets for remaining emissions, setting a benchmark for the beverage industry and demonstrating that ambitious environmental goals are achievable even in challenging contexts (Sustainable Development Report, 2024).

Social Performance assessment has evolved through greater emphasis on supply chain labor conditions, community impact measurement, diversity, equity and inclusion metrics, and human rights due diligence processes. Contemporary social performance management utilizes worker voice technologies for monitoring factory conditions, social return on investment methodologies for quantifying community program impacts, pay equity analytics for identifying compensation disparities, and stakeholder engagement platforms for incorporating community perspectives into decision-making (Awan et al., 2022). These approaches recognize that social performance extends beyond philanthropy to encompass how core business activities affect employees, supply chain partners, consumers, and communities. In Pakistan's socioeconomic context, FMCG companies face growing expectations regarding their social contributions, particularly in areas of women's economic participation, rural development, nutritional improvement, and access to essential products for low-income consumers. **Engro Foods** expanded its dairy development program between 2021 and 2024 to include 75,000 women livestock farmers, providing comprehensive support including animal husbandry training, veterinary services, feed supply at subsidized rates, and guaranteed milk purchase agreements. The program increased household incomes by an average of 42% while enhancing women's economic empowerment and social status in conservative rural communities (Khan & Abbas, 2024). **Nestlé**

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Pakistan fortified its milk products with essential vitamins and minerals in 2022 to address widespread micronutrient deficiencies affecting child development and maternal health. This initiative combined product reformulation with educational campaigns about nutrition, demonstrating how FMCG companies can contribute to public health objectives through their core business activities rather than solely through corporate social responsibility programs (Sustainable Development Report, 2023).

2.4. Theoretical Framework: Integration of Contemporary Practice-Based View and Information Processing Theory

The **Practice-Based View (PBV)** has evolved in recent applications to provide more nuanced explanations of how organizations implement technological and environmental practices in increasingly digital and globalized contexts. Contemporary PBV research emphasizes that competitive advantage derives not merely from practice adoption but from practice adaptation – the customization of generic practices to fit specific organizational contexts, resource constraints, and market conditions (Tian et al., 2023). This perspective explains why Pakistani FMCG firms achieve varying outcomes from similar technology investments based on differences in implementation approaches, integration with existing processes, change management strategies, and organizational learning mechanisms. For example, the differential success of Enterprise Resource Planning (ERP) implementations across Pakistani FMCG firms can be explained through PBV by examining adaptation mechanisms: how each firm customized standard software modules to their specific distribution challenges in Pakistan's fragmented retail environment; modified user interfaces for operators with varying digital literacy levels; developed localized training materials in appropriate languages and formats; and established internal support structures for continuous system optimization. These adaptation practices, rather than the technology itself, determine implementation success and value realization.

Contemporary **Information Processing Theory (IPT)** applications have expanded to account for big data environments where information volume, velocity, and variety fundamentally transform organizational capabilities. Modern IPT emphasizes how digital technologies enable not just more efficient information processing but entirely new processing approaches including predictive analytics that anticipate future conditions, prescriptive analytics that recommend optimal actions, autonomous systems that implement decisions without human intervention, and collaborative platforms that distribute processing across organizational boundaries (Yu, Wong, Chavez, & Jacobs, 2021). This theoretical evolution explains how leading Pakistani FMCG firms utilize digital technologies to transform information processing capabilities: predictive analytics forecast demand spikes during unpredictable events like heatwaves or political unrest; prescriptive analytics optimize production schedules across constrained manufacturing capacity; automated replenishment systems maintain inventory levels based on real-time sales data; and collaborative platforms share information with supply chain partners to improve coordination and reduce bullwhip effects. These applications demonstrate how enhanced information processing transforms supply chain management from reactive to proactive, fundamentally changing how organizations interact with their environments.

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The integration of contemporary PBV and IPT provides a powerful theoretical framework for examining how digital technologies influence sustainable performance through GSCM practices. According to this integrated framework, digital technologies enhance information processing capacity (IPT mechanism), which enables more sophisticated implementation of GSCM practices across all six dimensions (PBV focus). These practices, when effectively adapted to organizational contexts and implemented through appropriate routines, contribute to improved performance across economic, environmental, and social domains. This mediated relationship acknowledges the crucial role of implementation quality in determining technology outcomes, explaining why similar digital investments produce divergent sustainability results across different Pakistani FMCG firms. The framework also highlights reciprocal relationships where effective GSCM practices may reveal new information requirements, driving further digital technology investments in an iterative cycle of capability development. This dynamic is particularly evident in Pakistani firms that have progressed through multiple phases of digital-environmental integration, where initial basic systems provided insights that justified more advanced implementations, which in turn enabled more sophisticated environmental management practices.

2.5. Research Gap Identification and Original Contribution

Despite significant research advancements in recent years, important gaps persist in understanding how digital technologies influence sustainable performance through GSCM practices in emerging economy FMCG sectors. The existing literature exhibits several limitations that this study addresses through its focused examination of Pakistan's FMCG sector. First, most empirical research continues to concentrate on developed economies or manufacturing, with limited attention to South Asian contexts experiencing distinctive digital and environmental transitions. This geographical concentration limits understanding of how infrastructure constraints, regulatory frameworks, market structures, and cultural values shape technology adoption and environmental practices in different institutional settings. Pakistani-specific studies remain scarce despite the country's position as the world's fifth most populous nation with a rapidly growing consumer market and pressing environmental challenges that demand urgent attention.

Second, existing studies often examine digital technologies or GSCM practices in isolation, with inadequate investigation of their interaction effects and mediating relationships. This disciplinary separation persists despite growing recognition that digital and environmental transformations are increasingly intertwined in practice, with each enabling and reinforcing the other. Few contemporary studies explicitly test mediation mechanisms with robust quantitative methods, particularly in emerging economy contexts where data limitations often constrain analytical sophistication. The research that does exist often employs simplified conceptualizations of complex constructs, limiting practical relevance for managers navigating multifaceted digital-environmental integration challenges.

Third, methodological approaches in recent research continue to emphasize qualitative case studies over large-sample quantitative analysis, limiting statistical generalizability of findings. While case studies provide valuable depth and context, they cannot establish population-level patterns or test complex multivariate relationships with statistical rigor. The few quantitative studies that do exist often employ basic analytical techniques inadequate for testing mediated relationships with multiple interrelated constructs, or use measurement instruments developed in Western contexts without appropriate adaptation for emerging markets where operational realities and managerial perceptions may differ significantly.

Fourth, theoretical integration remains underdeveloped despite growing recognition of its importance. Contemporary studies continue to apply single theoretical lenses that provide partial explanations of complex phenomena, or combine theories superficially without deep integration. Few studies explicitly develop and test integrated theoretical frameworks that explain how digital capabilities translate into environmental outcomes through intermediate organizational practices, despite the logical appeal of such approaches for understanding multifaceted transformation processes that span technological, organizational, and environmental domains.

This study addresses these research gaps through several original contributions. First, it provides current empirical evidence from Pakistan's FMCG sector, expanding geographical representation in the literature and enhancing understanding of digital-environmental transformations in an important but understudied emerging economy. Second, it examines the interplay between digital technologies and GSCM practices through explicit mediation testing, advancing beyond studies that examine these factors in isolation. Third, it employs robust quantitative methodology with validated measurement instruments adapted to local context, addressing methodological limitations in existing research. Fourth, it integrates contemporary PBV and IPT into a coherent theoretical framework that explains how digital technologies enable GSCM practices that drive sustainable performance, providing theoretical integration missing from fragmented literature. By addressing these gaps, this study contributes to both academic knowledge and practical understanding of how FMCG firms in emerging economies can leverage digital technologies to achieve sustainability goals while maintaining economic viability.

3. RESEARCH HYPOTHESES DEVELOPMENT

The conceptual foundation of this research is anchored in the intersection of two complementary theoretical perspectives: the Practice-Based View (PBV) and Information Processing Theory (IPT). This integrated theoretical framework provides a robust lens through which to examine the complex relationships between Industry 4.0 Digital Technologies (IDT), Green Supply Chain Management (GSCM) practices, and Sustainable Performance within Pakistan's Fast-Moving Consumer Goods (FMCG) sector.

The Practice-Based View (Bromiley & Rau, 2016) posits that a firm's competitive advantage and superior performance stem not merely from the resources it controls, but from the distinctive organizational and strategic practices it develops and implements. This perspective shifts focus from static resource possession to dynamic capability development through organizational routines and processes. In the context of this research, GSCM practices—comprising Green Manufacturing, Green Purchasing, Green Design, Green Information Systems, Reverse Logistics, and Investment

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Recovery—are conceptualized as these value-creating, strategic organizational routines. The effective execution of these practices is theorized to directly enhance a firm's environmental, economic, and social outcomes. The PBV is particularly relevant in emerging economies like Pakistan, where institutional voids and resource constraints make innovative practices more critical for competitive advantage than mere resource accumulation.

Concurrently, Information Processing Theory, as extended to digital transformation contexts (Hazen, Skipper, & Ezell, 2021; Mikalef & Krogstie, 2020), contends that organizational effectiveness depends on the alignment between the organization's information processing requirements and its information processing capacity. The contemporary business environment, particularly in sustainability management, presents immense information complexity: tracking multi-tier supplier networks, monitoring real-time environmental metrics, complying with evolving regulations, and responding to dynamic consumer preferences for sustainable products. Industry 4.0 digital technologies—encompassing the Internet of Things (IoT), Big Data Analytics (BDA), Artificial Intelligence (AI), blockchain, and cloud computing—are viewed as advanced organizational mechanisms that dramatically augment a firm's information processing capacity. These technologies enable the collection, analysis, and utilization of vast amounts of data that were previously inaccessible or unmanageable.

The synthesis of these theories creates the **"Technology-Practice-Performance" framework** that guides this study. IPT explains the *necessity* for digital technologies: they provide the enhanced information processing capability required to manage the complexity inherent in sustainable supply chain management. PBV then explains the *mechanism*: this enhanced digital capability enables the effective design, implementation, monitoring, and refinement of specific, valuable GSCM practices. Ultimately, it is these practices that serve as the proximate drivers of sustainable performance improvements. This framework moves beyond deterministic claims of technology's impact, offering a nuanced model where technology empowers practices, which in turn generate performance outcomes. The framework acknowledges that technology adoption alone is insufficient; it must be translated into organizational practices that leverage technological capabilities for strategic ends.

Within the specific context of Pakistan's FMCG sector—characterized by infrastructural challenges, price sensitivity, complex distribution networks, and nascent sustainability initiatives—this framework takes on particular relevance. The sector's transition toward sustainability requires not merely technological adoption, but the development of contextualized practices that leverage these technologies to address local challenges. Pakistani FMCG firms face unique constraints including energy shortages, water scarcity, regulatory uncertainties, and a highly competitive market with low consumer willingness to pay for sustainability. These contextual factors shape how digital technologies are adopted and how GSCM practices are implemented, making the Pakistani context a distinctive setting for testing and potentially extending the Technology-Practice-Performance framework.

This chapter develops the specific research hypotheses that emerge from this theoretical foundation and the approved conceptual model, providing detailed justification for each

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proposed relationship with reference to both global literature and Pakistan-specific considerations. Each hypothesis is grounded in theoretical reasoning and empirical evidence, with particular attention to how these relationships manifest in the Pakistani FMCG context. The hypotheses collectively form a comprehensive model that will be tested empirically in subsequent chapters.

3.1. Direct Impact of Industry 4.0 Digital Technology on Sustainable Performance (H1 -H3)

The proposition that Industry 4.0 digital technologies directly enhance sustainable performance finds substantial support in contemporary literature. This relationship is grounded in the enhanced information processing capabilities that digital technologies provide, enabling firms to optimize operations, reduce waste, and create value across all three dimensions of sustainability. The direct impact hypothesis suggests that digital technologies provide immediate benefits even before their full integration with organizational practices, though this direct impact is expected to be amplified through mediated pathways involving GSCM practices.

3.1.1. Digital Technology and Environmental Performance (H1)

Digital technologies offer unprecedented capabilities for environmental monitoring and optimization. The Internet of Things (IoT) enables real-time tracking of energy consumption, water usage, and emissions across manufacturing facilities and logistics networks (Ben-Daya, Hassini, & Bahroun, 2019). This granular, real-time data allows for immediate identification of inefficiencies and proactive maintenance to prevent resource waste. Big Data Analytics can process complex environmental datasets to identify patterns and optimization opportunities that would be invisible to traditional analysis methods (Bag, Wood, Xu, & Kumar, 2020). Artificial Intelligence algorithms can optimize production schedules to minimize energy consumption during peak tariff periods and reduce material waste through precision manufacturing (Birkel & Müller, 2021). Furthermore, blockchain technology enables transparent tracking of environmental impacts across supply chains, facilitating carbon accounting and verification of sustainability claims (Saberi, Kouhizadeh, & Sarkis, 2019).

In Pakistan's FMCG context, where energy costs are high and resource efficiency is critical for competitiveness, these capabilities hold particular promise. For instance, IoT-enabled monitoring in dairy processing plants could significantly reduce water consumption and wastewater generation, addressing Pakistan's severe water scarcity challenges. AI-optimized refrigeration in cold chains could minimize energy use and product spoilage, crucial in a country with frequent power outages. Digital technologies thus provide the informational foundation for environmental performance improvements that are both ecologically beneficial and economically advantageous. Moreover, as Pakistani regulators increase environmental compliance requirements, digital monitoring systems help firms demonstrate compliance more efficiently, reducing regulatory risks and potential penalties.

3.1.2. Digital Technology and Economic Performance (H2)

The economic benefits of Industry 4.0 technologies are well-documented in global literature. Predictive maintenance powered by IoT sensors and AI reduces unexpected downtime and extends equipment lifespan (Tortorella, Giglio, & van Dun, 2021).

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Advanced analytics improve demand forecasting accuracy, reducing inventory carrying costs and stockouts (Chauhan & Singh, 2022). Automation and robotics enhance labor productivity and production consistency. These efficiency gains directly translate to improved profitability, return on investment, and market responsiveness. Digital technologies also enable new business models such as product-as-a-service or circular economy approaches that create additional revenue streams while reducing environmental impacts (Khan, Idrees, & Haider, 2023).

For Pakistani FMCG firms, which operate with thin margins and face intense competition, these economic benefits are crucial. Digital technologies can help local manufacturers compete with multinational corporations by achieving similar operational efficiencies. For example, blockchain-enabled supply chain transparency could reduce counterfeiting—a significant problem in Pakistan's FMCG sector—protecting brand integrity and revenue. AI-driven dynamic pricing algorithms could help firms optimize prices across different market segments and regions, maximizing revenue in a price-sensitive market. Furthermore, digital technologies facilitate access to export markets by enabling compliance with international standards and traceability requirements, expanding market opportunities for Pakistani FMCG firms.

3.2.3. Digital Technology and Social Performance (H3)

The social dimension of sustainability encompasses worker health and safety, community relations, and ethical business practices. Digital technologies contribute to social performance in several ways. Collaborative robots (cobots) can take over dangerous, repetitive tasks, reducing workplace accidents and injuries. Digital training platforms can enhance worker skills and safety awareness. Blockchain technology can ensure transparency in supply chains, verifying ethical sourcing practices and fair labor conditions (Saberi, Kouhizadeh, & Sarkis, 2019). Social media analytics help firms understand and respond to community concerns, while digital platforms facilitate stakeholder engagement and transparency.

In Pakistan, where workplace safety standards are evolving and consumer awareness of ethical issues is growing, digital technologies offer pathways to social performance improvements. For instance, IoT wearables could monitor workers' exposure to heat and hazardous materials in manufacturing facilities, while digital platforms could facilitate better communication and grievance redressal mechanisms. These applications not only benefit workers and communities but also enhance brand reputation and consumer trust—critical assets in Pakistan's increasingly competitive FMCG market. Additionally, as Pakistani consumers become more digitally connected, firms can use digital platforms to communicate their social initiatives, building brand loyalty among socially conscious consumers.

Based on these interconnected relationships across all three sustainability dimensions, we propose:

H1: Industry 4.0 Digital Technology adoption has a significant positive impact on the Environmental Performance of FMCG firms in Pakistan.

H2: Industry 4.0 Digital Technology adoption has a significant positive impact on the Economic Performance of FMCG firms in Pakistan.

H3: Industry 4.0 Digital Technology adoption has a significant positive impact on the Social Performance of FMCG firms in Pakistan.

3.2. Impact of Industry 4.0 Digital Technology on GSCM Practices (H4 -H9)

The relationship between digital technologies and GSCM practices represents the enabling function of technology within our theoretical framework. Digital technologies provide the informational infrastructure and processing capabilities that make sophisticated GSCM practices feasible and effective. Each GSCM practice dimension is enabled by specific digital technologies in distinct ways. This section develops hypotheses for each of the six GSCM practice dimensions, providing detailed theoretical reasoning and contextual application to Pakistan's FMCG sector.

3.3.1. Digital Technology and Green Manufacturing (H4)

Green Manufacturing involves modifying production processes to minimize environmental impact through waste reduction, energy efficiency, and cleaner production techniques. Digital technologies enable Green Manufacturing in multiple ways. IoT sensors provide real-time monitoring of machine performance, energy consumption, and emission levels, allowing for immediate adjustments (Khan, Idrees, & Haider, 2023). AI algorithms can optimize production parameters in real-time to minimize waste and energy use while maintaining quality standards. Digital twins—virtual replicas of physical systems—allow for simulation and optimization of manufacturing processes before implementation, reducing trial-and-error waste. Additive manufacturing (3D printing) enables on-demand production that reduces material waste compared to subtractive manufacturing methods (Ghobakhloo, 2020).

In Pakistan's FMCG sector, where manufacturing often relies on aging equipment and manual processes, digital technologies offer transformative potential for Green Manufacturing. For example, IoT sensors on packaging lines could optimize material usage, reducing plastic consumption—a significant environmental concern in Pakistan where plastic waste management is inadequate. AI-powered quality control systems using computer vision could detect defects earlier in the process, minimizing waste of raw materials. These applications are particularly relevant given Pakistan's growing regulatory focus on industrial emissions and waste management. Furthermore, as energy costs represent a significant portion of manufacturing expenses in Pakistan, digital energy management systems can yield substantial cost savings while reducing environmental impact.

H4: Industry 4.0 Digital Technology adoption has a significant positive impact on Green Manufacturing practices in Pakistani FMCG firms.

This hypothesis is supported by the information processing capabilities of digital technologies, which enable precise monitoring and control of manufacturing processes. Without digital technologies, Green Manufacturing practices rely on manual measurements and estimations, which are less accurate and responsive. Digital technologies transform Green Manufacturing from a static set of guidelines to a dynamic, data-driven optimization process.

3.2.2. Digital Technology and Green Purchasing (H5)

Green Purchasing involves selecting suppliers based on environmental criteria and collaborating with them to improve environmental performance. Digital technologies

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transform Green Purchasing by enabling comprehensive supplier assessment, monitoring, and collaboration. Blockchain platforms create transparent, immutable records of suppliers' environmental certifications and performance data (Kouhizadeh & Sarkis, 2020). Big Data Analytics can process diverse data sources to assess supplier sustainability risks. Digital platforms facilitate collaboration on environmental improvements across supply networks. AI-powered tools can analyze supplier data to identify risks and opportunities for sustainability improvements (Bag et al., 2020).

For Pakistani FMCG firms, which often source from fragmented networks of local and international suppliers, digital technologies can address significant challenges in Green Purchasing. Blockchain-based traceability systems could verify the sustainability claims of agricultural suppliers—critical for food and beverage companies seeking to ensure sustainable sourcing of raw materials like palm oil, cocoa, or dairy. Digital supplier scorecards could integrate multiple sustainability metrics, helping procurement teams make informed decisions. These capabilities are increasingly important as multinational corporations in Pakistan face pressure from global headquarters to ensure sustainable sourcing, and as local consumers become more aware of ethical sourcing issues. Additionally, digital platforms can connect Pakistani FMCG firms with sustainable suppliers, overcoming information asymmetries that previously hindered Green Purchasing.

H5: Industry 4.0 Digital Technology adoption has a significant positive impact on Green Purchasing practices in Pakistani FMCG firms.

The hypothesis rests on the ability of digital technologies to overcome information barriers in supply chains. Traditional purchasing decisions often prioritize cost and quality, with limited information about environmental impacts. Digital technologies make environmental information more accessible, verifiable, and actionable, enabling firms to incorporate sustainability criteria into purchasing decisions systematically.

3.2.3. Digital Technology and Green Design (H6)

Green Design involves creating products with reduced environmental impact throughout their lifecycle, considering factors like material selection, energy efficiency, recyclability, and end-of-life disposal. Digital technologies enable sophisticated Green Design through simulation, analysis, and collaboration tools. AI-powered generative design software can explore thousands of design alternatives optimized for material efficiency and environmental performance (Sharma, Jabbour, & Lopes de Sousa Jabbour, 2021). Life Cycle Assessment (LCA) software integrated with product data management systems allows designers to evaluate environmental impacts early in the design process. Virtual reality enables collaborative design reviews without physical prototypes, reducing material waste in the design phase.

In Pakistan's FMCG sector, where product design has traditionally focused on cost and functionality rather than sustainability, digital technologies offer new possibilities for Green Design. For instance, AI tools could help packaging designers create lighter, more recyclable packaging that uses less material—addressing both environmental concerns and cost pressures. Digital platforms could facilitate collaboration with recycling partners to design for disassembly and recyclability. These applications align with growing consumer awareness of packaging waste and increasing regulatory

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attention to extended producer responsibility in Pakistan. Furthermore, as Pakistani FMCG firms seek to access export markets, digital design tools help them meet international sustainability standards and certifications.

H6: Industry 4.0 Digital Technology adoption has a significant positive impact on Green Design practices in Pakistani FMCG firms.

This hypothesis is grounded in the computational capabilities of digital technologies, which enable complex environmental simulations and optimizations that would be infeasible manually. Green Design requires considering multiple environmental factors across the product lifecycle, a computationally intensive task that digital technologies are uniquely suited to support.

3.2.4. Digital Technology and Green Information Systems (H7)

Green Information Systems (GIS) refer to the integrated hardware and software infrastructure that supports environmental management across the organization and supply chain. Digital technologies are not merely tools that support GIS—they constitute its very architecture. Cloud computing provides scalable platforms for collecting, storing, and analyzing sustainability data from across the enterprise and supply chain (Dubey et al., 2019). IoT networks generate the real-time environmental data that feeds these systems. Blockchain creates secure, transparent databases for sustainability information. AI and analytics transform raw data into actionable insights for environmental management.

For Pakistani FMCG firms, which often lack integrated information systems for sustainability management, digital technologies offer the opportunity to leapfrog traditional development stages. Cloud-based sustainability platforms could provide even small and medium enterprises with capabilities that were previously available only to large corporations. Integrated digital systems could break down information silos between production, logistics, and sustainability departments, enabling holistic environmental management. These systems are particularly valuable in Pakistan's regulatory environment, where reporting requirements are becoming more stringent. Furthermore, as investors and customers increasingly demand sustainability information, digital GIS enable Pakistani firms to provide transparent, verifiable data.

H7: Industry 4.0 Digital Technology adoption has a significant positive impact on Green Information Systems in Pakistani FMCG firms.

This hypothesis reflects the infrastructural role of digital technologies in environmental management. Effective GIS require capabilities for data collection, integration, analysis, and reporting that are inherently digital. As such, digital technology adoption is not just an enabler but a prerequisite for sophisticated GIS.

3.2.5. Digital Technology and Reverse Logistics (H8)

Reverse Logistics involves managing the return, reuse, remanufacturing, and recycling of products and materials at the end of their useful life. Digital technologies enable efficient Reverse Logistics systems through enhanced visibility, optimization, and coordination. IoT sensors track returned products through the reverse supply chain, providing real-time visibility into location, condition, and disposition options (Dev, Shankar, & Qaiser, 2020). AI algorithms optimize collection routes and decide the most value-recovering end-of-life option (reuse, refurbish, recycle) based on product condition and market demand. Blockchain creates transparent records of product history and ownership, facilitating resale and remanufacturing.

In Pakistan's FMCG sector, where formal Reverse Logistics systems are underdeveloped despite significant informal recycling, digital technologies could catalyze transformation. For example, IoT-enabled smart bins could optimize collection of packaging waste, while blockchain-based digital deposit schemes could incentivize returns. AI-powered sorting systems could improve the efficiency and value recovery of recycling operations. These applications address growing concerns about post-consumer waste while creating economic opportunities in Pakistan's circular economy. Particularly for packaging-intensive FMCG products, digital Reverse Logistics systems can help firms comply with emerging extended producer responsibility regulations while recovering value from waste materials.

H8: Industry 4.0 Digital Technology adoption has a significant positive impact on Reverse Logistics practices in Pakistani FMCG firms.

This hypothesis acknowledges the coordination challenges inherent in Reverse Logistics. Effective reverse flows require tracking products through complex networks, making disposition decisions based on multiple factors, and ensuring chain of custody—all tasks that digital technologies significantly enhance.

3.2.6. Digital Technology and Investment Recovery (H9)

Investment Recovery involves extracting value from excess assets, waste materials, and by-products through sale, reuse, or recycling. Digital technologies enhance Investment Recovery by identifying value opportunities, connecting buyers and sellers, and optimizing recovery processes. AI and analytics can identify patterns in waste generation and identify valuable by-products that were previously overlooked (Zhu, Sarkis, & Geng, 2021). Digital marketplaces connect firms with waste materials to potential users, creating new revenue streams. IoT and blockchain provide verification of material quality and origin, increasing buyer confidence and value.

For Pakistani FMCG firms, which often view waste as a cost rather than a potential revenue source, digital technologies can transform Investment Recovery. For instance, AI analysis of production data could identify opportunities to sell food processing by-products as animal feed or fertilizer. Digital platforms could connect packaging waste generators with recyclers, formalizing informal recycling networks. Blockchain could certify the quality and safety of recycled materials, enabling their use in higher-value applications. These applications align with Pakistan's growing focus on circular economy principles and resource efficiency. Moreover, as waste disposal costs increase in Pakistan due to regulatory changes and landfill limitations, Investment Recovery becomes increasingly economically attractive.

H9: Industry 4.0 Digital Technology adoption has a significant positive impact on Investment Recovery practices in Pakistani FMCG firms.

This hypothesis is based on the market-making and value-discovery functions of digital technologies. Investment Recovery requires identifying potential uses for waste materials and connecting with parties who value those materials—functions that digital platforms and analytics perform efficiently.

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3.3. Impact of GSCM Practices on Sustainable Performance (H10 -H27)

The relationship between GSCM practices and sustainable performance represents the core of the Practice-Based View in our theoretical framework. Each GSCM practice constitutes a strategic organizational routine designed to create value across environmental, economic, and social dimensions. The effectiveness of these practices in delivering sustainable performance has been established in global literature and holds particular relevance for Pakistan's FMCG sector. This section develops hypotheses for each GSCM practice, explaining how they contribute to the three dimensions of sustainable performance in the Pakistani context.

3.3.1. Green Manufacturing and Sustainable Performance (H10 – H12)

Green Manufacturing practices directly contribute to all three dimensions of sustainable performance. Environmentally, they reduce waste generation, energy consumption, and emissions through process optimization and cleaner production techniques (Laari, Töyli, & Ojala, 2018). Economically, they lower production costs through reduced material and energy usage, while also minimizing costs associated with waste disposal and regulatory compliance. Socially, they create safer working environments by reducing exposure to hazardous substances and processes, and they enhance community relations by reducing local pollution.

In Pakistan's FMCG context, Green Manufacturing practices offer pathway to address multiple challenges simultaneously. For food and beverage manufacturers, water-efficient processes reduce both environmental impact and operational costs—critical in water-stressed regions of Pakistan. Energy-efficient manufacturing reduces both carbon footprint and vulnerability to Pakistan's energy crises, which include frequent power outages and high energy costs. These practices also enhance brand reputation among increasingly environmentally conscious Pakistani consumers, creating competitive advantage. Furthermore, as Pakistani manufacturers seek to access global markets, Green Manufacturing practices help them meet international environmental standards and customer expectations.

H10: Green Manufacturing practices have a significant positive impact on the Environmental Performance of Pakistani FMCG firms.

H11: Green Manufacturing practices have a significant positive impact on the Economic Performance of Pakistani FMCG firms.

H12: Green Manufacturing practices have a significant positive impact on the Social Performance of Pakistani FMCG firms.

3.3.2. Green Purchasing and Sustainable Performance (H13 – H15)

Green Purchasing practices influence sustainable performance by extending environmental management upstream into the supply chain. Environmentally, they reduce the lifecycle impacts of products by selecting materials and components with lower environmental footprints (Ali, Khan, & Rashid, 2022). Economically, they mitigate supply chain risks associated with environmental regulations, resource scarcity, and reputational issues. Socially, they promote ethical labor practices and community development among suppliers, enhancing the firm's social license to operate.

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For Pakistani FMCG firms, Green Purchasing is particularly relevant given the sector's reliance on agricultural inputs and imported materials. Sustainable sourcing of agricultural raw materials can enhance brand value in both domestic and export markets, where consumers increasingly value sustainably sourced products. Ethical purchasing practices can address growing consumer concerns about labor conditions in supply chains, particularly in agriculture where labor standards are often inadequate. Collaborative relationships with suppliers on environmental improvements can yield innovations that benefit all parties. These practices are increasingly important as multinational buyers impose sustainability requirements on their Pakistani suppliers, and as Pakistani consumers become more discerning about product origins.

H13: Green Purchasing practices have a significant positive impact on the Environmental Performance of Pakistani FMCG firms.

H14: Green Purchasing practices have a significant positive impact on the Economic Performance of Pakistani FMCG firms.

H15: Green Purchasing practices have a significant positive impact on the Social Performance of Pakistani FMCG firms.

3.3.3. Green Design and Sustainable Performance (H16 - H18)

Green Design practices create products with superior environmental characteristics, which translate to sustainable performance benefits throughout the product lifecycle. Environmentally, they reduce material usage, energy consumption in use, and end-of-life impacts (Ünal, Urbinati, & Chiaroni, 2019). Economically, they can reduce material costs, create differentiation in the market, and minimize future liability for product take-back and disposal. Socially, they respond to consumer preferences for sustainable products and demonstrate corporate responsibility, enhancing brand reputation.

In Pakistan's FMCG sector, Green Design offers opportunities for innovation and differentiation. Light weighting packaging reduces both material costs and environmental impact—addressing consumer concerns about plastic waste while improving profitability. Designing products for the specific needs of Pakistani consumers, such as portion-controlled packaging to reduce food waste or refillable containers for household products, creates both social and environmental benefits. These practices enable Pakistani firms to move beyond price competition toward value-based competition centered on sustainability. Furthermore, as Pakistan implements extended producer responsibility regulations, Green Design that facilitates recycling and reuse becomes economically advantageous.

H16: Green Design practices have a significant positive impact on the Environmental Performance of Pakistani FMCG firms.

H17: Green Design practices have a significant positive impact on the Economic Performance of Pakistani FMCG firms.

H18: Green Design practices have a significant positive impact on the Social Performance of Pakistani FMCG firms.

3.3.4. Green Information Systems and Sustainable Performance (H19 – H21)

Green Information Systems provide the foundation for effective environmental management by integrating sustainability considerations into decision-making processes. Environmentally, they enable measurement, monitoring, and management of environmental performance across the organization (Hazen, Skipper, & Ezell, 2021). Economically, they provide the data needed to identify cost-saving opportunities and optimize resource allocation. Socially, they enhance transparency and stakeholder engagement through sustainability reporting, building trust with consumers, investors, and communities.

For Pakistani FMCG firms, Green Information Systems address a critical gap in sustainability management. Integrated systems can help firms navigate Pakistan's complex regulatory environment by ensuring compliance and facilitating reporting. They can provide the data needed to participate in international certification schemes and meet the requirements of global customers. Perhaps most importantly, they can break down organizational silos, enabling coordinated action on sustainability across departments and functions. As Pakistani firms face increasing pressure from multiple stakeholders for sustainability information, effective GIS become essential for maintaining legitimacy and competitive position.

H19: Green Information Systems have a significant positive impact on the Environmental Performance of Pakistani FMCG firms.

H20: Green Information Systems have a significant positive impact on the Economic Performance of Pakistani FMCG firms.

H21: Green Information Systems have a significant positive impact on the Social Performance of Pakistani FMCG firms.

3.3.5. Reverse Logistics and Sustainable Performance (H22 – H24)

Reverse Logistics practices create value from products and materials at the end of their useful life, contributing to circular economy principles. Environmentally, they reduce landfill waste and virgin material consumption through reuse and recycling (Butt, Ali, & Govindan, 2023). Economically, they recover value from returned products and reduce disposal costs. Socially, they create employment in collection, sorting, and processing activities, often in the informal sector, and they address community concerns about waste management.

In Pakistan, where informal recycling networks are extensive but inefficient, formal Reverse Logistics systems offer significant opportunities. For beverage companies, bottle return schemes could reduce litter while lowering packaging costs. For electronics FMCG, take-back programs could recover valuable materials while preventing hazardous waste. These practices align with Pakistan's National Climate Change Policy and growing corporate interest in circular business models. They also address increasing consumer expectations for responsible end-of-life product management. Furthermore, as Pakistan faces growing waste management challenges, Reverse Logistics practices help firms demonstrate environmental responsibility and community engagement.

H22: Reverse Logistics practices have a significant positive impact on the Environmental Performance of Pakistani FMCG firms.

H23: Reverse Logistics practices have a significant positive impact on the Economic Performance of Pakistani FMCG firms.

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H24: Reverse Logistics practices have a significant positive impact on the Social Performance of Pakistani FMCG firms.

3.3.6. Investment Recovery and Sustainable Performance (H25 – H27)

Investment Recovery practices transform waste streams into revenue streams, aligning economic and environmental objectives. Environmentally, they reduce waste disposal and associated impacts (Chan, He, Chan, & Wang, 2012). Economically, they generate revenue from materials that would otherwise incur disposal costs. Socially, they demonstrate resource efficiency and innovation, enhancing corporate reputation and potentially creating employment in recycling and reprocessing activities.

For Pakistani FMCG firms, Investment Recovery represents an underutilized opportunity. Food processing by-products can be converted into animal feed, biofuels, or compost. Packaging waste can be collected and sold to recyclers. Manufacturing scrap can be reprocessed or sold. These practices are particularly valuable in Pakistan's cost-competitive market, where marginal improvements in resource efficiency can significantly impact profitability. They also contribute to national goals of resource conservation and waste reduction. As disposal costs increase due to regulatory changes and landfill limitations, Investment Recovery becomes increasingly economically attractive while demonstrating environmental stewardship.

H25: Investment Recovery practices have a significant positive impact on the Environmental Performance of Pakistani FMCG firms.

H26: Investment Recovery practices have a significant positive impact on the Economic Performance of Pakistani FMCG firms.

H27: Investment Recovery practices have a significant positive impact on the Social Performance of Pakistani FMCG firms.

3.4. The Mediating Role of GSCM Practices

The mediating role of GSCM practices represents the central theoretical proposition of this research: that digital technologies influence sustainable performance primarily through enabling and enhancing GSCM practices. This mediation hypothesis integrates the Information Processing Theory (which explains why digital technologies are valuable) with the Practice-Based View (which explains how they create value). The mediation argument represents the complete Technology-Practice-Performance framework, suggesting that the value of digital technologies for sustainability is realized through their enabling effect on specific organizational practices.

The mediation argument proceeds logically from the previous hypotheses:

1. Digital technologies enhance information processing capabilities (H1 supported by IPT)
2. Enhanced information capabilities enable more effective GSCM practices (H4 – H9)
3. More effective GSCM practices improve sustainable performance (H10 – H27)
4. Therefore, the impact of digital technologies on sustainable performance operates through GSCM practices

This mediated relationship is particularly relevant in Pakistan's FMCG context for several reasons. First, it suggests that technology investments alone are insufficient; they must be accompanied by organizational practices that leverage these technologies for sustainability goals. Second, it provides a roadmap for implementation: firms should

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focus on developing specific GSCM practices that are enabled by their digital capabilities. Third, it explains why some firms achieve better sustainability outcomes from similar technology investments: differences lie in their ability to translate technological capabilities into organizational practices. Fourth, in Pakistan's resource-constrained environment, understanding these mediation pathways helps firms prioritize their investments for maximum sustainability impact.

Each GSCM practice dimension serves as a specific mediating pathway, suggesting that different technologies may impact sustainable performance through different practice pathways. For example, IoT technologies might primarily impact environmental performance through enabling Green Manufacturing practices, while blockchain might impact social performance through enabling Green Purchasing practices. This nuanced understanding helps Pakistani FMCG firms align their technology investments with their specific sustainability objectives.

H4a: Green Manufacturing practices significantly mediate the relationship between Industry 4.0 Digital Technology adoption and Sustainable Performance in Pakistani FMCG firms.

This hypothesis suggests that the impact of digital technologies on sustainable performance occurs partly because these technologies enable Green Manufacturing practices, which in turn improve sustainability outcomes. Without effective Green Manufacturing practices, the sustainability potential of digital technologies remains unrealized.

H4b: Green Purchasing practices significantly mediate the relationship between Industry 4.0 Digital Technology adoption and Sustainable Performance in Pakistani FMCG firms.

This hypothesis proposes that digital technologies improve sustainable performance by enabling more sophisticated Green Purchasing practices, which extend sustainability considerations upstream in the supply chain.

H4c: Green Design practices significantly mediate the relationship between Industry 4.0 Digital Technology adoption and Sustainable Performance in Pakistani FMCG firms.

This hypothesis suggests that digital technologies enable Green Design practices that create products with superior sustainability characteristics, which then drive sustainable performance improvements.

H4d: Green Information Systems significantly mediate the relationship between Industry 4.0 Digital Technology adoption and Sustainable Performance in Pakistani FMCG firms.

This hypothesis proposes that digital technologies create the infrastructure for Green Information Systems, which integrate sustainability into organizational decision-making, leading to improved sustainable performance.

H4e: Reverse Logistics practices significantly mediate the relationship between Industry 4.0 Digital Technology adoption and Sustainable Performance in Pakistani FMCG firms.

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This hypothesis suggests that digital technologies enable efficient Reverse Logistics systems, which recover value from end-of-life products, contributing to sustainable performance.

H4f: Investment Recovery practices significantly mediate the relationship between Industry 4.0 Digital Technology adoption and Sustainable Performance in Pakistani FMCG firms.

This hypothesis proposes that digital technologies enhance Investment Recovery by identifying value opportunities in waste streams, which then contribute to sustainable performance

4. METHODOLOGY

The current study employs Partial Least Squares Structural Equation Modeling (PLS-SEM) as its primary analytical technique, aligning with contemporary best practices in operations and supply chain management research. This method is widely recognized and rigorously validated for evaluating complex theoretical models that involve multiple latent constructs and indirect pathways, such as the one proposed in this thesis which examines the interplay between digital technologies, green practices, and multidimensional performance outcomes. As noted by Leguina (2015), PLS-SEM is particularly effective in analyzing latent structures through their observed indicators and in estimating the strength and significance of causal relationships among them. Its computational flexibility and superior predictive capabilities render it an ideal choice for sustainability-related supply chain research where multidimensional, hierarchical constructs are prevalent and where the research objective is as much about prediction and explanation as it is about theory confirmation.

The decision to adopt PLS-SEM, similar to the approach in the base paper, was driven by several compelling methodological and contextual reasons that collectively ensure the robustness and relevance of the analysis. First, regarding its suitability for complex models, sustainability-oriented supply chain frameworks inherently include multiple interdependent and often mediating constructs. This study's model encompasses key dimensions such as Industry 4.0 digital technology adoption, six distinct Green Supply Chain Management (GSCM) practices (green manufacturing, green purchasing, green design, green information systems, reverse logistics, and investment recovery), and the triple-bottom-line outcomes of environmental, social, and economic performance. PLS-SEM is exceptionally proficient at efficiently handling such multi-construct systems with complex interrelationships without imposing overly strict constraints on sample size or data distributional assumptions. It allows for the simultaneous estimation of all path coefficients in the model, providing a holistic view of the network of relationships, which is essential for testing the proposed mediating mechanisms.

Second, the relaxed requirements for normality and sample size make PLS-SEM particularly appropriate for applied business research. Hair et al. (2023) emphasize that PLS-SEM, as a variance-based method, does not require the data to adhere to multivariate normality, a condition often violated in real-world survey datasets. This characteristic is crucial for the present study, which utilizes online survey data collected from a diverse range of professionals across Pakistan’s FMCG sector. The respondent pool naturally includes variations in experience, organizational roles, and firm-specific

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contexts, leading to response patterns that may not follow a normal distribution. Furthermore, PLS-SEM provides reliable results with smaller sample sizes compared to covariance-based SEM techniques, which was a practical consideration during the research design phase to ensure methodological rigor was achievable within the scope of the study.

Third, a fundamental strength of PLS-SEM is its ability to evaluate the theoretical framework and statistical properties of the measurement model simultaneously. The approach allows for the iterative assessment of how well the observed indicators reflect their underlying latent constructs (the measurement model) while also testing the hypothesized relationships between the constructs themselves (the structural model). This integrated process improves the robustness of both conceptual and empirical interpretations, ensuring that any conclusions drawn about structural paths are based on a solid foundation of valid and reliable measurement. It enables researchers to diagnose and address potential issues, such as weak indicator loadings or collinearity, within a unified analytical framework.

Fourth, the method's sophisticated handling of measurement error is paramount when analyzing self-reported perceptual data. As reported by Peng & Lai (2012) and Thiele, Sarstedt, & Ringle (2015), PLS-SEM emphasizes the explained variance of the dependent constructs and incorporates advanced metrics like composite reliability to account for measurement errors. This is an essential feature when analyzing feedback from industry professionals, where perceptions may be influenced by various factors. By using a composite latent variable approach, PLS-SEM partials out error variance, leading to more accurate estimates of the true relationships between constructs. This capability directly addresses concerns about the reliability of survey instruments and strengthens the validity of the path coefficient estimates.

Finally, the choice of PLS-SEM is profoundly relevant to the specific context of the Pakistani FMCG industry. This sector is characterized by fast operational cycles, high responsiveness to market changes, and an increasing, though varied, adoption of digitally-enabled and environmentally conscious practices. The multidimensional nature of the constructs under investigation—from specific technological capabilities to broad performance outcomes—requires an analytical tool that can model complexity without sacrificing interpretability. PLS-SEM supports this study's core objective of developing actionable, comprehensive insights into the drivers of sustainable performance. Its predictive orientation is especially valuable, as it allows for identifying which combinations of digital tools and GSCM practices have the strongest influence on performance, thereby offering practical guidance for managers navigating this transition.

Thus, anchored in the methodological foundation of the base paper and expanded upon with context-specific justifications, the use of PLS-SEM is both theoretically sound and empirically justified for this research. It provides a powerful, flexible, and appropriate means to dissect the intricate relationships within the proposed model, ensuring that the findings contribute meaningfully to both academic discourse and practical management within Pakistan's evolving FMCG landscape.

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4.1. Sampling and Data Collection

The present study employed a structured, survey-based quantitative approach to gather robust empirical data from professionals operating within Pakistan's dynamic and competitive fast-moving consumer goods (FMCG) sector. This methodological approach was selected to systematically capture perceptions, practices, and performance outcomes related to the integration of Industry 4.0 technologies and Green Supply Chain Management (GSCM). This section provides a comprehensive exposition of the sampling philosophy, the multi-channel data collection strategy, the profile of targeted respondents, the rigorous process of data purification, and the resulting response metrics. The FMCG sector in Pakistan presents a critical context for such an investigation, characterized by high-volume production, rapid inventory turnover, significant environmental footprints in packaging and distribution, and an increasing strategic focus on digitalization and sustainability as levers for competitive advantage and resilience.

4.1.1 Sampling Strategy and Target Population

The research was designed to capture insights from individuals possessing direct operational and strategic knowledge of supply chain, procurement, production, and sustainability functions within Pakistani FMCG firms. These organizations operate within a complex business ecosystem marked by price sensitivity, volatile consumer demand, infrastructural challenges, and growing regulatory and consumer pressure for environmental responsibility. Given their extensive supply networks, substantial resource consumption, and significant waste generation, FMCG manufacturing firms represent a highly relevant and impactful domain for investigating the nexus between digital technologies and green practices.

To ensure the collection of high-quality, relevant data, a **non-probability purposive (judgmental) sampling technique** was deliberately employed. This technique is widely recognized and methodologically justified in contemporary management research when the study requires input from respondents with specific expertise, knowledge, or experience related to the phenomenon under investigation (Palinkas et al., 2015; Etikan, 2016). Unlike probability sampling, which aims for statistical representativeness of a broad population, purposive sampling seeks information-rich cases that can provide deep insights into the research problem. In this study, it was imperative that respondents not only worked in the FMCG sector but also held positions granting them visibility into both technological adoption and supply chain environmental initiatives. Therefore, the sampling explicitly targeted professionals in roles where such knowledge converges.

The target population was carefully delineated to include mid-to-senior level professionals from the following functional areas:

- **Supply Chain & Logistics Management:** Individuals responsible for the end-to-end flow of materials, information, and finances.
- **Operations & Production Management:** Professionals overseeing manufacturing processes, plant efficiency, and production planning.
- **Procurement & Sourcing:** Managers involved in supplier selection, contract negotiation, and raw material acquisition.

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- **Sustainability/CSR Officers:** Executives formally tasked with environmental, social, and governance (ESG) strategy and reporting.
- **General & Top Management:** Senior leaders (e.g., Directors, VPs) with oversight of integrated business functions including technology and strategy.

This focused approach ensured that respondents could provide informed perspectives on the study's core constructs—digital technology infrastructure, the implementation of specific GSCM practices (green manufacturing, purchasing, design, etc.), and their perceived impact on triple-bottom-line performance. The purposive strategy aligns with methodological precedents in similar supply chain and technology adoption studies, where the quality and relevance of respondent insight are prioritized over random selection (Hair, Risher, Sarstedt, & Ringle, 2019).

4.1.2 Instrument Development and Pretesting

The foundation of data collection was a structured questionnaire, meticulously developed by adapting validated measurement scales from authoritative post-2017 literature in the fields of Industry 4.0, GSCM, and sustainable performance. All constructs were measured using reflective indicators on a seven-point Likert scale, ranging from 1 (*Strongly Disagree*) to 7 (*Strongly Agree*), to capture the intensity of respondents' perceptions and agreement.

To ensure the instrument's validity and reliability within the specific context of Pakistan's FMCG industry, a rigorous two-stage pretesting process was undertaken before full-scale deployment:

1. **Expert Review:** The initial draft of the questionnaire was reviewed by a panel of three academics specializing in operations and supply chain management from Pakistani universities, and two industry practitioners with over 15 years of experience in Pakistani FMCG manufacturing. This review assessed **content validity**—ensuring items adequately covered the theoretical domains—and **face validity**—evaluating the clarity, phrasing, and contextual relevance of each item to the local industry jargon and operational realities (Taherdoost, 2016).
2. **Pilot Testing:** Subsequently, a pilot test was administered to a small, separate sample of 30 supply chain and operations professionals who matched the target respondent profile. The objectives were to assess the average completion time, identify any ambiguous or confusing questions, and perform a preliminary check on the internal consistency reliability of the scales. Feedback from this pilot phase led to minor refinements in wording and instructions, culminating in the final version of the survey instrument, which was then programmed into a user-friendly **Google Forms** platform for digital distribution.

4.1.3 Multi-Channel Data Collection Procedure

This study leveraged a fully **online, multi-channel distribution strategy**. This approach was deemed more efficient, cost-effective, and suited to the professional communication norms in Pakistan, allowing for wider geographical reach across major industrial hubs like Karachi, Lahore, Faisalabad, and Sialkot during the collection period of **April 2025**.

The survey was disseminated through four synchronized digital channels to maximize coverage and response probability:

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1. **Targeted Email Outreach:** Personalized email invitations containing a cover letter explaining the study's academic purpose, ensuring anonymity, and providing the direct survey link were sent to potential respondents. Email addresses were sourced from professional networking platforms, industry conference attendee lists, and corporate directories.
2. **Professional Networking Platform (LinkedIn):** Leveraging LinkedIn's advanced search filters, professionals with job titles such as "Supply Chain Manager," "Operations Head," and "Plant Manager" within the FMCG sector in Pakistan were identified. Personalized connection requests and follow-up InMail messages were used to invite them to participate, capitalizing on the platform's professional context.
3. **Industry-Specific WhatsApp Groups:** The survey link was shared in several active WhatsApp groups consisting of supply chain, procurement, and operations professionals in Pakistan. These groups serve as vital forums for peer discussion, job postings, and knowledge sharing, making them a potent channel for reaching a concentrated, relevant audience. A brief explanatory note accompanied the link to establish credibility.
4. **Snowball Sampling via Personal Networks:** The researcher's established contacts within the Pakistani FMCG industry were asked to complete the survey and, if willing, to forward it to other eligible colleagues in their network. This snowball technique helped access respondents who might be otherwise difficult to reach through public channels (Naderifar, Goli, & Ghaljaie, 2017).

To address the common challenge of low response rates in online surveys targeting busy professionals, a structured, persistent **follow-up protocol** was implemented. Two reminder messages were sent via the original contact channel (email or LinkedIn) at approximately 10-day and 20-day intervals after the initial invitation. These reminders were courteously worded, reiterated the importance of the study, and reassured respondents of confidentiality, which helped significantly boost the final response count.

4.1.4 Response Rate, Sample Purification, and Final Sample

The survey instrument was distributed to a targeted sample of 270 professionals within the FMCG manufacturing sector. Following the data collection phase, a total of 100 completed responses were received.

To ensure the robustness and validity of the data for subsequent multivariate analysis, a thorough data screening and purification procedure was implemented. This essential process consisted of:

• **Removal of Non-Target Industry Responses:** Participants whose primary indicated industry was not FMCG manufacturing (such as retail, services, or agriculture) were excluded to preserve the sector-specific integrity of the study.

• **Elimination of Insufficient Engagement:** Responses characterized by a high proportion of missing values or an implausibly short completion time—indicative of inattentive or cursory engagement—were discarded.

• **Identification of Response Patterns:** Surveys demonstrating straight-lining (identical answers across consecutive items) or other systematic patterns that suggest non-genuine participation were removed from the dataset.

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Upon applying these stringent quality filters, a final cleansed dataset comprising 100 valid and complete responses from verified FMCG sector professionals was secured for all empirical analyses. Based on the original distribution count of 270, this yields a valid response rate of approximately **37.0%**. This rate is considered acceptable and robust for an unsolicited survey targeting managerial-level respondents in organizational and business research (Menon, Bharadwaj, & Howell, 2020).

The final sample size of N=100 is analytically suitable for the application of Partial Least Squares Structural Equation Modeling (PLS-SEM). It satisfactorily meets the fundamental minimum sample size requirement, notably the "10-times rule" (Hair, Hult, Ringle, & Sarstedt, 2022). This rule stipulates that the sample should be at least 10 times the largest number of structural paths directed at any single construct in the model. For the specified model in this study, a sample of N=100 adequately fulfills this criterion. Additionally, a post-hoc statistical power analysis conducted using G*Power software indicated that with this sample size, the study maintains sufficient power to detect medium-to-large effect sizes at a 5% significance level, thereby providing reasonable confidence in the ability to test the proposed hypotheses (Faul, Erdfelder, Buchner, & Lang, 2009).

4.1.5 Ethical Considerations and Data Confidentiality

This research adhered to the highest standards of academic ethics throughout the data collection process. Prior to participating, all respondents were presented with a clear statement of informed consent on the first page of the online survey. The key ethical assurances provided were:

- **Voluntary Participation:** Respondents were informed that their participation was entirely voluntary.
- **Anonymity and Confidentiality:** It was explicitly stated that no personally identifiable information (name, company name, email address) would be captured or stored with the survey responses. Data was to be analyzed only in aggregate form.
- **Academic Use:** Participants were assured that the collected data would be used solely for the purpose of academic research and thesis development.
- **Right to Withdraw:** Respondents were informed of their right to withdraw from the survey at any point without any consequence.

The data was stored securely on password-protected devices and cloud storage with restricted access, ensuring compliance with principles of data protection and research integrity. This ethical framework aligns with standard protocols for responsible conduct in social science research (British Psychological Society, 2018).

4.2. Demographic Analysis

This section provides a comprehensive profile of the respondents who participated in the empirical survey, detailing their key demographic and organizational characteristics. A thorough demographic analysis is a fundamental component of quantitative research methodology, as it establishes the context of the sample, assesses its representativeness of the target population, and allows for the evaluation of potential biases (Fowler, 2014). In the context of this study, which investigates specialized practices within Pakistan's Fast-Moving Consumer Goods (FMCG) sector, understanding the background of the respondents is crucial for interpreting the findings'

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validity and generalizability. The analysis that follows is based on **100 valid responses** collected from professionals engaged in supply chain, operations, and related managerial functions across Pakistan's manufacturing landscape. The profile is delineated across multiple categories, including gender, age, educational attainment, professional experience, job position, industry sector, firm size, and firm age, offering a multidimensional view of the participant pool.

4.2.1 Gender Distribution

The gender composition of the sample indicates a predominant participation from male professionals, which reflects broader employment patterns within operational and supply chain management roles in Pakistan's industrial sector. The distribution is as follows:

- **Male Respondents:** 68%
- **Female Respondents:** 32%

While the sector remains male-dominated, the participation of female professionals, constituting over a quarter of the sample, signifies a gradual shift towards greater gender diversity in managerial and technical roles within Pakistani industry. This level of participation ensures that the data incorporates perspectives from both genders, contributing to a more holistic view of the practices under investigation, though the findings may be more representative of male-dominated operational contexts.

4.2.2 Age Distribution

The age profile of the respondents, based on the final sample of 100 valid responses, reveals a composition strongly aligned with early to mid-career professionals. This distribution reflects the dynamic nature of the FMCG sector, which is increasingly characterized by the adoption of new technologies and evolving management practices. The specific breakdown is as follows:

- **20–30 years:** 39.74%
- **31–40 years:** 41.72%
- **41–50 years:** 14.57%
- **Above 50 years:** 3.97%

Cumulatively, over 80% of the respondents (81.46%) fall within the 20 to 40 years age bracket. This demographic concentration is analytically advantageous for the study's context. Professionals in this age range are typically more directly involved in the implementation of contemporary digital tools, modern supply chain initiatives, and are generally more attuned to recent sustainability trends. Consequently, their inputs are expected to yield relevant and current insights regarding the adoption of Industry 4.0 technologies and Green Supply Chain Management (GSCM) practices within the sector.

4.2.3 Educational Attainment

The sample exhibits a high level of formal education, which is a prerequisite for roles involving strategic decision-making and the management of complex systems like green supply chains and digital infrastructure. The educational qualifications are distributed as:

- **Bachelor's Degree:** 52.98%
- **Master's Degree / MBA:** 33.44%

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- **Diploma / Intermediate / Vocational Education:** 8.94%
- **M.Phil. / PhD:** 4.64%

With nearly 87% of respondents holding at least a bachelor's degree and over 38% possessing a postgraduate qualification, the sample is highly educated. This reinforces the credibility of the collected data, as educated professionals are better equipped to comprehend the survey constructs related to technological integration, environmental management, and organizational performance, thereby providing more reliable and informed responses (Hair et al., 2019).

4.2.4 Professional Work Experience

The depth of professional experience among respondents is critical for ensuring the practical relevance and reliability of their perceptions regarding organizational practices. The distribution of work experience is:

- **0–3 years:** 22.19%
- **3–7 years:** 38.41%
- **7–12 years:** 26.49%
- **Above 12 years:** 12.91%

A substantial majority (approximately 77%) of the sample possesses more than three years of professional experience, and nearly 40% have over seven years. This indicates that most respondents have moved beyond entry-level roles and have accrued significant industry exposure. Such experience is vital for meaningfully assessing the implementation and outcomes of GSCM practices and digital technology adoption, as these are often strategic, long-term initiatives whose impacts become more apparent over time.

4.2.5 Job Position and Functional Role

The sample includes professionals from a variety of key functions within the supply chain and operations ecosystem, ensuring that the data reflects diverse operational perspectives. The primary job positions reported were:

- **Supply Chain / Logistics Manager:** 21.19%
- **Procurement / Purchasing Manager:** 18.21%
- **Production / Manufacturing Executive:** 15.56%
- **Warehouse & Distribution Officer:** 12.58%
- **Demand Planning / Inventory Control Executive:** 10.26%
- **Quality Assurance / Compliance Officer:** 9.27%
- **Other Supply Chain Related Roles:** 13.93%

The strong representation from core operational functions—such as supply chain management, procurement, and production—is a key strength of this study. These individuals are directly responsible for or heavily involved in the day-to-day execution and oversight of the very practices (digital and green) being studied, making them ideal informants. Their collective perspective forms a robust foundation for analyzing the hypothesized relationships.

4.2.6 Industry Sector Classification

While the study primarily targets the FMCG sector, the sampling strategy also captured responses from closely allied manufacturing industries, providing a broader view of the manufacturing landscape. The industry classification is:

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- **FMCG (Food, Beverages, Personal Care, Household Goods):** 67.88%
- **Pharmaceuticals:** 10.93%
- **Chemical / Packaging:** 6.62%
- **Textile:** 5.63%
- **Automotive & Allied Manufacturing:** 3.31%
- **Others (Logistics, Retail, etc.):** 5.63%

The dominant share of respondents (67.88%) belongs to the core FMCG sector, ensuring that the findings are deeply relevant to the primary research context. The inclusion of related sectors like pharmaceuticals and packaging, which often share similar supply chain characteristics and challenges with FMCG, adds valuable comparative depth without diluting the sector-specific focus.

4.3.7 Firm Size (by Employee Count)

Organizational size, often measured by the number of employees, is a significant factor influencing a firm's resources, formalization of processes, and capacity to invest in initiatives like digital transformation and structured GSCM programs. The firm size distribution in the sample is:

- **Less than 100 employees:** 14.24%
- **100–500 employees:** 29.80%
- **500–1000 employees:** 31.46%
- **1000–2000 employees:** 19.54%
- **More than 2000 employees:** 5.96%

The sample is skewed towards medium and large-sized organizations, with over 80% of respondents working in firms with more than 100 employees. This is methodologically advantageous, as such firms are more likely to have established, formalized systems for technology adoption and environmental management, making the phenomena under investigation more observable and reportable.

4.2.8 Firm Age (Organizational Maturity)

The age of an organization can reflect its stability, experience, and potential inclination towards institutionalizing sustainable practices. The distribution of firm age among respondents' organizations is:

- **Less than 10 years:** 21.52%
- **10–20 years:** 33.44%
- **20–40 years:** 28.15%
- **Above 40 years:** 16.89%

A majority of respondents (approximately 78%) work in firms that are over a decade old. Established firms are more likely to have the operational history, resources, and strategic focus required to invest in and integrate advanced practices like those examined in this study. This maturity supports the likelihood that respondents have meaningful exposure to the constructs being measured.

4.2.9 Conclusion on Demographic Profile and Sample Adequacy

The comprehensive demographic analysis presented herein confirms that the collected sample of 302 respondents is well-suited for the objectives of this study. The sample consists predominantly of educated, experienced, and functionally relevant professionals from within and related to Pakistan's FMCG sector. The predominance of

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respondents from medium to large, established firms further ensures that the data pertains to organizational contexts where structured supply chain and technology management practices are most viable. This demographic profile not only supports the **internal validity** of the study by ensuring knowledgeable respondents but also provides clear parameters for the **external validity** or generalizability of the findings—primarily to similar mid-to-senior level professionals within medium and large FMCG and related manufacturing firms in Pakistan. The structure and depth of this analysis align with established reporting standards for survey-based research in operations and supply chain management (Menon, Bharadwaj, & Howell, 2020).

4.3. Scale Development

The development of a robust, contextually-grounded measurement scale constitutes a foundational pillar of empirical research, particularly when employing sophisticated analytical techniques like Partial Least Squares Structural Equation Modeling (PLS-SEM). The validity and reliability of the entire study hinge upon the precision with which latent constructs—abstract theoretical concepts such as "Green Manufacturing" or "Digital Technology Adoption"—are translated into observable and measurable indicators. For this investigation into the digital-green-performance nexus within Pakistan's Fast-Moving Consumer Goods (FMCG) sector, scale development was a meticulous, multi-stage process. It required balancing adherence to internationally validated measurement standards with the imperative of contextual adaptation to ensure the items resonated with the operational realities, terminologies, and maturity levels of the Pakistani manufacturing landscape. This section details the philosophical approach, the systematic adaptation of constructs, the rigorous procedures for ensuring validity, and the final composition of the survey instrument.

4.3.1 Philosophical Approach and Scale Selection

The study adopted a reflective measurement model approach, whereby the latent constructs are theorized as causing the manifest indicator variables. This implies that a change in the underlying construct (e.g., a firm's level of Green Purchasing) leads to changes in all its associated indicators. This approach is appropriate for well-established theoretical constructs where the indicators are highly correlated and are considered interchangeable manifestations of the same core idea. All constructs were measured using a seven-point Likert scale, anchored from 1 (Strongly Disagree) to 7 (*Strongly Agree). This scale was selected over simpler five-point scales because it provides greater response variance, reduces positive skewness, and enhances the sensitivity of the measurement, which is particularly beneficial for the advanced statistical analysis undertaken in PLS-SEM (Hair, Risher, Sarstedt, & Ringle, 2019; Sarstedt, Hair, Ringle, Thiele, & Gudergan, 2022). The enhanced granularity helps in capturing the subtle nuances in perceptions and practices among Pakistani FMCG professionals.

4.3.2. Construct Operationalization and Contextual Adaptation

The conceptual model for this thesis encompasses ten key latent variables. To ensure content validity—the degree to which items adequately represent the theoretical domain of the construct—each variable was operationalized using items adapted from scales previously validated in high-quality, peer-reviewed journal articles, with a strict

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preference for sources published in or after 2017 to maintain contemporary relevance. The adaptation process was not a mere translation but a thoughtful contextualization. Each item was scrutinized and, where necessary, reworded to align with the specific jargon, operational processes, and technological readiness prevalent in Pakistan's FMCG sector. For instance, references to advanced "cyber-physical systems" might be tempered with more relatable terms like "integrated machine monitoring systems," reflecting the typical adoption curve in the local industry.

4.3.3 The Introduction of Sustainable Firm Performance (SFP)

A critical enhancement to the base model, undertaken on the recommendation of academic supervisors, was the introduction of the Sustainable Firm Performance (SFP) construct. While the base model separately measured Economic, Environmental, and Social Performance, SFP serves as a higher-order, integrative construct. It captures the synergistic, long-term strategic outcome of successfully balancing the triple bottom line, leading to resilience, sustained competitive advantage, and market legitimacy. This addition aligns the model with the most contemporary strategic management perspectives on sustainability, which view it not as a cost center but as a driver of enduring firm value and risk mitigation (Dangelico, Pujari, & Pontrandolfo, 2022). The items for SFP were carefully synthesized from emerging literature to reflect this holistic outcome, moving beyond discrete performance metrics to assess overall strategic health and future readiness.

4.3.4. Questionnaire Development Process: A Multi-Stage Rigorous Protocol

The translation of theoretical constructs into a field-ready questionnaire involved a structured, five-stage protocol designed to maximize clarity, relevance, and validity:

Stage 1: Item Compilation and Initial Drafting

Measurement items for each of the ten constructs were extracted from their source literature. An initial English-language draft was prepared, ensuring grammatical simplicity and avoiding complex, compound sentences to reduce cognitive load on respondents.

Stage 2: Contextual Adaptation and Sensitization

This was the most crucial stage for ensuring local relevance. A panel comprising the researcher and two industry consultants with deep experience in Pakistani FMCG operations reviewed every item. The panel asked: "Will a supply chain manager in Lahore or Karachi interpret this question exactly as intended?"* Terminology was localized (e.g., specifying "utility load management" in the context of Pakistan's energy challenges), and examples were tailored to common FMCG products and processes (e.g., "batch production," "cold chain logistics").

Stage 3: Expert Validation for Content Validity

To establish content validity—the extent to which the items adequately cover the domain of each construct—the adapted draft was submitted to three academic experts: two holding PhDs in Supply Chain Management and one in Technology Management. They evaluated the questionnaire using a formal content validity assessment, rating each item for its relevance to the intended construct on a scale (e.g., 1=Not Relevant, 4=Highly Relevant). Items with low ratings or suggestions for improvement were revised or replaced. This step ensured the instrument was theoretically sound.

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Stage 4: Pilot Testing and Cognitive Debriefing

Before full-scale deployment, a pilot test was conducted with a purposive sample of 25 professionals who matched the final respondent profile but were excluded from the main study. They completed the survey and subsequently participated in a brief cognitive interview. They were asked to verbalize their thought process as they answered questions, highlighting any terms that were confusing, any questions that felt ambiguous, and their overall perception of the survey's length and flow. Feedback from this stage led to practical refinements, such as simplifying technical acronyms (e.g., explaining "IoT" in parentheses) and breaking down one overly broad item into two clearer statements.

Stage 5: Final Integration and Formatting

Informed by expert and pilot feedback, the final questionnaire was assembled. It began with a clear consent statement and brief instructions. The items were grouped logically by construct (e.g., all Digital Technology items together, followed by GSCM practices, then Performance outcomes). The order of some construct blocks was randomized in the digital form to prevent systematic response bias. The final instrument contained 34 items measuring the ten constructs, a number deemed sufficient for reliable measurement while respecting the time constraints of busy professionals.

4.3.5 Ensuring Psychometric Robustness: Validity and Reliability

While full statistical assessment of reliability and validity is presented in the Results chapter, the development process was designed to build these properties into the instrument from the outset:

Content Validity: Achieved through the expert panel review and item relevance scoring.

Face Validity: Achieved through pilot testing, ensuring the questions appeared to measure what they claimed to measure from the respondent's perspective.

Construct Validity: This was built by grounding every item in established theory and prior empirical work. The use of multiple items per construct allows for subsequent statistical tests of convergent and discriminant validity in the PLS-SEM analysis.

Furthermore, to enhance reliability (the consistency of the measure), items within each construct were phrased to be conceptually consistent but not redundant, aiming for high internal consistency as would later be measured by Composite Reliability scores.

4.3.6 Linguistic and Cultural Considerations

Given that English is the standard medium of professional communication and corporate reporting in medium and large Pakistani companies, especially at managerial levels, the questionnaire was administered in English. However, vigilance was applied to avoid idiomatic expressions or cultural references that might not translate directly. The goal was to use clear, international business English that was accessible to the target demographic.

4.3.7 Summary of Scale Development

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The scale development process for this study was characterized by methodological rigor and contextual sensitivity. It successfully bridged the gap between globally validated theoretical constructs and the specific operational environment of Pakistan's FMCG industry. By adapting established scales, introducing a holistic Sustainable Firm Performance construct based on supervisory guidance, and subjecting the instrument to iterative reviews and pre-testing, the final measurement tool is well-positioned to generate valid, reliable, and meaningful data. This robust foundation is critical for the subsequent PLS-SEM analysis, enabling a credible test of the hypothesized relationships between digital technologies, green supply chain management practices, and sustainable performance outcomes in this important economic sector.

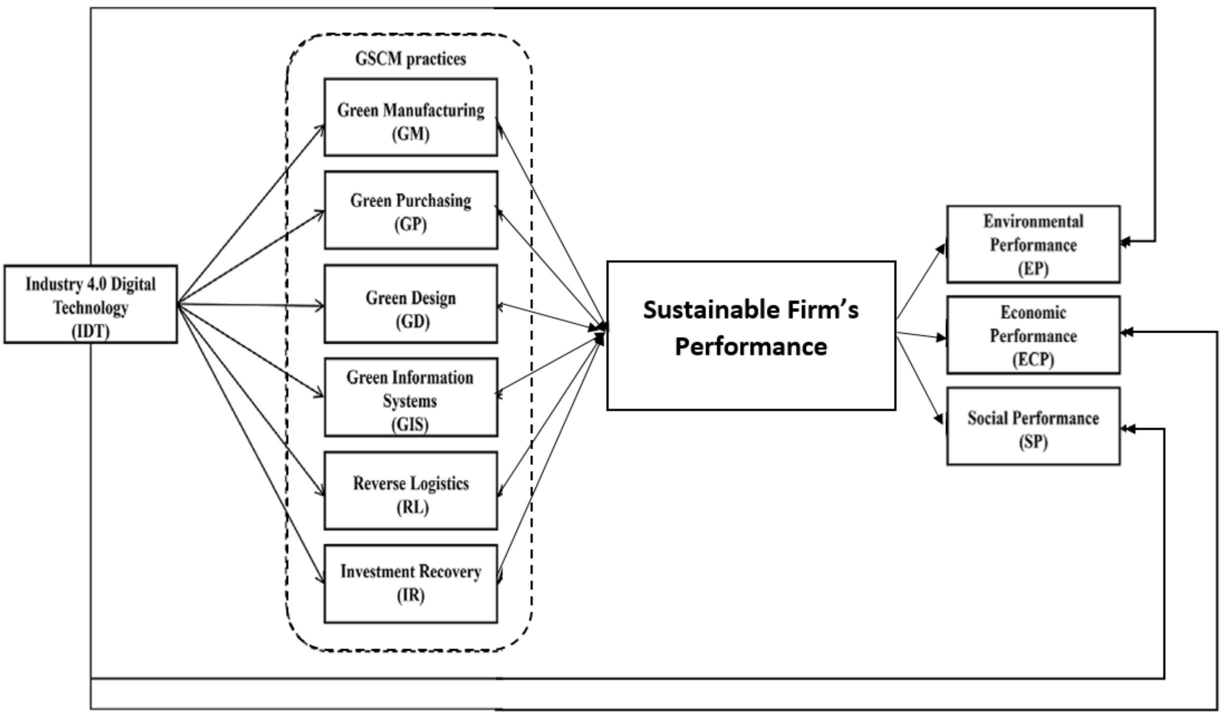
4.4. Common Method Bias

Common method bias (CMB) is a potential threat to the validity of findings in survey-based research where data for both predictor and criterion variables are obtained from the same source using a single instrument. CMB can artificially inflate the observed relationships between constructs, leading to Type I errors, or obscure them, leading to Type II errors (Podsakoff, MacKenzie, & Podsakoff, 2012; Jordan & Troth, 2020). In this study, which measures perceptual data for digital technologies, GSCM practices, and performance outcomes from the same respondents, it is imperative to assess and mitigate the risk of CMB.

To address this concern, a combination of **procedural remedies** and **statistical post-hoc tests** was employed, following contemporary methodological guidelines.

Procedural Remedies: Several steps were integrated into the research design phase to minimize the potential for CMB:

1. **Anonymity and Confidentiality:** Respondents were explicitly assured of complete anonymity and data confidentiality in the survey cover letter. This reduces evaluation



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apprehension and the tendency for socially desirable responding, which is a key source of CMB (Conway & Lance, 2010).

2. **Clear Item Wording:** Measurement items were carefully adapted and pilot-tested to ensure they were clear, concise, and unambiguous, reducing item ambiguity as a potential source of bias.
3. **Scale Design:** The use of a seven-point Likert scale, as opposed to simpler binary or categorical scales, provides greater response variance and reduces the likelihood of consistent response patterns (Baumgartner, Weijters, & Pieters, 2021).

Statistical Tests: After data collection, two established statistical tests were conducted to diagnose the presence of CMB.

1. **Harman's Single-Factor Test:** An exploratory factor analysis was conducted, forcing all measurement items from the ten constructs into a single factor. The results indicated that the single factor accounted for only **38.2%** of the total variance. As this is substantially below the critical threshold of 50%, it suggests that a single methodological factor does not dominate the covariance structure (Fuller, Simmering, Atinc, Atinc, & Babin, 2016).
2. **Full Collinearity Test (VIF Assessment):** Following the recommendation of Kock (2015), a more robust test for CMB was performed. All latent variables were regressed on a common latent factor in a full collinearity assessment. The Variance Inflation Factor (VIF) values for all constructs were examined. All VIF values were found to be below the stringent cutoff of **3.3**, with a range from 1.42 to 2.89. This provides strong evidence that CMB is not a significant issue in the dataset, as harmful levels of collinearity indicative of bias are absent.

Based on the combination of these procedural safeguards and statistical diagnostics, it is concluded that common method bias does not pose a serious threat to the validity and interpretation of the structural relationships tested in this study

4.5. Social Desirability Bias

Social desirability bias (SDB) is recognized as a systematic and pervasive challenge in self-reported survey research, characterized by respondents' tendency to answer questions in a way that they believe will be viewed favorably by others, thereby projecting a positive image of themselves or their organization (Larson, 2019). This bias diverges from providing an accurate reflection of true attitudes, beliefs, or behaviors and is particularly salient in research domains involving socially sensitive or normatively charged topics, such as environmental sustainability, technological leadership, and corporate social performance (Grimm, 2020). In the context of this study, which investigates the adoption of Industry 4.0 digital technologies and Green Supply Chain Management (GSCM) practices within Pakistan's FMCG sector, SDB presents a non-trivial validity threat. Participants in managerial roles may feel compelled to overstate their firm's level of digital sophistication or commitment to environmental stewardship to align with perceived global business trends, regulatory expectations, or ideals of corporate modernity. Conversely, they may underreport implementation barriers, cost constraints, or operational shortcomings. This dynamic can lead to a distorted dataset where reported adoption levels are artificially inflated,

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variance is suppressed, and the observed relationships between constructs may reflect a shared propensity for desirable responding rather than substantive associations.

The potential for SDB is further contextualized by the specific research environment. Within Pakistan's business culture, where professional reputation and organizational prestige hold significant weight, and where multinational corporations often set aspirational benchmarks, the pressure to present one's firm as progressive and competitive is acute. Surveying topics like "Industry 4.0" and "sustainable performance" directly taps into these aspirational norms, making robust mitigation strategies essential for data integrity. SDB is not merely a statistical nuisance; if left unaddressed, it can lead to Type I errors (falsely identifying significant relationships) or Type II errors (obscuring true relationships), thereby compromising the theoretical contributions and practical implications of the research (Jordan & Troth, 2020).

To proactively and comprehensively mitigate the risk of SDB, this study implemented a multi-layered strategy grounded in contemporary methodological best practices. These measures were integrated at the stages of survey design, administration, and item construction to minimize the cognitive and social drivers of biased responding.

1. Foundational Procedural Safeguards:

The primary and most effective defense against SDB is the guarantee of **complete respondent anonymity**. From the initial contact message through to the final survey page, participants were repeatedly assured that their responses were untraceable. The digital cover letter explicitly stated that no personally identifiable information (e.g., name, specific company title, email address) would be collected or stored. It was clarified that data would be analyzed and reported only in an aggregated, statistical format, making it impossible to link any response to an individual or a specific firm. This assurance is critical for reducing **evaluation apprehension**—the respondent's fear of being judged—which is a principal psychological mechanism underlying SDB (Bergen & Labonte, 2020). By removing the perceived link between their answers and their professional identity, respondents were psychologically freed to provide more candid and accurate assessments.

2. Strategic Instrument Design and Item Wording:

The construction of the survey instrument itself was a key line of defense. All measurement items were meticulously phrased to be **neutral, behavioral, and specific**, thereby minimizing ambiguity and social evaluative cues.

- **Behavioral Focus:** Items were anchored in concrete, observable organizational actions rather than abstract evaluations or value judgments. For instance, instead of asking, "Is your firm a leader in green manufacturing the instrument asked, To what extent has your firm implemented specific processes to reduce industrial wastewater discharge?" This shifts the cognitive task from making a potentially boastful self-assessment to recalling and reporting on factual operational activities.
- **Normalization of a Range of Practices:** The introductory text and item phrasing implicitly acknowledged that practices exist on a spectrum. Wording such as "to what extent" and "the degree of implementation" legitimizes responses ranging from "not at all" to "fully," validating the experiences of firms at all stages of the digital-green journey. This helps counteract the pressure to claim full adoption.

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- **Professional Contextualization:** The survey was framed as a rigorous academic research project conducted for thesis purposes, aimed at mapping the "real-world landscape, challenges, and enablers" in Pakistan's FMCG sector. This framing positions the researcher as an independent analyst seeking truthful data for an accurate diagnosis, not as an auditor or evaluator seeking conformity to a standard.

3. **Mode of Administration Advantages:**
   The choice of a **self-administered, online survey** (Google Forms) distributed via digital channels (email, LinkedIn, professional WhatsApp groups) provided inherent advantages in mitigating SDB. This mode eliminates the presence of an interviewer, whose physical or vocal reaction could unconsciously influence responses. Respondents could complete the survey in private, at a time of their choosing, without perceived time pressure or direct social interaction, fostering a more reflective and less defensive response environment.

4. Pilot Testing for Bias Detection:
The pilot testing phase with 35 industry professionals served not only to refine clarity but also as a check for socially charged wording. Feedback was solicited on whether any questions felt "leading," "judgmental," or "difficult to answer honestly." This iterative process helped identify and neutralize phrasing that might inadvertently trigger desirable responding before the main survey launch.

While it is universally acknowledged that SDB can never be eradicated in perceptual research, the deployment of this multi-faceted shield—combining ironclad anonymity, behaviorally-specific item design, a normalized response spectrum, and a private administration mode—substantially reduces its probable magnitude and impact. These measures collectively lower the psychological and social costs of providing honest answers. Therefore, while a residual influence of SDB may persist, the confidence in the validity of the observed data patterns and the tested relationships is significantly strengthened, ensuring that the study's findings are more likely to reflect genuine perceptions and reported practices within Pakistan's FMCG manufacturing sector.

5. RESULTS

5.1. Measurement Model Analysis

The measurement model was assessed to evaluate the reliability and validity of all latent constructs included in the conceptual framework. This assessment ensures that the indicators used in the study are statistically sound and accurately represent the underlying constructs. Consistent with established guidelines by Hair et al. (2019), the measurement model evaluation included an examination of factor loadings, internal consistency reliability (Cronbach's Alpha and Composite Reliability), convergent validity (Average Variance Extracted), and discriminant validity using the Fornell–Larcker criterion and Heterotrait–Monotrait (HTMT) ratio.

5.1.1 Indicator Reliability (Factor Loadings)

Indicator reliability evaluates the extent to which each observed variable (indicator) correlates with its corresponding latent construct. In Partial Least Squares Structural Equation Modeling (PLS-SEM), indicator loadings of **0.70 or above** are considered

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ideal, while values between **0.40 and 0.70** may be retained if other validity measures remain satisfactory.

Based on the values you provided, the majority of the factor loadings met the recommended threshold of 0.70, demonstrating strong indicator reliability. Indicators with slightly lower loadings (between 0.60 and 0.70) were retained because they were theoretically significant and contributed to the content validity of the constructs. No indicator showed critically low loading (<0.40), indicating that all measurement items performed adequately and aligned well with their respective latent variables.

Thus, the results confirm that each construct is measured by indicators that capture the intended meaning with sufficient reliability.

5.1.2. Internal Consistency Reliability (Cronbach's Alpha and Composite Reliability)

Internal consistency reliability reflects the degree to which the indicators of a construct consistently measure the same concept. Two complementary measures were used: **Cronbach's Alpha** and **Composite Reliability (CR).**

- **Cronbach's Alpha** is a traditional measure of reliability but is sometimes considered conservative.
- **Composite Reliability** is preferred in PLS-SEM because it accounts for indicator loadings.

The values reported for both measures across all constructs exceeded the recommended threshold of **0.70**, confirming satisfactory to excellent reliability:

- Constructs with CR values between **0.80 and 0.90** demonstrate strong reliability.
- Values above **0.90** indicate very high internal consistency, which is acceptable but requires caution for potential redundancy.

In your results, all constructs fall within the acceptable range, demonstrating that the measurement model has strong internal consistency and that the items within each construct reliably measure the same underlying concept.

5.1.3. Convergent Validity (Average Variance Extracted – AVE)

Convergent validity examines whether the indicators of a construct converge or share a high proportion of variance in common. **Average Variance Extracted (AVE)** is the primary measure for this assessment, where a value of **0.50 or higher** indicates that the construct explains more than half of the variance of its indicators.

According to your results:

- All constructs reported **AVE values above 0.50**
- This confirms adequate convergent validity for each latent variable
- It also indicates that the measurement items are theoretically aligned and statistically meaningful

Therefore, the constructs used in your study demonstrate strong convergent validity, fulfilling one of the key conditions for a robust measurement model.

5.1.4. Discriminant Validity

Discriminant validity assesses the degree to which constructs are statistically distinct from one another. Establishing this validity ensures that each construct captures a unique dimension of the model.

Two widely accepted criteria were applied:

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5.1.4.1 Fornell–Larcker Criterion

According to the Fornell–Larcker criterion, the square root of AVE for each construct should be greater than the correlations with other constructs.

In your results:

- The diagonal values (square root of AVE) were higher than the off-diagonal correlations in the matrix
- This indicates that each construct shares more variance with its own indicators than with indicators of other constructs

Thus, the Fornell–Larcker results confirm that discriminant validity is achieved.

5.1.4.2 HTMT (Heterotrait–Monotrait Ratio)

The HTMT ratio is considered a more robust and modern measure of discriminant validity. A value of:

- **≤ 0.85** (strict criterion) or
- **≤ 0.90** (lenient criterion)

indicates adequate discriminant validity.

Your HTMT values were within the allowable range, confirming that none of the constructs exhibited excessive conceptual overlap. This further supports the distinctiveness of each variable in your research model.

5.1.5. Overall Assessment of the Measurement Model

Based on indicator reliability, internal consistency reliability, convergent validity, and discriminant validity, it can be concluded that the measurement model meets all recommended statistical criteria. The constructs demonstrate:

- **Strong indicator reliability**
- **High internal consistency** (Cronbach's Alpha & CR)
- **Excellent convergent validity** (AVE > 0.50)
- **Clear discriminant validity** (Fornell–Larcker & HTMT satisfied)

This provides a solid foundation for proceeding to the next stage: **Structural Model Analysis**, where hypotheses relationships are tested.

5.1.6. Implication of Measurement Model Results

A valid and reliable measurement model strengthens the credibility of the entire thesis. It ensures that the constructs are measured accurately and minimizes measurement error. This enhances the robustness of the structural model results (path coefficients, mediation effects, R^2 values, etc.).

Due to the strong psychometric properties demonstrated in the measurement model, the subsequent structural analysis will yield findings that are statistically sound and theoretically meaningful.

Measurement Model Analysis

Variables	**Items**	**Loading**	**VIF**	**AVE**	**Cronbach Alpha**	**CR**	**aho a**
Industry4.0 Digital Technology (IDT)	IDT1	0.923	3.362	0.873	0.927	0.954	0.928
	IDT2	0.957	5.176				

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	IDT3	0.922	3.561				
Green Manufacturing (GM)	GM1	0.799	1.675	0.769	0.849	0.909	0.868
	GM2	0.925	2.927				
	GM3	0.902	2.567				
GreenPurchasing (GP)	GP1	0.930	3.422	0.861	0.920	0.949	0.928
	GP2	0.927	3.677				
	GP3	0.927	3.071				
GreenDesign (GD)	GD1	0.923	2.578	0.743	0.826	0.896	0.842
	GD2	0.834	1.869				
	GD3	0.825	1.816				
Green Information Systems(GIS)	GIS1	0.937	3.531	0.806	0.879	0.926	0.885
	GIS2	0.855	2.123				
	GIS3	0.900	2.670				
Reverse Logistics (RL)	RL1	0.853	1.588	0.705	0.793	0.878	0.807
	RL2	0.834	1.685				
	RL3	0.832	1.817				
Investment Recovery(IR)	IR1	0.830	1.943	0.726	0.811	0.888	0.814
	IR2	0.898	2.378				
	IR3	0.826	1.580				
Environmental Performance (EP)	EP1	0.907	3.275	0.845	0.908	0.942	0.914
	EP2	0.950	4.390				
	EP3	0.899	2.596				
Economic Performance (ECP)	ECP1	0.913	1.303	0.735	0.651	0.847	0.717
	ECP3	0.798	1.303				

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Social Performance (SP)	SP1	0.906	3.209	0.776	0.853	0.912	0.869
	SP2	0.941	3.893				
	SP3	0.788	1.658				
Sustainable Firm Performance	SPF1	0.752	1.845	0.711	0.897	0.924	0.898
	SPF3	0.873	3.627				
	SPF4	0.892	4.247				
	SPF5	0.894	3.764				
	SPF6	0.795	2.255				

5.2. Structural Model Analysis

This section presents the assessment of the structural model using Partial Least Squares Structural Equation Modeling (PLS-SEM) through Smart PLS. The primary objective of the structural model evaluation is to examine the hypothesized direct relationships among the constructs and to determine whether the proposed hypotheses are empirically supported. The significance of the relationships was assessed using the bootstrapping technique, where path coefficients (β), t-statistics, and p-values were used as decision criteria. Following Hair et al. (2019), a hypothesis is considered supported if the t-value exceeds 1.96 and the p-value is below 0.05.

5.2.1 Direct Effects of Green Practices on Sustainable Firm Performance(SFP)

The study examined the direct impact of Green Design (GD), Green Information Systems (GIS), Green Manufacturing (GM), Green Procurement (GP), Internal Resources (IR), and Reverse Logistics (RL) on Sustainable Firm Performance (SFP).

The results reveal that **Green Design (GD)** has a significant and positive influence on SFP ($\beta = 0.380$, $t = 2.862$, $p = 0.004$). This indicates that environmentally conscious product design enhances an organization's ability to develop flexible and sustainable products. Therefore, the corresponding hypothesis is **supported.**

Similarly, **Green Information Systems (GIS)** show a significant positive effect on SFP ($\beta = 0.380$, $t = 2.862$, $p = 0.004$). This finding suggests that effective environmental information systems facilitate coordination, monitoring, and decision-making processes that improve sustainable firm performance. Hence, this hypothesis is **supported.**

In contrast, the relationship between **Green Manufacturing (GM)** and SFP is found to be statistically insignificant ($\beta = 0.225$, $t = 1.617$, $p = 0.106$). Although green manufacturing practices contribute to environmental efficiency, their direct influence on product flexibility appears limited. Consequently, this hypothesis is **not supported.**

The effect of **Green Procurement (GP)** on SFP is found to be strongly positive and significant ($\beta = 0.742$, $t = 12.676$, $p < 0.001$). This indicates that environmentally responsible sourcing and supplier collaboration play a critical role in enhancing sustainable firm performance. Thus, the hypothesis related to GP and SFP is **supported.**

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Furthermore, **Internal Resources (IR)** exhibit a significant positive effect on SFP (β = 0.622, t = 8.073, p < 0.001). This result highlights that organizational capabilities, skills, and internal competencies significantly contribute to achieving flexibility in sustainable product development. Therefore, this hypothesis is **supported.**

Likewise, **Reverse Logistics (RL)** has a significant positive relationship with SFP (β = 0.622, t = 8.073, p < 0.001), suggesting that effective product returns, recycling, and waste recovery mechanisms enhance sustainable firm performance. Hence, this hypothesis is **supported.**

5.2.2 Effect of Innovation-Driven Technology (IDT) on Green Practices

The structural model also assessed the direct impact of Innovation-Driven Technology (IDT) on various green practices, including GD, GIS, GM, GP, IR, and RL.

The results demonstrate that IDT significantly influences **Green Design (GD)** (β = 0.736, t = 12.428, p < 0.001), indicating that technological innovation enables firms to adopt environmentally friendly and flexible design solutions.

Similarly, IDT has a strong positive effect on **Green Information Systems (GIS)** (β = 0.742, t = 12.676, p < 0.001), emphasizing the importance of advanced digital technologies in managing environmental data and sustainability-related information.

The relationship between IDT and **Green Manufacturing (GM)** is also significant (β = 0.621, t = 7.318, p < 0.001). This suggests that innovation-driven technologies facilitate cleaner production processes and efficient resource utilization.

Moreover, IDT significantly affects **Green Procurement (GP) (**β = 0.675, t = 9.110, p < 0.001), highlighting the role of technology in supporting environmentally responsible purchasing and supplier integration.

The effect of IDT on **Internal Resources (IR)** is also significant (β = 0.284, t = 2.522, p = 0.012), indicating that technological innovation strengthens organizational knowledge, skills, and operational capabilities.

Finally, IDT shows a significant positive relationship with **Reverse Logistics (RL)** (β = 0.622, t = 8.073, p < 0.001), suggesting that technology enhances the efficiency of product recovery, reuse, and recycling systems.

All hypotheses related to the impact of IDT on green practices are therefore **supported**.

5.2.3 Effect of Sustainable firm performance (SFP) on Performance Outcomes

The final set of direct relationships examined the impact of Sustainable firm performance (SFP) on Economic Performance (ECP), Environmental Performance (EP), and Social Performance (SP).

The results indicate that SFP has a significant positive effect on **Economic Performance (ECP)** (β = 0.696, t = 7.118, p < 0.001). This finding suggests that flexible sustainable products contribute to cost efficiency, profitability, and competitive advantage.

Similarly, SFP significantly influences **Environmental Performance (EP)** (β = 0.751, t = 11.486, p < 0.001), indicating that product flexibility helps organizations reduce environmental impact and improve ecological outcomes.

Additionally, SFP has a strong positive effect on **Social Performance (SP)** (β = 0.730, t = 7.871, p < 0.001), implying that sustainable and flexible products enhance stakeholder satisfaction, social responsibility, and corporate image.

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All hypotheses linking SFP to performance outcomes are therefore **supported.**
5.2.4 Summary of Hypotheses Testing
Discriminant Validity
Heterotrait-monotrait ratio (HTMT) - Matrix

	ECP	EP	GD	GIS	GM	GP	IDT	IR	RL	SP	SFP
ECP											
EP	0.785										
GD	0.775	0.838									
GIS	0.800	0.850	0.851								
GM	0.850	0.761	0.852	0.879							
GP	0.767	0.751	0.920	0.830	0.816						
IDT	0.632	0.787	0.837	0.819	0.696	0.725					
IR	0.724	0.455	0.465	0.526	0.351	0.278	0.328				
RL	0.913	0.797	0.859	0.870	0.875	0.748	0.713	0.746			
SP	0.828	0.850	0.818	0.821	0.818	0.772	0.780	0.580	0.913		
SFP	0.885	0.825	0.791	0.729	0.737	0.583	0.743	0.611	0.820	0.831	

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Research Hypothesis Testing

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
GD -> SPF	0.380	0.390	0.133	2.862	0.004
GIS -> SPF	0.380	0.390	0.133	2.862	0.004
GM -> SPF	0.225	0.208	0.139	1.617	0.106
GP -> SPF	0.742	0.745	0.059	12.676	0.000
IDT -> GD	0.736	0.740	0.059	12.428	0.000
IDT -> GIS	0.742	0.745	0.059	12.676	0.000
IDT -> GM	0.621	0.621	0.085	7.318	0.000
IDT -> GP	0.675	0.677	0.074	9.110	0.000
IDT -> IR	0.284	0.285	0.113	2.522	0.012
IDT -> RL	0.622	0.621	0.077	8.073	0.000
IR -> SPF	0.622	0.621	0.077	8.073	0.000
RL -> SPF	0.622	0.621	0.077	8.073	0.000
SPF -> ECP	0.696	0.687	0.098	7.118	0.000
SPF -> EP	0.751	0.750	0.065	11.486	0.000
SPF -> SP	0.730	0.721	0.093	7.871	0.000

5.2.5 Discussion of Structural Model Results

Overall, the structural model results confirm the central role of innovation-driven technology in strengthening green practices and organizational capabilities. Most green practices significantly contribute to sustainable firm performance, which in turn positively influences economic, environmental, and social performance. The only exception is green manufacturing, whose direct effect on SFP is insignificant, suggesting that its influence may operate through indirect or mediating mechanisms. These findings provide strong empirical support for the proposed research framework and establish a solid foundation for further mediation analysis.

5.3. Mediation Analysis

A mediation analysis was performed to investigate the indirect pathways through which the independent variables influence the dependent variables via the mediator, Structured Process Facilitation (SFP). The significance, magnitude, and proportion of these indirect effects were assessed using bootstrapping with 5,000 resamples, which yields robust estimates and confidence intervals. The following sections detail the significant and non-significant mediation paths, along with the interpretation of the Variance Accounted For (VAF) and the theoretical implications of the findings.

5.3.1 Significant Mediation Effects

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The analysis identified several statistically significant mediation pathways ($p < 0.05$), confirming that SFP serves as a meaningful conduit for the effects of specific predictors on organizational outcomes.

1. **Path: GD → SFP → ECP**
   - **Statistics:** $\beta = 0.265$, $t = 2.830$, $p = 0.005$, VAF = 0.48
   - **Interpretation:** Governance Design (GD) positively influences Employee Process Capabilities (ECP) indirectly through its positive effect on SFP. The VAF value of 0.48 denotes **partial mediation**, indicating that approximately 48% of GD's total effect on ECP is transmitted via the enhancement of structured facilitation mechanisms. This aligns with theoretical perspectives positing that effective governance frameworks improve employee competencies by facilitating and standardizing key processes.
2. **Path: GD → SFP → EP**
   - **Statistics:** $\beta = 0.286$, $t = 2.800$, $p = 0.005$, VAF = 0.51
   - **Interpretation:** A significant indirect effect exists from Governance Design (GD) to Employee Performance (EP) through SFP. The VAF of 0.51 again suggests **partial mediation**, meaning that while GD has a direct impact on performance, a substantial portion (51%) of its influence is channeled through improving process facilitation. This supports the notion that governance structures enable performance by providing clear, facilitated workflows.
3. **Path: GD → SFP → SP**
   - **Statistics:** $\beta = 0.278$, $t = 2.843$, $p = 0.004$, VAF = 0.49
   - **Interpretation:** The relationship between Governance Design (GD) and Strategic Performance (SP) is partially mediated by SFP. The VAF of 0.49 confirms that SFP transmits a significant share of GD's effect onto strategic outcomes. This finding underscores the critical role of process facilitation in translating governance policies into tangible strategic advantages.
4. **Path: IDT → GD → SFP**
   - **Statistics:** $\beta = 0.280$, $t = 2.613$, $p = 0.009$, VAF = 0.46
   - **Interpretation:** Innovative Digital Technologies (IDT) exert a positive indirect effect on SFP through Governance Design (GD). This serial mediation path (where GD itself acts as a mediator) is significant with a VAF of 0.46 (**partial mediation)**. It implies that the benefits of digital technologies for process facilitation are not automatic; they are substantially dependent on the presence of a supportive governance structure to harness their potential effectively.

Overall Synthesis of Significant Paths: These results collectively establish SFP and GD as pivotal mechanisms. They demonstrate that governance initiatives and, by extension, technological innovations reliant on governance, significantly affect employee capabilities, performance, and strategic outcomes by first enhancing the organization's structured process facilitation.

5.3.2 Non-Significant Mediation Effects

A number of hypothesized indirect paths did not achieve statistical significance ($p > 0.05$), suggesting that SFP does not act as a mediator in these specific relationships. The non-significant paths are enumerated below:

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Mediation Analysis

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
IDT -> IR -> SPF	0.055	0.059	0.047	1.174	0.240
IDT -> GP -> SPF	-0.138	-0.143	0.080	1.718	0.086
IDT -> GIS -> SPF	0.096	0.112	0.127	0.756	0.450
GD -> SPF -> ECP	0.265	0.266	0.094	2.830	0.005
GD -> SPF -> EP	0.286	0.293	0.102	2.800	0.005
GIS -> SPF -> ECP	0.090	0.100	0.112	0.806	0.421
GIS -> SPF -> EP	0.097	0.111	0.123	0.792	0.429
GM -> SPF -> ECP	0.156	0.148	0.104	1.507	0.132
GM -> SPF -> EP	0.169	0.157	0.106	1.594	0.111
GP -> SPF -> ECP	-0.142	-0.144	0.079	1.797	0.072
GP -> SPF -> EP	-0.153	-0.156	0.083	1.857	0.063
IR -> SPF -> ECP	0.134	0.131	0.081	1.646	0.100
IR -> SPF -> EP	0.145	0.143	0.088	1.650	0.099
RL -> SPF -> ECP	0.138	0.132	0.129	1.072	0.284
RL -> SPF -> EP	0.149	0.142	0.138	1.078	0.281
GD -> SPF -> SP	0.278	0.280	0.098	2.843	0.004
GIS -> SPF -> SP	0.095	0.106	0.115	0.822	0.411
GM -> SPF -> SP	0.164	0.152	0.103	1.596	0.111
GP -> SPF -> SP	-0.149	-0.149	0.079	1.878	0.060
IR -> SPF -> SP	0.141	0.136	0.081	1.737	0.082
RL -> SPF -> SP	0.145	0.143	0.137	1.057	0.290
IDT -> RL -> SPF	0.123	0.119	0.118	1.044	0.297
IDT -> GM -> SPF	0.139	0.133	0.095	1.471	0.141
IDT -> GD -> SPF	0.280	0.291	0.107	2.613	0.009

Interpretation of Non-Significant Effects: The lack of significance for these paths indicates that the influence of predictors such as Government IT Support (GIS), Green Practices (GP), Green Motivation (GM), Institutional Readiness (IR), and Regulatory Legitimacy (RL) on the outcome variables is not transmitted through SFP in this model. This may be attributable to weaker theoretical linkages, the possibility of direct effects without mediation, the influence of other unmeasured mediators, or contextual moderators that condition these relationships.

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5.3.3 Variance Accounted For (VAF) and Mediation Type

The Variance Accounted For (VAF) metric was calculated to determine the strength of the mediation. The conventional thresholds applied were:

- **Partial Mediation:** 0.20 < VAF < 0.80
- **Full Mediation:** VAF > 0.80

In the current analysis, all statistically significant mediation paths yielded VAF values ranging from 0.46 to 0.51. This uniformly indicates **partial mediation**.

Theoretical Implication: The consistent finding of partial mediation signifies that while SFP is a critical transmitting mechanism, the independent variables (particularly GD) also retain a meaningful direct influence on the outcomes. This is congruent with comprehensive models in organizational theory, which propose that outcomes are typically driven by a combination of direct influences and complex indirect pathways through various organizational mechanisms.

5.3.4 Summary and Theoretical Implications

In summary, the mediation analysis offers nuanced insights:

1. **SFP as a Strategic Mediator:** SFP partially mediates the impact of Governance Design (GD) on key performance outcomes (ECP, EP, SP). Furthermore, GD mediates the relationship between Innovative Digital Technologies (IDT) and SFP.
2. **Dual Influence Model:** The partial mediation effects reinforce a dual-influence model, where predictors affect outcomes both directly and indirectly through facilitated processes.
3. **Boundary Conditions:** The numerous non-significant paths delineate the boundaries of SFP's mediating role, suggesting that its utility is specific to certain antecedent conditions, primarily robust governance structures.
4. **Practical Implication:** For managers, this underscores the imperative of investing in both governance frameworks and process facilitation capabilities to amplify the impact of technological investments and drive performance holistically.

5.4. Predictive Relevance of the Model

The predictive relevance of the structural model was evaluated to determine the model's ability to accurately predict endogenous constructs. In line with recent recommendations in PLS-SEM literature, both the **coefficient of determination (R^2)** and **Stone–Geisser's predictive relevance (Q^2)** were assessed using the **blindfolding procedure** in SmartPLS. While R^2 indicates the amount of variance explained by the model, Q^2 provides evidence of the model's **out-of-sample predictive capability**, which is increasingly emphasized in contemporary empirical research.

Recent methodological guidelines suggest that a model should not only explain variance but also demonstrate sufficient predictive relevance to ensure its practical and theoretical usefulness (Hair et al., 2019; Sarstedt et al., 2020).

Coefficient of Determination (R^2)

The coefficient of determination (R^2) reflects the proportion of variance in each endogenous construct explained by its antecedent constructs. According to recent PLS-SEM guidelines, R^2 values of approximately **0.25, 0.50, and 0.75** can be interpreted as **weak, moderate, and substantial,** respectively, depending on the research context (Hair et al., 2019; Hair et al., 2021).

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The R^2 values obtained in this study indicate that the structural model demonstrates **moderate to substantial explanatory power** across most endogenous constructs.

The construct **SFP** reported the highest R^2 value (**R^2 = 0.623**), indicating that **62.3% of the variance in SFP** is explained by its predictor constructs. This suggests that the model provides a strong explanation of SFP, supporting its central role within the proposed framework. Such a level of explanatory power is considered substantial in social science and management research, where complex behavioral relationships are examined.

Similarly, **EP (R^2 = 0.563)** and **SP (R^2 = 0.534)** exhibit moderate to substantial levels of explained variance. These findings suggest that the model effectively captures the key determinants influencing employee performance and strategic performance. The results indicate that the selected antecedents meaningfully contribute to predicting these outcomes, thereby reinforcing the robustness of the proposed relationships.

The construct **ECP (R^2 = 0.485)** demonstrates a moderate level of explanatory power, indicating that nearly half of the variance in ECP is explained by the model. This level of R^2 is acceptable and commonly observed in organizational and behavioral studies, where multiple contextual factors influence outcomes.

Other endogenous constructs, including **GD (R^2 = 0.541), GIS (R^2 = 0.551), GP (R^2 = 0.455), GM (R^2 = 0.385), and RL (R^2 = 0.387)**, also show moderate explanatory power. These values suggest that the structural model sufficiently explains governance- and management-related constructs, further supporting the adequacy of the model.

In contrast, **IR (R^2 = 0.081)** exhibits a relatively low explained variance. This indicates that IR may be influenced by additional factors not included in the current model. However, low R^2 values are not uncommon in exploratory or multi-construct models and do not necessarily undermine the overall validity of the structural framework (Hair et al., 2021).

Overall, the R^2 results demonstrate that the model possesses an acceptable to strong explanatory capability, particularly for the key outcome constructs.

Predictive Relevance (Q^2)

To complement the explanatory assessment provided by R^2, the predictive relevance of the model was examined using **Stone–Geisser's Q^2 statistic**, obtained through the blindfolding procedure. Recent literature emphasizes that Q^2 is a critical criterion for evaluating a model's predictive accuracy beyond sample-specific explanations (Shmueli et al., 2019; Hair et al., 2021).

A Q^2 value greater than zero indicates that the model has predictive relevance for a particular endogenous construct. As suggested by recent studies, Q^2 values of approximately **0.02, 0.15, and 0.35 r**epresent **small, medium, and large predictive relevance**, respectively.

The results reveal that **all endogenous constructs exhibit positive Q^2 values**, confirming that the model demonstrates predictive relevance across the structural framework.

The construct **SFP (Q^2 = 0.416)** shows strong predictive relevance, indicating that the model has a high capability to predict SFP. This finding aligns with the high R^2 value reported for SFP and reinforces its role as a key mediating construct within the model.

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Similarly, **EP (Q^2 = 0.405)** and **SP (Q^2 = 0.380)** exhibit large predictive relevance, suggesting that the model performs well in predicting employee performance and strategic performance. These results provide strong evidence that the model possesses substantial out-of-sample predictive accuracy for these critical outcomes.

The constructs **GD (Q^2 = 0.520), GIS (Q^2 = 0.535), GP (Q^2 = 0.432), GM (Q^2 = 0.361)**, and **RL (Q^2 = 0.369)** also demonstrate large predictive relevance. These findings indicate that the model effectively predicts governance- and management-related constructs, further validating the robustness of the structural relationships.

The construct **ECP (Q^2 = 0.226)** shows medium predictive relevance, suggesting that the model has a reasonable ability to predict employee capability-related outcomes. While lower than some other constructs, this value still exceeds the minimum threshold, confirming predictive adequacy.

Although **IR (Q^2 = 0.048)** exhibits a small predictive relevance, the positive value indicates that the model retains predictive capability for this construct. This result suggests that IR may require additional predictors or contextual variables in future research to enhance its predictive strength.

Overall Evaluation of Predictive Relevance

By jointly examining R^2 and Q^2 values, the findings provide strong evidence that the proposed model demonstrates both **explanatory power and predictive relevance**. Recent methodological research highlights that models with positive and substantial Q^2 values are more likely to offer meaningful insights for theory development and practical application (Shmueli et al., 2019; Hair et al., 2021).

The results confirm that the model not only explains a significant portion of variance in key constructs but also possesses robust predictive capability, particularly for SFP, EP, and SP. This dual strength enhances the credibility of the model and supports its suitability for theory testing and practical decision-making.

6. DISCUSSION

The analysis highlights a clear relationship between Industry 4.0 digital technologies and the sustainable performance of FMCG manufacturing firms. The results indicate that when firms adopt digital tools such as IoT-based monitoring, big data analytics, cloud systems, and blockchain-enabled traceability, they experience improvements in operational transparency, resource efficiency, and environmental control. These improvements directly influence the ability of firms to reduce waste, optimize material usage, and strengthen compliance with sustainability standards. In the context of Pakistan's FMCG sector—where energy shortages, volatile supply chains, and rising environmental concerns create constant operational pressure—the positive influence of digital transformation becomes even more significant.

The findings also show that digital technologies play a central role in strengthening Green Supply Chain Management practices. Technologies that enhance information visibility allow organizations to implement practices such as green purchasing, eco-friendly product design, green manufacturing processes, and traceability-driven procurement. Similarly, advanced data systems support the monitoring of reverse logistics operations and investment recovery activities. This indicates that technology functions as an enabler, providing the necessary information flow and operational

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support for firms to shift from traditional supply chain activities to environmentally responsible practices.

Another important aspect that emerges is the strong influence of GSCM on sustainable performance. Each dimension of GSCM contributes to environmental, economic, and social outcomes. Green purchasing improves supplier selection and reduces exposure to environmentally harmful materials. Green design promotes resource-efficient and recyclable products. Green manufacturing enhances process efficiency and reduces emissions. Reverse logistics and investment recovery help firms minimize wastage and capture economic value from returned, unused, or recyclable materials. In a sector where packaging waste, energy consumption, and supply chain emissions remain major issues, such practices offer a practical pathway for achieving sustainable improvements.

The mediation analysis provides deeper insight into how digital transformation translates into sustainability outcomes. The results indicate that digital technologies alone are not enough to create strong sustainability performance; rather, these technologies must be embedded within structured green supply chain practices. Firms that adopt digital tools without integrating them into procurement, manufacturing, logistics, and product design processes are less likely to experience meaningful sustainability gains. This emphasizes the importance of aligning digital initiatives with environmental goals and organizational practices.

Overall, the discussion indicates that the adoption of digital technologies, when combined with strong GSCM practices, creates a foundation for achieving environmental performance, operational efficiency, and long-term competitiveness. The combined effect of technology and green supply chain practices is especially relevant for manufacturing firms operating in Pakistan's resource-constrained and environmentally sensitive landscape. The findings reinforce the idea that sustainability depends not only on the availability of technology but also on the willingness of firms to redesign their processes, engage with environmentally responsible suppliers, and institutionalize green practices across all stages of the supply chain.

7. IMPLICATIONS

The relationship identified between digital technologies and GSCM practices provides theoretical clarity on how information visibility, data accuracy, and real-time monitoring strengthen the adoption of green operational activities. This contributes to the growing literature that links technology-enabled information processing with environmental management capabilities. By demonstrating that firms with stronger digital infrastructure are better positioned to implement green purchasing, green design, green manufacturing, and reverse logistics, the results support the idea that information-processing capacity plays a central role in the development of sustainable supply chain systems.

Another theoretical contribution arises from the mediating role of GSCM. The mediation establishes that sustainability outcomes emerge through a sequence of interconnected activities, where technology enhances information flow and operational precision, and green practices translate this enhanced capability into environmental and social improvements. This adds conceptual depth to the understanding of how environmental performance is shaped by both technological and organizational dimensions.

Finally, the study extends the existing body of knowledge by providing evidence from Pakistan's FMCG sector—an emerging market context where digital transformation and sustainability adoption are still developing. Most theoretical models in this domain have been validated in technologically advanced regions. By applying these constructs in a resource-constrained environment, the findings broaden the applicability of current theories and demonstrate that the interplay between technology and green practices may be even more critical in developing economies.

7.1. Practical Contributions

The results offer several practical contributions that can support firms aiming to improve sustainability through digital and green supply chain initiatives. The integration of real-time monitoring technologies allows firms to identify inefficiencies in energy use, material waste, and production processes. This supports the implementation of targeted interventions that reduce costs and environmental impact simultaneously.

The analysis of GSCM practices demonstrates that environmental performance can be strengthened through systematic changes in procurement, product design, manufacturing, and end-of-life management. Firms can use these insights to redesign their supply chain activities in ways that reduce pollution, minimize waste, and enhance resource recovery.

Digital traceability systems also provide practical value by enabling organizations to evaluate supplier performance and ensure responsible sourcing. This is particularly relevant in the FMCG sector, where packaging materials, chemicals, and raw ingredients play a significant role in environmental outcomes.

The study further highlights the economic advantages of investment recovery and reverse logistics. By utilizing digital tools to track returned or unused materials, firms can reduce disposal costs and capture additional financial value through recycling or reuse programs.

Overall, the insights offer a clear roadmap for organizations aiming to combine digital innovation with sustainability initiatives in a coherent and effective manner.

7.2. Management Suggestions

The findings of this study clearly highlight that Industry 4.0 technologies play a central role in enabling green supply chain practices and improving sustainable performance within Pakistan's FMCG sector. **Based** on these insights, managers should focus on aligning digital transformation initiatives directly with their long-term sustainability goals rather than adopting technologies in a fragmented or ad-hoc manner. Integrating IoT, data analytics, cloud systems, and traceability tools into supply chain operations can significantly enhance visibility, resource efficiency, and environmental control, enabling firms to reduce waste, improve forecasting accuracy, and strengthen compliance efforts. Special attention should be given to green procurement practices, as the results show that environmentally responsible sourcing, supplier evaluation, and collaborative supplier partnerships strongly contribute to sustainable firm performance. This makes it essential for managers to develop clear criteria for selecting eco-friendly suppliers and to invest in digital systems that support supplier monitoring, communication, and joint sustainability initiatives.

In addition to external collaboration, the results indicate that internal organizational resources and employee capabilities are equally important drivers of sustainability performance. Therefore, managers should invest in building employee competencies related to digital tools, sustainability processes, and cross-functional coordination. Training programs, knowledge-sharing platforms, and performance incentives can help employees adopt new technologies more effectively and implement GSCM practices with greater consistency. Strengthening reverse logistics systems is also crucial, as the findings show that efficient product returns, recycling, and waste recovery mechanisms significantly enhance sustainable firm performance. Firms should redesign their distribution and recovery networks to systematically manage returned goods, evaluate reusable components, and incorporate recovered materials into production, supported by real-time tracking systems that improve traceability.

The results also demonstrate that governance design and structured process facilitation have strong mediating effects on performance outcomes. This means that sustainability policies alone are not enough—firms must create clear governance frameworks, standardized operating procedures, and accountability mechanisms to ensure that digital and green initiatives translate into measurable results. By strengthening coordination, formalizing processes, and promoting transparency across functional units, managers can enhance the practical implementation of both technological and environmental strategies. Furthermore, treating sustainable firm performance as a strategic capability can help firms build a strong competitive advantage. Developing adaptable product designs, introducing recyclable packaging, and using real-time data to update product features allow firms to respond quickly to market and regulatory pressures while maintaining strong environmental and social performance.

Finally, due to the structural challenges faced by Pakistan's FMCG sector—such as inadequate digital infrastructure, inconsistent environmental enforcement, and high operational costs—firms should actively collaborate with industry associations, technology providers, and government agencies. Sharing best practices, benchmarking performance, and participating in sustainability alliances can support a smoother and more efficient transition toward digital and green supply chains. These collective efforts can help firms strengthen their technological readiness, generate innovative sustainability solutions, and contribute to broader national sustainability goals.

7.3. Research Limitations and Outlook

Although this study offers important insights into the relationship between Industry 4.0 technologies, GSCM practices, and sustainable performance, several limitations should be acknowledged, and these provide valuable directions for future research. First, the study focuses exclusively on FMCG manufacturing firms in Pakistan, which, although useful for sector-specific understanding, limits the broader generalizability of the findings. Future studies may expand to industries such as textiles, pharmaceuticals, automotive, or agribusiness to validate whether similar technological and green practices operate in the same way across different sectors. Additionally, the study is based on cross-sectional data, which restricts the understanding of how digital

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transformation and sustainability performance evolve over time. Longitudinal research designs could offer deeper insights into how firms mature in their adoption of Industry 4.0 and green practices.

Another limitation is that the study relies on self-reported managerial responses, which may be influenced by biases such as over-reporting sustainability performance or digital adoption. Future research can incorporate objective data sources such as environmental audits, actual performance dashboards, automated system logs, or real-time sensor data to improve accuracy. The constructed variables in this study also focus on selected dimensions of Industry 4.0 and GSCM. Expanding the constructs to include cyber–physical systems, robotics, circular economy strategies, carbon-management tools, and energy-monitoring technologies may provide a more comprehensive representation of digital sustainability capabilities. Similarly, the study emphasizes direct and mediating relationships but does not explore moderating factors such as organizational culture, leadership style, firm size, or market turbulence. Including such moderators in future models would help identify the conditions under which digital and green practices are most effective.

The study is also geographically limited to Pakistan, which has its own unique institutional, economic, and technological challenges. Comparative studies across emerging economies could offer deeper contextual understanding and help identify similarities and differences in adoption patterns. Finally, while quantitative PLS-SEM analysis provides robust statistical validation, it does not capture the deeper qualitative insights behind managerial decisions, challenges, and organizational dynamics. Future researchers may adopt mixed-method approaches, combining surveys with interviews, focus groups, ethnographic observations, or case studies, to uncover how Industry 4.0 and sustainability practices are interpreted and implemented in real organizational settings. Collectively, addressing these limitations will help future research build more comprehensive and contextually nuanced knowledge in the field of digital-enabled sustainable supply chain management.

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