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Role of Green Initiatives in Sustainable Performance of Manufacturing Sector: Moderation and Mediation Effects

Abstract

The manufacturing industry is one where sustainability has changed its nature, no longer limited to regulation but transformed into a strategic resource generating competitive advantage. The study examines how green actions that green entrepreneurial orientation represents, innovation through Industry 4.0 technologies, and investment in environmental management systems mutually affect and contribute to sustainable performance. It also explores the mediation effects of innovation performance and the moderation effects of top management commitment (TMC) in a model inspired by the Natural Resource-Based View (NRBV) and Natural Resource Orchestration Theory. The model explains the interaction between technological invention and environmental strategy to create long-term value. These findings have implications for industrial policy, corporate leadership, and sustainability practice. By integrating digital transformation, innovation, and environmental responsibility, manufacturing firms can align environmental concerns with competitiveness in the global resource-active landscape.

Keywords: Green Entrepreneurial Orientation, Industry 4.0, Environmental Management System, Top management commitment, Innovation Performance

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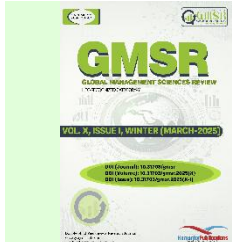


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The manufacturing industry is one where sustainability has changed its nature, no longer limited to regulation but transformed into a strategic resource generating competitive advantage. The study examines how green actions that green entrepreneurial orientation represents, innovation through Industry 4.0 technologies, and investment in environmental management systems mutually affect and contribute to sustainable performance. It also explores the mediation effects of innovation performance and the moderation effects of top management commitment (TMC) in a model inspired by the Natural Resource-Based View (NRBV) and Natural Resource Orchestration Theory. The model explains the interaction between technological invention and environmental strategy to create long-term value. These findings have implications for industrial policy, corporate leadership, and sustainability practice. By integrating digital transformation, innovation, and environmental responsibility, manufacturing firms can align environmental concerns with competitiveness in the global resource-active landscape.

Keywords: [Green Entrepreneurial Orientation](#), [Industry 4.0](#), [Environmental Management System](#), [Top management commitment](#), [Innovation Performance](#)

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Introduction

Recent studies have highlighted the critical importance of green entrepreneurial orientation (GEO) towards promoting the sustainability process in the manufacturing industry. According to Guo, Wang et al. (2020), firm GEO positively influences proactive development of a firm-level environmental strategy formation, and, hence, significantly enhances green innovation performance. The authors

demonstrate that this alignment mechanism, in particular supply chain learning, allows the firm endowed with a strong GEO to internalize environmental values into its innovation processes thus achieving increasingly higher sustainability performances. In modern-day industries, eco-friendliness in business environments, coupled with technology improvements, is indispensable in business organizations that need to become



innovative and environmentally friendly. Businesses are currently facing the increasing pressure of meeting the international environmental regulations and remaining competitive. Green entrepreneurship makes this course of action possible by promoting sustainable business motives that reduce the environmental footprint without lowering profitability. Over the past few years, the worldwide manufacturing industry has gone down the sustainability trail due to increased environmental awareness and the current rapid technological changes. In this respect, green entrepreneurial orientation (GEO), the use of Industry 4.0, and investment in environmental management have become instrumental strategies to enhance sustainable performance.

Hammad, et al. (2025) in a recent study show that alignment between Environmental, Social, and Governance (ESG) criteria and Industry 4.0, as a concept, that is, artificial intelligence (AI), internet of things (IoT), and blockchain, can enhance organizational flexibility and environmental governance despite limitations associated with cost and available capabilities. The research by Sahoo, Kumar et al. (2024) supports the idea that the meeting point of Industry 4.0 and the development of eco-products and their coordination in the supply chain has quantifiable returns regarding environmental sustainability, hence the criticality of the technological infrastructure in achieving long-term environmental targets. These findings emphasize the importance of a holistic and collective green approach involving innovation, commitment of the management, and green finance in initiating the process of improving the performance of the manufacturing sector. Green entrepreneurial initiatives place emphasis on strategies that increase the level of resource consumption, reduce emissions, as well as support sustainable business strategies without compromising stringent environmental standards. These programs stress green and sustainable operation: they recognize the opportunities tailored in accordance with environmental protection, resource efficiency, and reduction of the environmental impact of manufacturing. Based on the above following are the research questions of the study:

1. How do green entrepreneurial orientation, Industry 4.0 adoption, and environmental management investment impact sustainable performance?
2. Does innovation performance mediate the connection between green entrepreneurial orientation, Industry 4.0 adoption, and

environmental management investment and sustainable performance?

3. Does top management commitment moderate the connection between innovation performance and sustainable performance?
4. What is the combined effect of green entrepreneurial orientation, industry 4.0 adoption, and investment in environmental management, innovation performance, and top management commitment on sustainable performance?

Literature Review:

Green entrepreneurial and sustainable performance:

Green entrepreneurship comprises the coordinated incorporation of sustainability standards in business innovation and strategy. These efforts cannot be ignored when it comes to sustainable business practice since they indicate a meaningful dedication to sustainable ways of doing business and, at the same time, creating economic gains. According to Gerlich, Kanbach et al. (2025), green entrepreneurship goes beyond the requirement to engage in a laborious task of ensuring regulatory compliance and provides a public statement of corporate commitment to sustainable practice. Ecologically-based solutions (such as green design of products, resource use wisely, and efficient production processes) allow companies to reduce the load on nature and strengthen their sustainability in the long term. Mankgele and Fatoki (2024) also weigh in on the posit that even small and medium-sized enterprises (SMEs) can benefit, especially under green entrepreneurship. By taking.. advantage of their limited resources and the readiness to systematize newly emerging sustainable technologies, such companies have an opportunity to save costs, build strong relationships with their stakeholders, and exploit new opportunities in the new "green" markets.

H1: Green entrepreneurial initiatives positively influence sustainable performance.

Industry 4.0 and Sustainable Performance

The adoption of Industry 4.0, technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics, cyber-physical systems, and automation is now a decision that organizations need to make, particularly those that seek to remain competitive and achieve sustainable performance. Toward this goal is Industry 4.0, which aims for larger, faster, and greener activities with the help of digitalization. Berman et al. (2023) indicated that the use of these tools, companies will have the capability

not only to control energy or reduce material waste but also could optimize their production to reach more fine sustainability outcomes. Most notably, this occurs through real-time decision-making, predictive maintenance, and intelligent supply chains – business focus. These innovations not only lead to increased productivity and reduced operating costs but also help reduce the environmental impacts of manufacturing and service activities. Subsequently, it is observed that the firms are more conscious of regulatory requirements and customer demands towards greener products.

H2: Industry 4.0 adoption positively affects sustainable performance.

Investment in Environmental Management and Sustainable Performance

The field of environmental management has risen as an inevitable factor that stimulates sustainable performance in various industries. The range of action within this domain includes efforts to reduce the negative environmental implications, such as pollution control, waste reduction, increasing energy efficiency, and complying with governmental regulations. According to Li, Tang et al. (2023), the companies where significant resources are directed towards the environment management systems (EMS) and green technologies, as well as general sustainable practices, are constantly better in their environmental and operational performance. These types of efforts not only deal with environmental issues but also lead to savings in the long term, optimization of resource distribution, and a reduction in the company's image. Modern companies are facing raised demands of the governments, customers, investors, and civil society concerning environmental stewardship. Through investing in environmental management, organizations meet these needs as they build resilience and create innovation.

H3: Investment in environmental management positively affects sustainable performance.

Mediation of Innovation Performance between GEO and SP

Innovation performance is a very important mechanism that relates green entrepreneurial orientation (GEO) and sustainable performance. Green entrepreneurial orientation refers to a company's strategy that prioritizes creative, proactive, and risk-taking actions that support environmental sustainability. Companies with high GEO actively work to integrate ecological concerns into their innovation processes. They aim to create products, services, and technologies that minimize

environmental harm. Chang and Chen (2025) state that the direct benefit of GEO on sustainable performance often comes from better innovative abilities. Green innovation serves as a key link between green entrepreneurship and sustainability. This leads to better economic and environmental performance. Similarly, Mubeen, Nisar et al. (2024) highlights that green innovation significantly boosts the sustainability of SMEs through green dynamic skills and practices. According to Frare and Beuren (2022), firms that adopt green entrepreneurial values usually direct their strategic efforts toward innovations that create environmentally friendly solutions. These innovations, which include green products and energy-efficient processes, help turn GEO into real sustainable outcomes.

H4: Innovation performance mediates between green entrepreneurial orientation and sustainable performance.

Mediation of Innovation Performance between Industry 4.0 and SP

Innovation performance is rapidly being regarded as a critical mediator in the link between Industry 4.0 adoption and long-term success. Industry 4.0, which includes advanced innovations such as the Internet of Things (IoT), big data analytics, artificial intelligence (AI), cyber-physical systems, and smart automation, allows businesses to significantly modify their operations. However, the true value of these technologies in achieving sustainability lies in their ability to drive innovation. According to Wang, Jin et al. (2024), adopting Industry 4.0 technologies allows firms to improve their innovation performance. It does this by making product development more efficient, improving processes, and creating environmentally friendly solutions. The implementation of Industry 4.0 technologies fosters technological advancements, which ultimately contribute to sustainability. The introduction of smart technologies enhances sustainable production by reducing resource wastage and improving process efficiency.

H5: Innovation performance mediates between Industry 4.0 adoption and sustainable performance.

Mediation of Innovation Performance IEM and SP

Innovation performance serves as a critical link between investment in environmental management and the achievement of sustainable performance. Organizations that set aside resources for environmental initiatives like pollution control technologies, energy-efficient systems, eco-friendly materials, and sustainable waste management usually create an environment open to innovation. Yang,

Wang et al. (2024) state that environmental investments not only improve ecological results but also drive innovation by pushing companies to rethink traditional methods and embrace greener, more efficient practices. Companies that focus on environmental management often build new skills in product design, process optimization, and sustainable resource use. These capabilities reflect improvements in innovation performance, which in turn drive advancements in environmental, social, and economic dimensions of sustainability. As highlighted by Ye, Ouyang et al. (2023), the transition from compliance-driven environmental investment to strategic green innovation is critical to establishing long-term value and uniqueness in the market. Investments in environmental sustainability stimulate innovation, which further enhances long-term sustainable performance.

H6: Innovation performance mediates between investment in environmental management and sustainable performance.

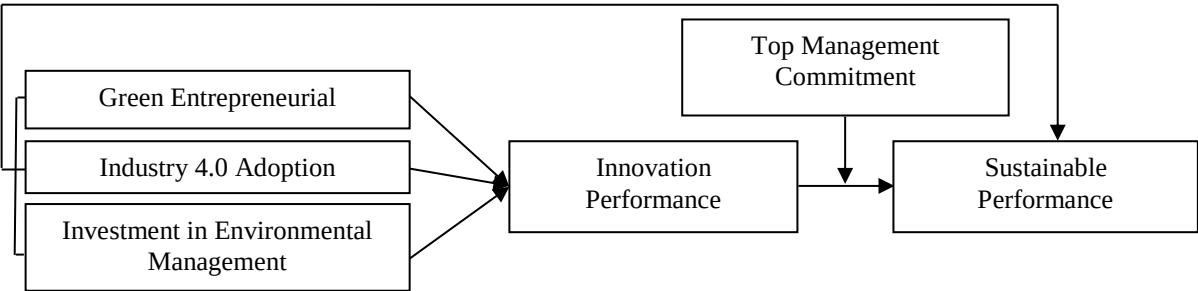
TMC Moderates between IP and SP:

Top management commitment has an important moderating function in enhancing the link between innovative performance and sustainable performance. Innovation performance, which measures a company's capacity to create new products,

processes, or practices, is critical for meeting sustainability objectives. However, the extent to which innovation leads to long-term results is frequently determined by top-level leadership's commitment and support. According to Wu, Wu et al. (2023), firms with highly committed top management teams are better positioned to leverage innovation efforts for sustainability by fostering a supportive culture, allocating necessary resources, and setting clear strategic priorities. Strong leadership and managerial dedication improve the efficiency of innovation in attaining the goals of sustainability. Wei, Abbas et al. (2023) argue that top management commitment increases the relationship between green intellectual capital and environmental performance, resulting in long-term competitive benefits. Top management commitment ensures that innovation initiatives are aligned with the firm's sustainability vision and objectives. Leaders who actively champion sustainability encourage cross-functional collaboration, risk-taking, and long-term thinking, which enhance the effectiveness of innovation in delivering environmental, social, and economic benefits (Lee and Kim 2022).

H7: Top management commitment moderates between innovation performance and sustainable performance.

Figure 1
Study Framework



The current study is a quantitative research that involves the gathering and analysis of numerical data. The current research applies a cross-sectional data-collection design, where the data were collected only once at a specific moment. A design of this nature allows the study of the relationships of variables without lengthy monitoring over time. Such a framework will especially be suitable in evaluating how such green initiatives are influential or familiar with future success in the manufacturing industry in Pakistan. A purposive sampling technique was adopted, targeting individuals with relevant knowledge and involvement in green initiatives. This

non-random method ensures that participants are well-positioned to provide insightful responses based on actual experience. To meet the requirements of SEM, a minimum of 400 responses was targeted. In total, around 474 valid responses were collected and analyzed after data cleaning and screening for accuracy and completeness. In current research, descriptive statistical methods were used, which helped to outline and display the demographic nature of the organizations that took part in the study in a coherent form. Some of the variables of interest included: sectorial categorization (i.e., textile, pharmaceutical, electronics, and food

manufacturing), and firm size, which was operationalized as small, medium, or large based on the number of employees and revenue earned. Frequencies and percentages were descriptive techniques used to define the distribution of these categories. In addition to this, mean and median values were calculated as measures of central tendency to estimate average values and midpoint values of the continuous variables (Number of years the facility has been in operation and the total number of employees), whereas the standard deviation was used to measure the dispersion within a group. All of this put together provided useful insight into the makeup of the sample and validated the adequacy of the data set in further exploration of green initiatives, innovation performance, and sustainable results within the sphere of manufacturing.

Results

This section analyzes the results of data obtained through a large-scale survey and with a view to empirically testing the above hypothesis and explaining the interconnections between the key study variables, or, in other words, Green Entrepreneurial Orientation (GEO), Industry 4.0 adoption, investment in environmental management, performance in innovation, commitment of top management, and sustainable performance. The results achieved through the use of the structured questionnaire were analyzed in tabular form and then interpreted using the data elicited through the survey. Several tests, such as descriptive statistics, reliability analysis, and validity tests, were carried out before the hypothesis testing to measure the fitness of the data to carry on with the investigation procedure.

Figure 2
Structural Model

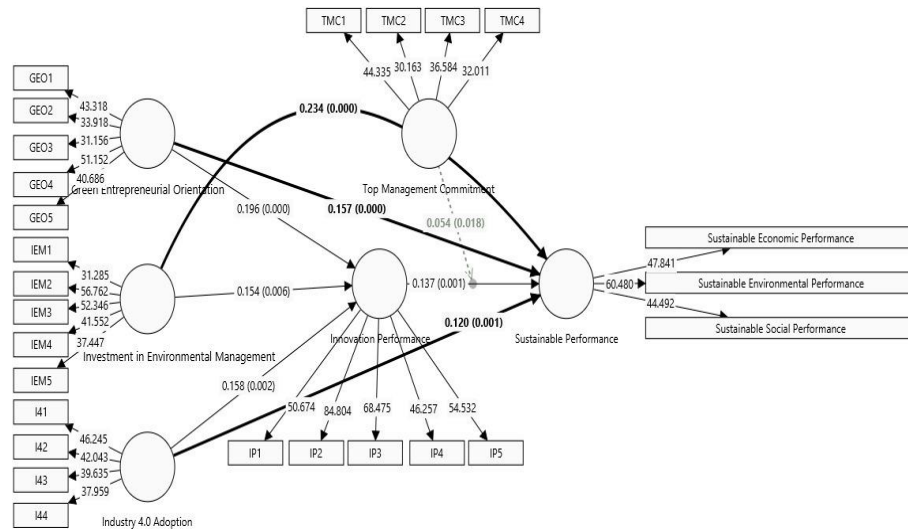


Table 1

Hypothesis	Paths	B-values	t-values	p-values	f-square	Remarks
H1	Green Entrepreneurial Orientation → SP	0.157	3.926	0.000	0.131	Supported
H2	Industry 4.0 Adoption → SP	0.120	3.510	0.001	0.137	Supported
H3	Investment in Environmental Management → SP	0.234	6.626	0.000	0.070	Supported
H4	Green Entrepreneurial Orientation → Innovation Performance → SP	0.027	2.537	0.013		Supported
H5	Industry 4.0 Adoption → Innovation Performance → SP	0.022	2.142	0.035		Supported
H6	Investment in Environmental Management → Innovation Performance → SP	0.021	2.224	0.028		Supported
H7	TMC* IP → SP	0.054	2.539	0.018	0.045	Supported

The results of structural equation modeling (SEM), which are given in Table 1, specify the direct and indirect relationships that exist between the key constructs that we are examining. H1 explored the effect of Green Entrepreneurial Orientation (GEO) on Sustainable Performance (SP). The research demonstrates a positive and statistically significant connection ($\beta = 0.157$, $t = 3.926$, $p < 0.001$), indicating that firms with a stronger orientation toward environmentally conscious entrepreneurship tend to achieve better sustainability outcomes. This implies that GEO contributes significantly to promoting sustainable practices and outcomes within organizations. H2 examined the impact of Industry 4.0 Adoption on SP. The results ($\beta = 0.120$, $t = 3.510$, $p = 0.001$) support the hypothesis, highlighting that the acceptance of Industry 4.0 technologies contributes significantly to sustainable performance. The implication here is that technological innovation not only improves operational effectiveness but also supports sustainability objectives. H3 investigated the link between Investment in Environmental Management and SP. The results ($\beta = 0.234$, $t = 6.626$, $p < 0.001$) show the strongest direct influence among all tested paths, underscoring that organizations allocating more resources to environmental initiatives are more likely to have better results in terms of sustainability. H4, H5, and H6 focused on the mediating role of Innovation Performance (IP) in the connection between the three predictors: GEO, Industry 4.0 Adoption, Environmental Management Investment, and SP. These results indicate that innovation performance partially mediates the association between these predictors and sustainable outcomes, implying that environmental and technological strategies enhance sustainability more effectively when they also lead to innovation. H7 tested the moderating impact of Top Management Commitment (TMC) on the relationship between Innovation Performance and SP. The moderation was statistically significant ($\beta = 0.054$, $t = 2.539$, $p = 0.018$), suggesting that the significant effect of innovation on sustainability is strengthened when top management is actively committed to the cause. Overall, all seven hypotheses were supported, reflecting the robustness of the proposed model. The f-square values, though small to medium, indicate meaningful effect sizes, further validating the significance of integrating green orientation, Industry 4.0, and environmental investments with strong leadership to drive sustainable outcomes through innovation.

Conclusion and Recommendation

Initial analysis confirmed the validity and reliability of all constructs, allowing for a robust examination of the relationships proposed in the theoretical framework. The proposed relationships were examined using the structural equation modelling (SEM) method, thus enabling the research study to account for both direct and indirect effects. The results highlighted that inner green tactics and technological progress not only have a direct influence on PW and New but also an indirect influence when organizations implement innovation and are supported by a dedicated leader. Empirically, the findings of the study offer substantial support for all the proposed hypotheses, thus confirming the research model and significantly extending our understanding of sustainable business practices. The GEO is a useful and direct contributor to sustainability. Enterprises that adopted environmentally sound entrepreneurial causes were more successful in terms of environmental, social, and economic sustainability. Industry 4.0 Adoption was positively related to Innovation Performance and Sustainable Performance, implying that digital transformation projects such as automation, artificial intelligence, and the Internet of Things (IOT) were conducive to ecological development.

Investment in Environmental Management showed the strongest direct effect on Sustainable Performance among the predictors. This result emphasized that proactive environmental investment is a key strategic way for achieving long-term sustainability goals. Innovation Performance served as a significant mediator between the strategic factors (GEO, Industry 4.0 Adoption, and Investment in Environmental Management) and Sustainable Performance. Firms that innovated in response to environmental and technological challenges achieved better sustainability outcomes. Top Management Commitment was discovered to considerably moderate the link between Innovation Performance and Sustainable Performance. Organizations where senior leadership was deeply engaged in sustainability efforts witnessed stronger positive impacts of innovation on overall performance. These findings collectively highlight that the path to sustainability is not linear but involves complex interactions between leadership, strategy, technology, and innovation.

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