

Green Innovation Strategies and Environmental Sustainability: A Structural Equation Modeling Analysis of Manufacturing Firms in Kenya

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DOI: <https://doi.org/10.47772/IJRISS.2026.100601294>

Received: 04 July 2026; Accepted: 09 July 2026; Published: 17 July 2026

ABSTRACT

Environmental degradation, climate change, increasing resource depletion, and stricter environmental regulations have intensified pressure on manufacturing firms to adopt sustainable production practices. Green innovation has emerged as an important strategic approach for enhancing environmental sustainability. However, existing empirical studies have predominantly examined its influence on financial performance, organizational competitiveness, and operational efficiency, with comparatively limited attention given to environmental sustainability as the primary organizational outcome, especially in Kenya. Guided by the Diffusion of Innovation (DOI) Theory, this study examined the influence of green innovation strategies on environmental sustainability among manufacturing firms in the South Rift region of Kenya. The study adopted a positivist research philosophy and a causal cross-sectional survey design. A census of 81 registered manufacturing firms was undertaken, with primary data collected from 162 senior managers using structured questionnaires and supported by qualitative evidence from semi-structured interviews with 15 purposively selected managers. The measurement model was validated using Cronbach's alpha, Composite Reliability, Average Variance Extracted, the Fornell-Larcker criterion, and the Heterotrait-Monotrait ratio. Descriptive statistics were analyzed using IBM SPSS Statistics Version 27, while the hypothesized relationships were tested using Partial Least Squares Structural Equation Modeling (PLS-SEM) in SmartPLS 4. The findings established that green process innovation ($\beta = 0.245, p = 0.005$) and green product innovation ($\beta = 0.297, p = 0.003$) positively and significantly influenced environmental sustainability, whereas green marketing innovation exhibited a negative but statistically insignificant effect ($\beta = -0.120, p = 0.222$). The higher-order construct, green innovation strategies, also exerted a positive and statistically significant influence on environmental sustainability ($\beta = 0.386, p = 0.005$). The study concludes that integrated green innovation strategies significantly improve environmental sustainability through cleaner production processes and sustainable product development. It recommends increased investment in cleaner technologies, eco-design, circular economy practices, and supportive policy incentives to accelerate sustainable manufacturing. The findings extend the Diffusion of Innovation Theory by demonstrating that coordinated adoption of complementary green innovations generates superior environmental sustainability outcomes within manufacturing firms.

Keywords: Green innovation strategies, environmental sustainability, green process innovation, green product innovation, green marketing innovation, manufacturing firms, Kenya, PLS-SEM.

INTRODUCTION

Climate change, environmental degradation, biodiversity loss, and the depletion of natural resources have intensified global efforts toward sustainable industrial development. Manufacturing industries are recognized as major contributors to greenhouse gas emissions, industrial waste, excessive energy consumption, and water

pollution, making them central to global sustainability initiatives (Abbas & Dogan, 2022; Alkaraan et al., 2022). Consequently, governments, international organizations, and private sector stakeholders have increasingly promoted green growth and sustainable manufacturing as viable pathways for balancing economic development with environmental protection. These initiatives are consistent with the Sustainable Development Goals (SDGs), particularly SDG 9 (Industry, Innovation and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action), which advocate sustainable industrialization, resource efficiency, pollution reduction, and climate resilience (UNDP, 2021). As environmental regulations become more stringent and stakeholders increasingly demand environmentally responsible business practices, manufacturing firms are under growing pressure to adopt innovative strategies that simultaneously improve environmental performance and organizational competitiveness.

Green innovation has emerged as one of the most important strategic responses to contemporary environmental challenges because it enables firms to integrate environmental considerations into organizational processes, products, and market activities while enhancing long-term competitiveness (Lv, Shao, & Lee, 2021; Rehman et al., 2021). Green innovation strategies refer to systematic organizational efforts aimed at minimizing environmental impacts through environmentally friendly technologies, cleaner production systems, sustainable product development, and environmentally responsible marketing practices (Polas, Tabash, Bhattacharjee, & Dávila, 2023). Unlike conventional innovation, green innovation simultaneously pursues economic value creation and environmental protection by reducing pollution, conserving natural resources, improving resource utilization, and promoting sustainable production systems (Mutai & Bett, 2026). Within manufacturing industries, green innovation strategies are commonly operationalized through three complementary dimensions: green process innovation, green product innovation, and green marketing innovation. Together, these strategies facilitate sustainable production while enabling firms to comply with environmental regulations and satisfy increasing market demand for environmentally responsible products.

Green process innovation focuses on improving production systems through cleaner technologies, efficient resource utilization, waste minimization, pollution prevention, and reduced greenhouse gas emissions (Khan, Kaur, Jabeen, & Dhir, 2021). By redesigning production processes, firms can lower energy consumption, minimize industrial waste, improve operational efficiency, and reduce their ecological footprint. Green product innovation emphasizes the design and development of environmentally friendly products using recyclable materials, eco-friendly packaging, renewable resources, and life-cycle sustainability principles (Ma et al., 2018; Muthoka & Mutuku, 2023). Such innovations not only reduce environmental degradation but also respond to growing consumer demand for sustainable products. Green marketing innovation complements these production-oriented initiatives by integrating environmental sustainability into product promotion, branding, pricing, distribution, and corporate social responsibility initiatives, thereby encouraging environmentally conscious consumption while strengthening organizational commitment to sustainable development (Kar & Harichandan, 2022; Zuhairah & Noor, 2015). Collectively, these three dimensions represent an integrated strategic approach through which manufacturing firms can enhance environmental sustainability while maintaining long-term competitiveness.

Globally, manufacturing firms have increasingly embraced green innovation strategies as governments tighten environmental regulations and consumers become more environmentally conscious. In developed economies such as the United States, manufacturing organizations have substantially invested in cleaner production technologies, renewable energy systems, eco-friendly product development, and environmentally responsible operational practices to reduce their environmental footprint (Jahanger et al., 2023). Empirical evidence indicates that organizations investing in green innovation achieve improvements in resource efficiency, pollution prevention, waste reduction, and environmental performance while simultaneously strengthening their competitive advantage (Dos-Santos-Dalbelo & Rutkowski, 2021). Green innovation has therefore evolved beyond regulatory compliance to become a strategic capability that supports sustainable business growth and organizational resilience.

Europe has similarly positioned itself as a global leader in sustainable manufacturing through comprehensive environmental legislation and substantial investments in green technologies. The European Union has introduced

stringent environmental regulations that encourage manufacturing firms to adopt cleaner production systems, circular economy principles, and environmentally sustainable innovation practices (Raza, 2020). Consequently, European manufacturers have significantly improved environmental sustainability through reduced carbon emissions, increased resource efficiency, and sustainable supply chain practices (Cainelli, D'Amato, & Mazzanti, 2020). Recent studies further demonstrate that organizations capable of simultaneously pursuing exploratory and exploitative green innovations achieve superior environmental performance and long-term sustainability (Úbeda-García et al., 2022). These findings suggest that integrating multiple dimensions of green innovation can substantially strengthen organizational environmental outcomes.

Across Asia, green innovation has become an important component of industrial transformation, particularly in rapidly industrializing economies such as China, Japan, South Korea, and Malaysia. Growing concerns regarding air pollution, industrial emissions, and resource scarcity have prompted governments and manufacturing firms to invest heavily in cleaner production technologies, green product development, renewable energy utilization, and environmentally sustainable manufacturing systems (Shahab et al., 2020; Qiu, Jie, Wang, & Zhao, 2020). Malaysian manufacturing firms have increasingly incorporated green organizational practices that improve environmental sustainability while reducing carbon footprints and enhancing operational efficiency (Nisar et al., 2021). Nevertheless, empirical evidence suggests considerable variation in the effectiveness of green innovation across industries, indicating that organizational capabilities and contextual factors significantly influence environmental sustainability outcomes.

The adoption of green innovation strategies within Africa has progressed more gradually because of financial constraints, technological limitations, inadequate infrastructure, and relatively weak regulatory enforcement. Although awareness regarding environmental sustainability has increased substantially, many manufacturing firms continue to experience challenges in implementing environmentally sustainable technologies and production systems (Amankwah-Amoah, 2019). Empirical evidence from Nigeria indicates that larger manufacturing organizations are more likely to implement green innovation practices than small and medium-sized enterprises because of greater access to financial resources and technological capabilities (Agyabeng-Mensah, Afum, & Baah, 2022). Similarly, studies conducted in Ghana demonstrate that manufacturing firms continue to face challenges in integrating environmentally sustainable production systems despite increasing regulatory pressure (Antwi, Agyapong, & Owusu, 2022). These findings highlight the need for additional empirical evidence regarding the effectiveness of green innovation strategies within developing economies.

Kenya has increasingly prioritized environmental sustainability through national policy frameworks including Vision 2030, the Climate Change Act (2016), and the Green Economy Strategy and Implementation Plan, all of which emphasize sustainable industrialization, low-carbon economic growth, and responsible resource utilization (Mukabi, 2023). The manufacturing sector remains an important contributor to Kenya's economic development through employment creation, industrial growth, and export earnings. However, manufacturing activities also represent significant sources of environmental degradation through greenhouse gas emissions, industrial effluents, solid waste generation, excessive energy consumption, and water pollution (Kiongo et al., 2021). Regulatory institutions such as the National Environment Management Authority (NEMA) have strengthened environmental compliance requirements; nevertheless, enforcement challenges and limited adoption of integrated green innovation strategies continue to constrain improvements in environmental sustainability (Lema, 2025). Although some large manufacturing organizations have invested in cleaner production technologies and environmentally responsible business practices, many firms continue to rely on conventional manufacturing systems that contribute substantially to environmental degradation.

Environmental sustainability concerns are particularly evident within Kenya's South Rift region, which hosts numerous manufacturing industries including tea processing factories, agro-processing industries, cement manufacturing plants, sugar processing factories, steel industries, and plastic manufacturing firms. The region encompasses ecologically sensitive ecosystems, particularly the Mau Forest Complex, which serves as one of East Africa's most important water catchment areas (Albertazzi, Bini, & Trivellini, 2023). Industrial activities within the region generate significant quantities of greenhouse gas emissions, industrial waste, wastewater effluents, and air pollutants that threaten biodiversity, water quality, ecosystem integrity, and public health

(Rotich, Chepkirui, Musyimi, & Kipruto, 2024). Moreover, the South Rift region has experienced increasing climate-related challenges characterized by prolonged droughts, rising temperatures, irregular rainfall patterns, and declining agricultural productivity (Njenga, 2021). These environmental challenges underscore the importance of strengthening environmentally sustainable manufacturing practices through the adoption of integrated green innovation strategies.

Environmental sustainability refers to an organization's ability to minimize negative environmental impacts while ensuring the efficient utilization of natural resources and compliance with environmental regulations for present and future generations (Ullah, Ahmad, & Rehman, 2021). Within manufacturing industries, environmental sustainability is reflected through reduced greenhouse gas emissions, improved energy and water efficiency, effective waste management, responsible utilization of raw materials, pollution prevention, and adherence to environmental regulations (Wang et al., 2022). Previous studies consistently demonstrate that organizations implementing environmentally sustainable production systems achieve improvements in environmental performance through cleaner technologies, efficient resource utilization, and environmentally responsible operational practices (Sukarta et al., 2023; Rauf et al., 2022). Consequently, environmental sustainability has become an important performance outcome for manufacturing organizations seeking to balance industrial growth with environmental stewardship.

Despite increasing scholarly attention to green innovation, important knowledge gaps remain. First, previous studies have predominantly examined the relationship between green innovation and financial performance, organizational competitiveness, or operational efficiency, with comparatively limited attention devoted to environmental sustainability as the primary organizational outcome (Xie, Huo, & Zou, 2019; Ma et al., 2018; Zuhairah & Noor, 2015). Second, much of the existing literature has investigated green process innovation, green product innovation, and green marketing innovation independently, thereby providing limited understanding of their combined contribution to environmental sustainability (Cancela, Coelho, & Neves, 2022). Third, empirical evidence from developing economies remains relatively scarce despite increasing policy emphasis on sustainable industrialization and climate change mitigation. Within Kenya, existing studies have largely concentrated on green procurement, green supply chain management, or environmental compliance in selected industries, leaving limited evidence regarding the integrated influence of green innovation strategies on environmental sustainability within the manufacturing sector (Wanjiru & Ochiri, 2019; Muthoka & Mutuku, 2023). Furthermore, empirical evidence from environmentally vulnerable manufacturing regions such as the South Rift remains particularly limited.

Against this background, the present study examines the relationship between green innovation strategies and environmental sustainability among manufacturing firms in the South Rift region of Kenya. Specifically, the study investigates the influence of green process innovation, green product innovation, and green marketing innovation on environmental sustainability using Structural Equation Modeling (SEM). By integrating these three dimensions of green innovation within a single analytical framework, the study contributes to the growing literature on sustainable manufacturing in developing economies while providing evidence that can inform environmental policy, manufacturing practice, and sustainable industrial development in Kenya.

LITERATURE REVIEW

Green Innovation Strategies and Environmental Sustainability

Globally, Ullah, Ahmad, and Rehman (2021) investigated the influence of green innovation on the achievement of sustainable development goals among 204 small and medium-sized enterprises (SMEs) in Pakistan. Using structural equation modeling, the study established that green innovation significantly enhanced environmental initiatives and sustainable development, although its effectiveness largely depended on government support and institutional incentives. However, the study conceptualized green innovation as a single construct and did not examine how individual green innovation strategies contribute to environmental sustainability. The present study addressed this limitation by examining the individual contributions of green process innovation, green product innovation, and green marketing innovation to environmental sustainability among manufacturing firms.

Similarly, Wang et al. (2022) examined the moderating role of organizational green culture in the relationship between green innovation and sustainable development using structural equation modeling among manufacturing and service enterprises. The findings revealed that green organizational culture strengthens green knowledge management, thereby enhancing green innovation and sustainable development. Nevertheless, the study treated green innovation as a broad organizational capability without distinguishing the specific innovation strategies that influence environmental sustainability. The present study extended this work by examining green process innovation, green product innovation, and green marketing innovation as distinct dimensions of green innovation strategies and assessing their individual relationships with environmental sustainability.

In Saudi Arabia, Alyahya et al. (2022) investigated the influence of institutional pressures on green innovation and sustainable development practices. The findings demonstrated that regulatory, competitive, and governance pressures significantly promote the adoption of green innovation. However, the study emphasized external institutional drivers while paying limited attention to the specific green innovation strategies implemented within organizations. The present study addressed this gap by examining how different green innovation strategies influence environmental sustainability among manufacturing firms.

Wang et al. (2022) further explored the contribution of green knowledge management to sustainable development through green innovation across manufacturing and service organizations. The study concluded that effective green knowledge management enhances organizational capabilities for green innovation, thereby improving sustainability performance. However, the study combined manufacturing and service industries, overlooking the unique environmental challenges associated with manufacturing operations. The present study addressed this limitation by focusing exclusively on manufacturing firms, where environmental sustainability remains a critical operational and strategic concern.

In Southeast Asia, Khan et al. (2023) examined the relationship between green innovation, corporate governance, and financial performance among firms in Malaysia and Indonesia using panel data analysis. The findings revealed that green innovation positively influences financial performance, with stronger effects observed among Malaysian firms. However, the study emphasized financial outcomes while overlooking environmental sustainability as an organizational performance outcome. The present study extended the literature by examining the influence of green innovation strategies on environmental sustainability among manufacturing firms.

Su et al. (2020) investigated the relationships among environmental knowledge acquisition, green innovation strategies, environmental leadership, and business performance in Chinese agricultural firms. The findings indicated that green innovation mediates the relationship between environmental leadership and organizational performance. Nevertheless, the study focused primarily on business performance rather than environmental sustainability. The present study addressed this gap by empirically examining the relationship between green innovation strategies and environmental sustainability within the manufacturing sector.

Similarly, Soewarno et al. (2019) examined the influence of green innovation strategy on green innovation performance through the mediating roles of green organizational identity and environmental legitimacy in Indonesian manufacturing firms. Their findings demonstrated that green innovation strategy significantly enhances green innovation performance. However, the study did not investigate whether green innovation strategies translate into improved environmental sustainability. The present study extended this work by examining environmental sustainability as the primary outcome of green innovation strategies.

Singh et al. (2020) investigated the relationship among green transformational leadership, green innovation, green human resource management, and environmental performance in small and medium-sized enterprises. The study found that green human resource management significantly mediates the relationship between green innovation and environmental performance. However, the study focused primarily on SMEs, limiting the generalizability of the findings to the broader manufacturing sector. The present study addressed this contextual limitation by focusing on manufacturing firms that significantly contribute to environmental degradation and therefore require effective green innovation strategies.

Yan and Zhang (2021) examined the effects of environmental management and green innovation on firm value and environmental performance among high-energy-consuming enterprises. Their findings established that green innovation significantly improves both environmental performance and firm value. However, the study was conducted in high-energy-consuming industries without specifically examining manufacturing firms, where environmental sustainability remains a major operational and regulatory concern. The present study addressed this contextual gap by investigating manufacturing firms in the South Rift region of Kenya.

Arsawan et al. (2021) explored the role of green innovation and environmental strategies in enhancing environmental performance among SMEs in emerging economies. The findings revealed that environmental strategy significantly strengthens the influence of green innovation on environmental performance. However, the study relied on SMEs from multiple sectors, limiting the applicability of the findings to environmentally intensive manufacturing industries. The present study focused specifically on manufacturing firms, which are among the largest contributors to industrial pollution and environmental degradation.

Within the Kenyan context, Nzomo, Kinyua, and Mwasiagi (2023) examined the relationship between green innovation strategies and sustainability performance among ISO 14001-certified manufacturing firms. The findings established a significant positive relationship between green innovation strategies and organizational sustainability. However, the study assessed green innovation as a composite construct and did not distinguish the contributions of green process innovation, green product innovation, and green marketing innovation to environmental sustainability. The present study addressed this limitation by examining the individual influence of these three dimensions of green innovation strategies on environmental sustainability among manufacturing firms.

Similarly, Bett (2024) conducted a systematic literature review on the relationship between green innovation and sustainable development. The review revealed that green innovation positively contributes to sustainable development by improving environmental, economic, and social sustainability. Nevertheless, it also identified persistent challenges, including inadequate environmental policies, weak regulatory frameworks, and limited institutional support for implementing green innovation initiatives. Furthermore, the review treated green innovation as a multidimensional construct without empirically examining the individual contributions of green process innovation, green product innovation, and green marketing innovation. The present study addressed this gap by empirically investigating these three dimensions of green innovation strategies and determining their individual relationships with environmental sustainability among manufacturing firms in the South Rift region of Kenya.

The empirical reviewed literature demonstrates that green innovation is increasingly recognized as a strategic mechanism for improving organizational sustainability. Nevertheless, previous studies have predominantly emphasized financial performance, operational performance, or sustainable development as aggregate outcomes, while giving comparatively limited attention to environmental sustainability as the primary outcome variable. Moreover, existing studies have frequently conceptualized green innovation as a single construct rather than examining the distinct contributions of green process innovation, green product innovation, and green marketing innovation. Empirical evidence from Kenya's manufacturing sector remains limited, particularly within the South Rift region. Consequently, the present study addresses these conceptual, contextual, and empirical gaps by examining the relationship between green process innovation, green product innovation, green marketing innovation, and environmental sustainability among manufacturing firms in the South Rift region of Kenya.

THEORETICAL REVIEW

The Diffusion of Innovation (DOI) Theory, developed by Rogers (1962), explains how new ideas, technologies, and innovations are communicated and adopted within a social system over time. The theory proposes that innovation adoption follows a predictable pattern comprising innovators, early adopters, early majority, late majority, and laggards, with adoption influenced by communication channels, social systems, and the perceived characteristics of the innovation (Godin, 2019). Rogers further argues that the likelihood of adopting an innovation depends on five key attributes: relative advantage, compatibility, complexity, trialability, and

observability. Innovations perceived as offering greater benefits, being compatible with existing practices, easy to implement, testable, and capable of producing observable results are more readily adopted by organizations.

Diffusion of Innovation Theory provides a useful framework for explaining how manufacturing firms adopt environmentally friendly innovations aimed at reducing ecological degradation. Green innovation strategies including green process innovation, green product innovation, and green marketing innovation represent organizational innovations that diffuse across firms as they respond to increasing environmental regulations, stakeholder expectations, technological advancements, and competitive pressures (Huang et al., 2022). The theory suggests that firms are more likely to adopt these green innovations when they perceive them as improving operational efficiency, reducing production costs, strengthening corporate reputation, enhancing regulatory compliance, and generating long-term competitive advantage.

Recent empirical studies have increasingly applied the Diffusion of Innovation Theory to explain the adoption of environmentally sustainable technologies and practices. Shahzad, Qu, Rehman, and Zafar (2022) argued that the diffusion of environmentally friendly technologies is essential for achieving sustainable development because it encourages organizations to integrate cleaner production systems, resource-efficient technologies, and environmentally responsible management practices. Similarly, Bett (2024) observed that the theory effectively explains the organizational adoption of green innovation practices by illustrating how firms progressively embrace environmentally sustainable technologies and management approaches in response to changing institutional and market conditions. These studies demonstrate that the Diffusion of Innovation Theory is particularly useful for explaining the adoption process of green innovation strategies rather than defining the concept of green innovation itself.

The theory is particularly relevant to the present study because it explains how manufacturing firms adopt green innovation strategies to improve environmental sustainability. Green process innovation reflects the adoption of cleaner production technologies and environmentally efficient manufacturing processes that minimize waste, pollution, and energy consumption. Green product innovation represents the development and commercialization of environmentally friendly products using sustainable materials and eco-design principles. Green marketing innovation involves adopting environmentally responsible marketing practices, including eco-labeling, green branding, and promoting sustainable consumption. According to the Diffusion of Innovation Theory, the successful adoption and implementation of these innovations depend on how manufacturing firms perceive their relative advantages and compatibility with organizational goals and stakeholder expectations. As the adoption of these green innovations increases, firms are expected to achieve higher levels of environmental sustainability through reduced emissions, improved resource efficiency, effective waste management, and enhanced compliance with environmental regulations.

Therefore, the Diffusion of Innovation Theory provides the theoretical foundation for this study by explaining how the adoption of green process innovation, green product innovation, and green marketing innovation contributes to environmental sustainability among manufacturing firms. The theory supports the proposition that organizations adopting environmentally friendly innovations are more likely to improve their environmental performance and contribute to sustainable industrial development.

RESEARCH METHODOLOGY

This study adopted a positivist research philosophy and employed a causal cross-sectional survey design to examine the relationship between green innovation strategies and environmental sustainability among manufacturing firms in the South Rift region of Kenya. Positivism was appropriate because the study sought to test hypothesized relationships using objective, measurable data and statistical analysis. The causal design enabled the examination of the influence of green process innovation, green product innovation, and green marketing innovation on environmental sustainability, while the cross-sectional approach facilitated the collection of data from respondents at a single point in time. This design is widely recommended for studies seeking to investigate relationships among latent constructs using survey data and Structural Equation Modeling (Remler & Van Ryzin, 2021; Hamaker, 2024).

The study was conducted among registered manufacturing firms operating in the South Rift region of Kenya, comprising Baringo, Bomet, Kericho, Nakuru, Narok, and Samburu counties. The region hosts diverse manufacturing subsectors, including tea and coffee processing, dairy processing, cement production, steel fabrication, plastics, timber, textiles, beverages, pharmaceuticals, and construction materials. The target population consisted of 81 registered manufacturing firms, which formed the unit of analysis. Because the population was relatively small, a census approach was adopted whereby all firms were included in the study. Two senior managers, typically the General Manager and the Operations Manager, were purposively selected from each firm as the unit of observation because of their strategic knowledge of environmental management and innovation practices, yielding 162 targeted respondents. Primary data were collected using a structured questionnaire administered through both online and physical modes to improve accessibility and response rates. To complement the survey findings, semi-structured interviews were conducted with 15 purposively selected senior managers, each representing one manufacturing subsector. The qualitative evidence was used to provide contextual interpretation of the quantitative findings rather than for hypothesis testing.

The questionnaire items were adapted from validated scales reported in previous studies and measured using a five-point Likert scale. Prior to the main survey, the instrument was pilot-tested to evaluate its clarity and psychometric properties. Internal consistency reliability was assessed using Cronbach's alpha and Composite Reliability (CR), while construct validity was evaluated through factor loadings, Average Variance Extracted (AVE), the Fornell–Larcker criterion, and the Heterotrait–Monotrait (HTMT) ratio where the study met all required assumption. Data were coded and analyzed using IBM SPSS Statistics Version 27 to generate descriptive statistics, including frequencies, means, and standard deviations. The hypothesized relationships were subsequently tested using SmartPLS 4 through Partial Least Squares Structural Equation Modeling (PLS-SEM). PLS-SEM was considered appropriate because it effectively estimates relationships among multiple latent constructs, accommodates complex predictive models, and simultaneously evaluates both the measurement model and the structural model, making it suitable for examining the effects of green process innovation, green product innovation, and green marketing innovation on environmental sustainability.

RESULTS AND DISCUSSION

Descriptive and Thematic Results

The findings demonstrate that manufacturing firms have achieved a moderate-to-high level of green process innovation adoption, with greater emphasis placed on operational improvements that generate immediate environmental and efficiency gains than on capital-intensive technological transformation. Firms primarily focused on energy efficiency, waste minimization, recycling, and environmental monitoring, while investments in renewable energy and advanced clean production technologies remained comparatively limited. The interview findings corroborated these results by indicating that financial constraints, technological capability, and implementation costs continue to limit adoption of more sophisticated green production systems. Collectively, these findings suggest that green process innovation within Kenyan manufacturing is currently characterized by incremental process improvements rather than radical technological change. This extends existing literature by demonstrating that resource efficiency and pollution prevention constitute the dominant pathways through which process innovation contributes to environmental sustainability in emerging manufacturing economies.

The results indicate that green product innovation has become firmly integrated into manufacturing activities, particularly through environmentally conscious product design, sustainable packaging, and lifecycle management. Firms demonstrated substantial commitment to developing recyclable products, improving product longevity, reducing packaging waste, and strengthening waste recovery practices, reflecting an increasing transition toward circular economy principles. Qualitative evidence further revealed that organizations are progressively embedding environmental considerations throughout the product lifecycle while collaborating with recycling systems and investing in waste treatment technologies. These findings suggest that green product innovation has evolved beyond product modification to become a strategic mechanism for reducing environmental impacts across the entire product value chain. The study therefore contributes to the

literature by providing evidence that eco-design, sustainable packaging, and lifecycle optimization collectively represent important drivers of environmental sustainability within manufacturing firms.

The findings reveal that green marketing innovation is widely embedded within manufacturing firms, reflecting the increasing integration of environmental considerations into customer engagement, distribution, and marketing communication. Firms predominantly adopted digital marketing platforms, sustainability-oriented marketing strategies, and logistics optimization initiatives that simultaneously reduced environmental impacts and improved operational efficiency. The qualitative findings reinforced these results by demonstrating that digital communication, customer feedback systems, optimized distribution networks, and environmentally focused promotional practices have become important mechanisms for reducing waste, transportation emissions, and unnecessary production. Overall, the findings indicate that green marketing innovation extends beyond promotional activities to encompass environmentally sustainable market delivery systems. This study therefore contributes to existing knowledge by demonstrating that digitalization and logistics optimization constitute critical channels through which marketing innovation enhances environmental sustainability in manufacturing firms.

The findings demonstrate that manufacturing firms have attained relatively high levels of environmental sustainability, primarily through regulatory compliance, resource efficiency, environmental conservation initiatives, and operational improvements. The strongest performance was observed in environmental certification, material utilization, corporate environmental responsibility, and energy efficiency, whereas greenhouse gas reduction, toxic emission management, and low-carbon supply chain practices remain comparatively less developed. The qualitative evidence confirmed that improvements in sustainability are being driven by modernization of production processes, water conservation, lean manufacturing, environmental management systems, and compliance with environmental regulations, although transitioning toward low-carbon operations remains a significant challenge. These findings suggest that environmental sustainability within Kenyan manufacturing is increasingly supported by integrated organizational, operational, and regulatory initiatives while highlighting decarbonization as an emerging area requiring further strategic investment. The study therefore extends previous research by demonstrating that sustainable environmental performance is achieved through the combined influence of resource optimization, regulatory compliance, operational innovation, and corporate environmental stewardship.

Direct Effects Structural Model

The direct effects structural model was estimated using Partial Least Squares Structural Equation Modeling (PLS-SEM) to examine the hypothesized relationships between the dimensions of green innovation strategies and environmental sustainability. The significance of the structural paths was assessed using the standardized path coefficients (β), t -statistics, and p -values obtained through the bootstrapping procedure. The results of the direct effects analysis are presented in Table 1.

Table 1. Direct Effects Structural Model

	Original sample (β)	Sample mean (M)	Standard deviation (STDEV)	T statistics (O/STDEV)	P values
Green Process Innovation -> Environmental Sustainability	0.245	0.248	0.087	2.810	0.005
Green Product Innovation ->	0.297	0.292	0.100	2.972	0.003

Environmental Sustainability					
Green Marketing Innovation -> Environmental Sustainability	-0.120	-0.114	0.098	1.220	0.222
GIS -> ES	0.386	0.387	0.137	2.813	0.005

Source: Field Questionnaire Results (2026)

Table 1 presents the direct effects of green innovation strategy dimensions on environmental sustainability. The structural model indicates that Green Process Innovation has a positive and statistically significant effect on Environmental Sustainability ($\beta = 0.245$, $t = 2.810$, $p = 0.005$), indicating support for the hypothesized relationship. Likewise, Green Product Innovation exhibits a positive and statistically significant effect on Environmental Sustainability ($\beta = 0.297$, $t = 2.972$, $p = 0.003$), demonstrating that improvements in environmentally sustainable products are associated with enhanced environmental sustainability outcomes.

Conversely, Green Marketing Innovation does not have a statistically significant direct effect on Environmental Sustainability ($\beta = -0.120$, $t = 1.220$, $p = 0.222$). Although the estimated coefficient is negative, the relationship is not statistically significant at the 5 percent significance level, indicating that the proposed direct relationship is not supported.

The higher-order construct, Green Innovation Strategies, has a positive and statistically significant direct effect on Environmental Sustainability ($\beta = 0.386$, $t = 2.813$, $p = 0.005$). The results therefore indicate that the overall implementation of green innovation strategies contributes significantly to improvements in environmental sustainability among manufacturing firms.

The structural model demonstrates that Green Process Innovation, Green Product Innovation, and the higher-order Green Innovation Strategies construct significantly influence Environmental Sustainability, whereas Green Marketing Innovation does not exert a significant direct effect. These findings provide the basis for subsequent examination of the indirect relationships through the proposed mediating variable, Green Supply Chain Management.

DISCUSSION OF FINDINGS

The findings demonstrate that green innovation strategies significantly enhance environmental sustainability among manufacturing firms in the South Rift region of Kenya. The higher-order construct of Green Innovation Strategies exhibited a positive and statistically significant effect on environmental sustainability ($\beta = 0.386$, $p = 0.005$), indicating that firms adopting integrated green innovation practices achieve superior environmental outcomes through improved resource efficiency, pollution prevention, cleaner production, and environmentally responsible operations. This finding supports the proposition of the Diffusion of Innovation Theory that organizational adoption of beneficial innovations contributes to improved organizational performance. The result is consistent with Ullah et al. (2021), who found that green innovation significantly enhances environmental initiatives and sustainable development among SMEs in Pakistan. Similarly, the findings corroborate those of Nzomo et al. (2023), who reported that green innovation strategies significantly improve sustainability performance among ISO 14001-certified manufacturing firms in Kenya. Likewise, the results agree with Yan and Zhang (2021), Arsawan et al. (2021), and Bett (2024), who concluded that green innovation contributes positively to environmental performance and sustainable development. However, unlike previous studies that conceptualized green innovation as a composite organizational capability, the present study extends the literature by empirically distinguishing the individual contributions of green process innovation, green product innovation, and green marketing innovation to environmental sustainability.

The study established that green process innovation positively and significantly influences environmental sustainability ($\beta = 0.245$, $p = 0.005$). The descriptive findings further revealed that manufacturing firms have increasingly invested in cleaner production systems, energy-efficient technologies, waste minimization, recycling initiatives, and environmental monitoring, although adoption of advanced clean technologies remains constrained by financial and technological limitations. These findings suggest that incremental improvements in production processes constitute the primary mechanism through which manufacturing firms enhance environmental sustainability. The results are consistent with Yan and Zhang (2021), who found that green innovation significantly improves environmental performance among environmentally intensive industries. Similarly, the findings support Arsawan et al. (2021), who concluded that environmental strategies strengthen the contribution of green innovation toward environmental performance. The findings also align with Wang et al. (2022), who observed that organizational capabilities supporting green innovation enhance sustainability outcomes. The present study contributes additional evidence by demonstrating that within manufacturing firms, process innovation directly improves environmental sustainability through operational resource optimization, pollution prevention, and efficient production systems.

The findings further indicate that green product innovation exerts the strongest positive direct influence on environmental sustainability ($\beta = 0.297$, $p = 0.003$). Manufacturing firms increasingly adopted environmentally sustainable product design, recyclable materials, sustainable packaging, product lifecycle management, and waste recovery systems, reflecting growing integration of circular economy principles into product development. These findings support Ullah et al. (2021), who reported that green innovation enhances sustainable development through environmentally responsible organizational practices. Likewise, the findings agree with Soewarno et al. (2019), who established that green innovation strategies significantly improve green innovation performance within manufacturing firms. Similarly, Su et al. (2020) found that green innovation strategies improve organizational performance by strengthening environmentally responsible business practices. While these previous studies emphasized innovation performance and business performance, the present study extends existing knowledge by demonstrating that environmentally sustainable product development directly contributes to measurable environmental sustainability within manufacturing firms.

Contrary to expectations, green marketing innovation did not exert a statistically significant direct influence on environmental sustainability ($\beta = -0.120$, $p = 0.222$). Although manufacturing firms reported widespread adoption of digital marketing, sustainability-oriented communication, environmentally friendly distribution systems, and logistics optimization, these practices did not independently produce measurable improvements in environmental sustainability. This finding suggests that marketing-related environmental initiatives may primarily strengthen stakeholder awareness, organizational image, and customer engagement rather than directly reducing environmental impacts unless complemented by substantive operational and product innovations. This result differs from the broader conclusions of Wang et al. (2022), who argued that organizational capabilities supporting green innovation generally improve sustainability outcomes, and from Ullah et al. (2021), who found an overall positive relationship between green innovation and sustainable development. The divergence may arise because earlier studies treated green innovation as a unified construct without isolating the individual effects of its constituent dimensions. By separately estimating the influence of green marketing innovation, the present study provides new empirical evidence that marketing innovation alone may be insufficient to generate direct environmental sustainability improvements within manufacturing firms.

The descriptive and thematic findings further demonstrate that manufacturing firms have attained relatively high levels of environmental sustainability through regulatory compliance, efficient resource utilization, environmental certification, lean production systems, and corporate environmental stewardship. Nevertheless, greenhouse gas reduction, toxic emission control, renewable energy adoption, and low-carbon supply chain practices remain comparatively less developed, indicating that environmental sustainability efforts are still largely concentrated on operational efficiency and regulatory compliance rather than complete decarbonization. These findings support Alyahya et al. (2022), who found that regulatory and institutional pressures encourage organizations to adopt environmentally responsible innovations. Similarly, the findings are consistent with Bett (2024), whose systematic review identified inadequate policy support, financial constraints, and institutional limitations as persistent barriers to effective implementation of green innovation initiatives. The present study

therefore provides contextual evidence that while Kenyan manufacturing firms have made substantial progress in integrating green innovation into their operations, continued investment in advanced clean technologies and supportive policy frameworks is necessary to accelerate the transition toward low-carbon manufacturing and long-term environmental sustainability.

The study advances the literature by demonstrating that environmental sustainability is achieved not through uniform adoption of all green innovation practices but through the strategic integration of those innovations that directly transform production systems and product development. The findings therefore provide empirical support for the Diffusion of Innovation Theory by showing that the environmental benefits of innovation depend not merely on innovation adoption itself but on the successful implementation of innovations that directly address environmental challenges within manufacturing operations. This contribution fills an important empirical gap in Kenyan manufacturing by distinguishing the relative effects of green process innovation, green product innovation, and green marketing innovation on environmental sustainability.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary of the Results

The study examined the influence of green innovation strategies on environmental sustainability among manufacturing firms in the South Rift region of Kenya using Partial Least Squares Structural Equation Modeling (PLS-SEM). The descriptive and thematic findings revealed that manufacturing firms have substantially integrated green innovation practices into their operations, although the level of adoption varied across the three dimensions. Green process innovation was primarily characterized by investments in energy efficiency, waste minimization, recycling, environmental monitoring, and cleaner production processes, while adoption of advanced clean technologies remained constrained by financial and technological limitations. Green product innovation was widely embedded through eco-design, recyclable products, sustainable packaging, product lifecycle management, and circular economy practices. Green marketing innovation was mainly reflected in the use of digital marketing platforms, sustainability-oriented customer communication, optimized distribution systems, and environmentally responsible promotional activities. The findings further established that firms had attained relatively high levels of environmental sustainability through regulatory compliance, resource efficiency, environmental stewardship, and operational improvements, although low-carbon production and greenhouse gas reduction remained comparatively underdeveloped.

The structural model results demonstrated that Green Process Innovation had a positive and statistically significant influence on environmental sustainability ($\beta = 0.245$, $p = 0.005$), indicating that improvements in cleaner production technologies, resource efficiency, and waste reduction significantly enhance environmental performance. Similarly, Green Product Innovation exerted a positive and statistically significant effect on environmental sustainability ($\beta = 0.297$, $p = 0.003$), suggesting that environmentally sustainable product design, packaging, and lifecycle management contribute significantly to environmental outcomes. However, Green Marketing Innovation had a negative but statistically insignificant effect on environmental sustainability ($\beta = -0.120$, $p = 0.222$), implying that environmentally oriented marketing practices alone do not directly translate into measurable environmental improvements. At the higher-order construct level, Green Innovation Strategies (GIS) had a positive and statistically significant effect on environmental sustainability ($\beta = 0.386$, $p = 0.005$), confirming that the combined implementation of green innovation strategies significantly enhances environmental sustainability among manufacturing firms.

Conclusions

The study concludes that green innovation strategies constitute an important organizational capability for improving environmental sustainability within manufacturing firms. The significant positive influence of the higher-order green innovation strategies construct demonstrates that firms adopting integrated environmental innovation practices achieve superior environmental outcomes through improved resource efficiency, pollution prevention, waste minimization, and environmental stewardship.

The findings further conclude that green process innovation and green product innovation are the primary drivers of environmental sustainability. Green process innovation improves sustainability by embedding environmental objectives within production processes through cleaner technologies, efficient resource utilization, and pollution control. Likewise, green product innovation contributes by promoting environmentally sustainable product design, recyclable materials, sustainable packaging, and lifecycle management, thereby reducing environmental impacts across the product value chain.

However, the study concludes that green marketing innovation does not independently improve environmental sustainability. Although firms have increasingly adopted digital marketing, environmentally focused communication, and optimized distribution systems, these initiatives do not directly generate measurable environmental performance unless supported by substantive operational and product-related environmental improvements. Overall, environmental sustainability is achieved through integrated organizational innovation rather than isolated marketing initiatives.

Recommendations of the Study

Manufacturing firms should strengthen investments in green process innovation by modernizing production systems, expanding the adoption of cleaner technologies, improving energy efficiency, reducing waste generation, and increasing automation that minimizes environmental pollution. These initiatives should be supported through continuous investment in environmentally friendly production technologies despite the initial capital requirements.

Firms should further expand green product innovation by prioritizing eco-design, recyclable materials, environmentally friendly packaging, product durability, and product lifecycle management. Greater emphasis should also be placed on circular economy practices, including waste recovery, remanufacturing, and recycling systems, to reduce environmental impacts throughout the product lifecycle.

Although green marketing innovation did not exhibit a significant direct influence on environmental sustainability, organizations should continue utilizing digital marketing platforms, sustainability communication, customer environmental education, and optimized distribution systems. These practices should complement operational and product innovations rather than function as standalone environmental strategies.

Managerial Recommendations

Managers should adopt an integrated green innovation strategy that simultaneously strengthens production processes, product development, and environmental management systems instead of implementing isolated environmental initiatives. Strategic resource allocation should prioritize investments that generate measurable environmental improvements, particularly cleaner production technologies, energy-efficient equipment, pollution control systems, and sustainable product development.

Management should also institutionalize environmental performance monitoring through regular measurement of energy consumption, emissions, waste generation, recycling performance, and resource utilization. Building employee environmental competencies through continuous training and strengthening cross-functional collaboration among production, research and development, marketing, and environmental management departments will further enhance successful implementation of green innovation initiatives.

Policy Recommendations

Government agencies should strengthen policies that encourage manufacturing firms to adopt green innovation through financial incentives, tax relief, low-interest green financing, research and development support, and investment subsidies for cleaner production technologies. Such interventions would reduce the financial barriers limiting the adoption of advanced green technologies among manufacturers.

Environmental regulators should continue strengthening environmental standards while promoting industry-wide adoption of eco-design, cleaner production, circular economy practices, and environmental management systems. In addition, greater collaboration between government agencies, manufacturing associations, research institutions, and universities should be encouraged to facilitate technology transfer, innovation diffusion, and capacity building for sustainable manufacturing. Policymakers should also develop targeted interventions that accelerate low-carbon manufacturing and greenhouse gas reduction, given that these areas remain comparatively less developed.

Theoretical Contribution

The study contributes to the Diffusion of Innovation (DOI) Theory by providing empirical evidence that the diffusion of green innovations does not occur uniformly across all dimensions of organizational innovation. While green process innovation and green product innovation significantly improved environmental sustainability, green marketing innovation did not exert a significant direct effect. These findings suggest that the environmental value of innovation depends not only on the adoption of new practices but also on the functional relevance of those innovations to core production and product development activities.

Furthermore, the significant positive effect of the higher-order Green Innovation Strategies construct ($\beta = 0.386$, $p = 0.005$) extends DOI Theory by demonstrating that environmental sustainability is more effectively achieved through the integrated adoption of complementary green innovations than through isolated innovation initiatives. The study therefore broadens the application of DOI Theory within sustainable manufacturing by showing that successful diffusion of innovation involves coordinated organizational implementation of process, product, and marketing innovations, with the greatest environmental benefits arising from innovations that directly transform production systems and product development.

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