

From Biostatistics to Environmental Compliance and Business Sustainability: The Contributions of Environmental Monitoring and Green Knowledge Sharing in Manufacturing Firms

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ABSTRACT

This study examines how biostatistical analytics capability contributes to environmental compliance and business sustainability through environmental monitoring and green knowledge acquisition. Guided by the natural-resource-based view, the study proposes eight hypotheses connecting five constructs. A cross-sectional survey was conducted using purposive sampling. Two hundred and ten (210) questionnaires were returned and used in data analysis. The data were analyzed using Structural Equation Modeling (SEM). Results indicate biostatistical analytics capability positively predicts environmental monitoring and environmental compliance, but does not significantly predict green knowledge acquisition. Environmental monitoring and green knowledge acquisition positively predict environmental compliance which lead to predict business sustainability. Mediation analysis indicates that environmental monitoring significantly mediates the relationship between biostatistical analytics capability and environmental compliance. However, the indirect effect through green knowledge acquisition is not significant. These findings highlight environmental monitoring as a pathway for translating analytical capability into compliance and suggest that firms should combine analytics with stronger environmental oversight and green knowledge acquisition.

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1. Introduction

Manufacturing firms face increasing pressure to balance operational efficiency, regulatory compliance, and long-term business sustainability (TOMMY, 2026). Environmental problems, resource constraints, industrial pollution, and the increasing demands of stakeholders have put environmental responsibility on the agenda of modern business (Ali et al., 2026). Environmental regulations should not be considered as operational constraints, but as a part of the strategic capabilities of the firms for increasing the effectiveness of the use of resources and competitiveness of the firms. Pollution prevention and sustainable development are all strategic issues in the natural-resource-based view of the firm, as emphasized by Hart (1995). Furthermore, Porter and Linde (1995) reported that the use of the right environmental regulations can encourage innovation and increase resource productivity. However, to achieve these results, companies need to have analytical, informational, and organizational skills to identify environmental risks, obtain the knowledge required, keep track of their operations, and ensure compliance.

Biostatistical analytics capability can be a tool to achieve these objectives by providing an ability to apply statistical tools to operational and environmental data for evidence-based decision making. This capability can assist businesses to recognize patterns, assess production process variations, spot possible environmental issues, and enhance the reliability of management choices (Ahmed, 2026). The latest studies on the impact of big data analytics capabilities also show that analytical resources can help improve environmental performance via organizational innovation and competitive advantage (Haylemariam et al., 2025). However, just knowing how to analyze is not enough to ensure responsible environmental practices. The value of their potential lies in whether firms convert analytical results into systematic environmental monitoring in making organizational decisions based on the analyses, and in implementing compliance mechanisms.

There are two mechanisms that analytical capability could play an important role in environmental compliance that are of potential interest: environmental monitoring and green knowledge acquisition. Environmental monitoring helps organizations to evaluate environmental concerns, assess operational activities, identify deviations and monitor compliance with relevant requirements. External stakeholders such as regulators, customers and communities, and organizational priorities (Delmas & Toffel, 2008) also influence organizational responses to environmental demands. Green knowledge acquisition refers to the process of acquiring technical, market and product information related to environmental protection (Sahoo et al., 2023). Wang et al. (2020) found that green knowledge acquisition plays a critical role between green learning orientation and green innovation. Similarly, Fuzi et al. (2022) investigated the mediating effect of environmental management systems between sustainability management accounting and organizational performance. The studies emphasize the significance of environmental management processes and knowledge-based capabilities to turn organizational resources into outcomes related to sustainability.

However, there is a lack of a unified perspective on the value added by biostatistical analytics capability to environmental compliance and business sustainability. The relationship between information technology capabilities, green intellectual capital and sustainable business outcomes has been studied by Ullah et al. (2021). Furthermore, the relationship between analytical capabilities and sustainable business outcomes via green innovation and competitive advantage has been studied by Haylemariam et al. (2025). The roles of environmental monitoring and green knowledge acquisition as separate mechanisms between biostatistical analytics capability and environmental compliance, which is noted explored by previous studies. Furthermore, environmental compliance should be seen as a regulatory result and as a means of achieving long-term business development. Discussing these connections can provide a more holistic picture of the link between analytics and benefits to the environment and organization.

Thus, the purpose of this study is to investigate the relationships between biostatistical analytics capability, environmental monitoring, green knowledge acquisition, environmental compliance, and business sustainability. Specifically, it examines the relationship between biostatistical analytics, environmental monitoring, green knowledge acquisition and environmental compliance in relation to business sustainability. The study also investigates the mediating effect of environmental monitoring and green knowledge acquisition between the biostatistical analytics capability and environmental compliance. This study brings together the analytical capability, environmental management processes, and knowledge acquisition in a single framework. The results can continue the research of sustainability-related organizational capabilities and provide practical advice for managers who want to enhance environmental management, compliance and promote business sustainability. In this way, the study offers a framework which can guide future empirical research in other industries and in other organizational environments.

2. Conceptual Framework of the Study

The natural-resource based view (NRBV) is best suited to explain this framework as it places environmental capabilities as a source of competitive advantage through pollution prevention and sustainable development (Hart, 1995). Biostatistical analytics capability is an organizational resource that enables enterprises to understand data, identify risks and uncover inefficiencies (Fosso Wamba et al., 2024). Environmental monitoring is a regular process for the monitoring and assessment of environmental conditions and operations in relation to the relevant requirements. Stakeholders' requirements and internal practices affect organizational responses to environmental pressures (Delmas & Toffel, 2008). Green knowledge acquisition is an additional tool for monitoring as it provides technical, market, and product knowledge for decision-making on the environment and green innovation (Wang et al., 2020). The mechanisms can transform analytical skills into improved environmental compliance. Compliance can help to reduce environmental exposure, provide legitimacy and promote efficient use of resources, which are important factors for business sustainability. This is consistent with the argument by Porter and Linde (1995) that improvement of the environment and competitiveness can reinforce each other. Thus, NRBV describes the direct links and proposed mediation of the environmental monitoring and green knowledge acquisition.

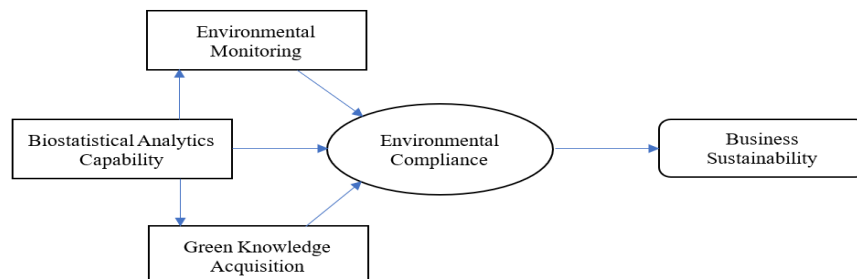


Figure 1: Conceptual Framework of the Study

3. Hypotheses Development

3.1 Biostatistical Analytics Capability

Biostatistical analytics capability is the ability to gather, analyze and interpret data using statistical methods for evidence-based decision making (Li et al., 2024). For manufacturing, data can include production variability, product quality, resource usage, waste generation, emissions, and operational efficiency data (Ahmed, 2026). The capability of analytics is not limited to the software itself, but rather to data resources, analytical technologies, employee expertise, and organizational routines that transform data into actionable insights (Gupta & George, 2016). In this context, this capability is expected to be the input that will support environmental monitoring, green knowledge acquisition and environmental compliance. Environmental risks can be prioritized using statistical analysis and assessed for corrective action by identifying trends and deviations. But it is important to note that capability is not the same as a willingness to learn or use tools.

3.2 Environmental Monitoring

Environmental monitoring is repetitive observation, measurement, recording and analysis of environmental conditions and the operational impacts of a firm (Francisco et al., 2026). In the manufacturing sector, it can involve monitoring emissions, waste, wastewater, energy consumption, raw-material usage, and improvements in environmental performance (AlSuwaidi & Kim, 2026). Monitoring can be used to identify issues, to compare performance to agreed thresholds and to provide evidence for acting. Records provide accountability and prompt corrective action decisions. Monitoring is a process-control activity to track the environmental conditions and to prevent or minimize environmental damage (Sargaonkar & Deshpande, 2003). In the context of this study, environmental monitoring is a process for converting the capability for analytics to environmental oversight and compliance. Monitoring is the measurement and follow-up process, it is not compliance itself, which is the process of applying applicable requirements.

Companies can leverage biostatistical analytics capability to convert operational data into information for environmental management. Analytics capabilities involve technological, human, and organizational resources for managing and analyzing data and using the analysis to inform decision making (Gupta & George, 2016). In manufacturing, abnormal consumption of resources, process variation, waste patterns, and changes in emissions may be identified by statistical analysis, and then a manager can set up indicators and systematically monitor environmental performance. Henri and Journeault (2008) identified several organizational uses for environmental performance indicators, such as compliance monitoring, decision making and continuous improvement. Another study that connects to this research is the study by Cheng et al. (2023) which demonstrates that big data analytics capability is associated with sustainability outcomes, providing evidence that analytical resources are useful when integrated into operations. Therefore, companies with greater biostatistical analytics skills are likely to be more successful in implementing regular, evidence-based environmental monitoring procedures. Hence, the following hypothesis is proposed:

H1: Biostatistical analytics capability can promote environmental monitoring.

3.3 Green Knowledge Acquisition

Green knowledge acquisition is the firm's process of acquiring and updating knowledge related to environmental protection and integrating it into operations (Abdelwahed et al., 2026). It could relate to cleaner technologies, environmentally friendly materials, product design, customer expectations, market trends and regulatory changes. A study carried out by Wang et al. (2020) examines the role of knowledge acquisition in the process of green learning and innovation, highlighting how acquired knowledge can contribute to the solutions for the environment. In the current context, biostatistical analytics capability can support managers to determine their information needs and understand the environmental information, and green knowledge acquisition can enrich the information base for responding. This information can be used to inform operational adjustments and compliance decisions. It is different from green knowledge sharing, which focuses on sharing knowledge among employees.

Capability of biostatistical analytics can foster green knowledge acquisition by enhancing a firm's capacity to interpret and learn from environmental information (Makhloufi, 2024). By analyzing the data, organizations can identify information gaps, patterns in operational data and assess different production or resource-use practices. These activities can be used to help navigate the search for technical, product and market information for making environmentally responsible decisions. According to Gupta and George (2016), the analytics capability relies on complementary resources and routines that transform data into useful insights. Cheng et al. (2023) discuss business intelligence, big data analytics capability, green knowledge management, and sustainability performance in the context of sustainability, focusing on the importance of analytical resources for knowledge-driven environmental management. Moreover, green knowledge acquisition has been linked to green innovation outcomes (Sahoo et al., 2023; Wang et al., 2020). Therefore, it is expected that the higher the analytics capability, the greener knowledge will be acquired. Hence, following hypothesis is proposed:

H2: Biostatistical analytics capability can promote green knowledge acquisition.

3.4 Environmental Compliance

Environmental compliance is the degree to which a company products, production processes, and activities comply with environmental laws, regulations, standards and formal requirements (Harahap et al., 2026). In manufacturing, it could be about emission control, waste management, safe handling of material, and production processes meeting the required standards (Sibi Kumar & Razaviarani, 2026). Compliance involves organizations being aware of the rules that are applicable, converting them into operating procedures and assessing performance against these rules. Environmental compliance is recognized as a crucial organizational outcome and as a factor in the relationship between organizational capabilities and business performance (Truong & Nguyen, 2024). In this framework, compliance is expected to follow from analytical capacity and compliance by monitoring and knowledge acquisition. It can also help the businesses sustain themselves by minimizing their regulatory exposure and enabling them to manage the environment in a credible way.

The ability to conduct biostatistical analytics can enhance environmental compliance by helping companies detect environmental risks, track performance trends, and make informed decisions based on data (Wolniak & Grebski, 2023). Compliance involves an organization knowing what is required and determining if products and production processes meet this compliance. Analytics can help with these activities by identifying irregularities, monitoring indicators and guiding corrective action to higher risks. Gupta and George (2016) define analytics capability as resources that facilitate data-driven decisions, and Henri and Journeault (2008) demonstrate that environmental performance indicators are used to ensure compliance and to inform environmental decisions in manufacturing companies. Big data analytics capability is also found to be associated with sustainability-oriented practices and outcomes (Cheng et al., 2023). Pollution prevention and environmental management can be strategically valuable capabilities from a natural-resource-based perspective (Hart, 1995). As a result, companies that have more biostatistical analytics are likely to exhibit higher environmental compliance. Hence, it is proposed that:

H3: Biostatistical analytics capability can promote environmental compliance.

Environmental monitoring is expected to help in the achievement of environmental compliance as it enables organizations to identify environmental impacts, monitor operating practices and to detect deviations from requirements. Absence of systematic monitoring may result in a lack of timely evidence to managers of whether emissions, waste handling, resource use or production procedures are meeting the standards. Monitoring helps to generate feedback in which the performance is measured, compared to legal or internal limits, and corrective measures are taken when there are differences. Henri and Journeault (2008) conclude that manufacturing companies use environmental performance indicators to monitor compliance, to make decisions and to drive continuous improvement. In a review of empirical evidence, Gray and Shimshack (2011) also conclude that monitoring and enforcement are key elements of regulatory compliance. The results indicate that monitoring can become an operational control of environmental obligations. As a result, companies that have a regular environmental monitoring program in place will have an easier time detecting and correcting environmental noncompliance. Thus, the following hypothesis is proposed:

H4: Environmental monitoring can promote environmental compliance.

Green knowledge acquisition can also be used to enhance environmental compliance (Abdelwahed et al., 2026; Baquero, 2025), as it can help firms to gain a better understanding of environmental requirements and how they can meet them. Technical knowledge can provide information for cleaner production and pollution control, and market and product knowledge can provide information on the expectations of the stakeholders and environmentally preferable alternatives. Learning relevant knowledge allows managers to convert environmental goals into actions. Wang et al. (2020) revealed that green knowledge acquisition is a mediator between green learning orientation and green innovation, which is a contribution to the environmental-oriented outcomes. In addition, green knowledge acquisition is found to be a determinant of green knowledge management and green technology innovation, which are also related to environmental performance (Sahoo et al., 2023). While these studies do not directly test all aspects of regulatory compliance, they do suggest that green knowledge enables firms to make informed environmental decisions. Thus, there is a higher probability that environmental compliance will be linked to higher green knowledge acquisition, leading to following hypothesis:

H5: Green knowledge acquisition can promote environmental compliance.

3.5 Business Sustainability

Business sustainability means the capability of a business to sustain itself and to compete in the future while meeting the expectations of the market and fulfilling its resource and environment responsibilities (Mushtaq, 2025). A wide view encompasses economic, environmental and social aspects of performance (Hashmi & Abdullah, 2026). The natural-resource-based view of the firm (Hart, 1995) explains that environmental capabilities could be a source of sustained competitive advantage. Ullah et al. (2021) show that green intellectual capital and information technology capability are related to business sustainability in manufacturing firms. This study provides a definition of business sustainability that is represented by the perceptions of long-term growth, industry competitiveness, sales related to sustainable products and long-term strategies. Environmental compliance can help achieve these outcomes by minimizing legal and reputational risks

and promote responsible operations.

Environmental compliance can be a part of business sustainability because it can help firms keep their legitimacy, minimize regulatory and reputational risks, and integrate environmental responsibility into their long-term business operations (Baah et al., 2021). Compliance can foster consistent practices, responsible use of resources, and prevention of interruptions due to non-compliance, penalties or corrective actions. Pollution prevention and responsible practices can contribute to sustained competitive advantage through the incorporation of pollution prevention into organizational capabilities (Hart, 1995). Porter and Linde (1995) also contend that good environmental design can foster innovation and increase the productivity of resources, but the effect is contingent upon the reaction of firms. Empirical findings also suggest that environmental compliance is a relevant mechanism linking organizational capabilities and business performance (Truong & Nguyen, 2024). These views indicate that compliance is not just a legal requirement, but could be a key component of continuity, competitiveness, and strategic planning. Therefore, it is expected that companies with better environmental compliance will have better business sustainability.

H6: Environmental compliance can promote business sustainability.

The relationship between biostatistical analytics capability and environmental compliance could be mediated by environmental monitoring (Ncube & Ngulube, 2024). As compliance benefits are realized using analytics in environmental monitoring routines. While analytics can process data and detect patterns, insights need to be transferred to indicators and operational controls in the environment to impact compliance. Monitoring is the mechanism that provides this by keep track of conditions, detect deviations, and trigger corrective actions. Gupta and George (2016) point out that the capability for analytics is founded on resources and routines that transform data into actionable decisions. Measurement routines are used to monitor compliance and to facilitate improvement, as demonstrated by Henri and Journeault (2008) with environmental performance indicators. The impact of information related practices on performance has been shown in related studies, such as the study by Fuzi et al. (2022) which analyzed environmental management systems as a mediator between sustainability management accounting and organizational performance. Thus, following indirect relationship is proposed:

H7: Environmental monitoring serves as an intermediary mechanism linking biostatistical analytics capability to environmental compliance.

The biostatistical analytics capability and environmental compliance could be indirectly linked through green knowledge acquisition (Sahoo, 2024), which transforms the analytical information into knowledge that is relevant to the decision. Patterns are identified through statistical analysis, but it is the environmental knowledge that is required to interpret the results and choose the correct response. The information can be used to assist companies in understanding their environmental responsibilities, pinpointing control measures, and ensuring adherence to environmental regulations. According to Gupta and George (2016), the capability to transform data into useful information is called analytics capability. Wang et al. (2020) define green knowledge acquisition as a channel by which green learning orientation leads to green innovation. Similarly, the researchers Sahoo et al. (2023) conclude that green knowledge acquisition also enhances green knowledge management and green technology innovation. Consequently, following hypothesis is proposed:

H8: Green knowledge acquisition acts as an intervening mechanism through which biostatistical analytics capability contributes to environmental compliance.

4. Methodology

In this study, a quantitative research design with a cross-sectional research approach was used to study the relationships between the biostatistical analytics capability, environmental monitoring, green knowledge acquisition, environmental compliance, and business sustainability. Primary data were collected from the manufacturing firms through a structured questionnaire survey from the respondents who are knowledgeable about the activities and environmental practices of the organizations. The target group included managers, supervisors and professionals with knowledge of operational management, environmental monitoring, regulatory compliance and sustainability practices.

Twenty-one items were adapted from previous research to measure five constructs. Biostatistical analytics capability was evaluated with four items adapted from Li et al. (2024) which included intention to use biostatistical tools, commitment, involvement in training in the use of these tools and learning about the use of the tools. Environmental monitoring was assessed with the following five items adapted from: monitoring environmental issues, observing environmental regulations, following environmental rules, following environmental procedures. Three items were used to measure the green knowledge acquisition, which were adapted from Wang et al. (2020) and included technical, market and product or service-related knowledge associated with environmental protection. The environmental compliance was evaluated by five items based on Truong and Nguyen (2024), which include compliance with national and international environmental requirements for products and production processes, and stringent government regulations. Lastly, business sustainability was assessed using four indicators based on the Ullah et al. (2021), which include long term growth, industry competitiveness, sales related to sustainability and long-term strategic development. All constructs were conceptualized as reflective and measured by the Likert scale format of the questionnaire. The scale items are as follows:

4.1 Biostatistical Analytics Capability (Li et al., 2024)

“Our SME plans to apply biostatistical tools in its business activities.

1. Our SME is committed to making efforts to implement biostatistical tools in its business activities.
2. Our SME plans to participate in training sessions on the application of biostatistical tools in business.
3. Our SME plans to learn about biostatistical tools to apply them in its business activities.”

4.2 Environmental Monitoring (Measured Based on Environmental Regulations) (Fuzi et al., 2022)

1. “Organization monitors and deals with environmental issues.
2. Organization complies with the environmental rules.
3. Organization monitors environmental regulations.
4. Organization complies with environmental procedures.
5. Organization is committed to environmental regulation.”

4.3 Green Knowledge Acquisition (Wang et al., 2020)

1. “Our firm obtains a lot of technical knowledge related to environmental protection.
2. Our firm obtains a lot of market knowledge related to environmental protection.
3. Our firm obtains a lot of product and service knowledge related to environmental protection.”

4.4 Environmental Compliance (Truong & Nguyen, 2024)

1. “Our products must meet national environmental regulations.
2. Our products must meet international environmental regulations.
3. Our production process must meet national environmental regulations.
4. Our production process must meet international environmental regulations.
5. It is important for us to comply with stringent government regulations on the environment.”

4.5 Business Sustainability (Ullah et al., 2021)

1. “Business sustainability is necessary for our company to ensure long-term growth.
2. Business sustainability helps our company to compete well in the industry.
3. Sustainability increases the sales of our company as consumers are more attracted to sustainable products.
4. Sustainability helps company firm to develop long-term strategies.”

To identify respondents who possessed the necessary organizational knowledge and could give informed assessments of the study constructs, purposive sampling was used. This method was suitable as it was necessary to obtain responses from people who had knowledge of the analytical capacities and environmental management of their firms. 285 questionnaires were distributed and 215 were returned. After screening, 210 questionnaires were used in the analysis, and five questionnaires were not used. The return rate of the questionnaires was 75.43% and usable return rate was 73.86% of the questionnaires distributed. The adequacy of the samples was determined by considering statistical power. According to G*Power (Cohen, 1988; Faul et al., 2009) for a regression model with three predictors, a medium effect size ($f^2 = 0.15$), a 5% significance level and 80% statistical power, a minimum sample size of around 77 observations is required. Consequently, 210 valid responses met or exceeded this standard. However, the appropriateness of the sample for PLS-SEM should also be considered based on the complexity of the model and the expected effect sizes (Kock & Hadaya, 2018).

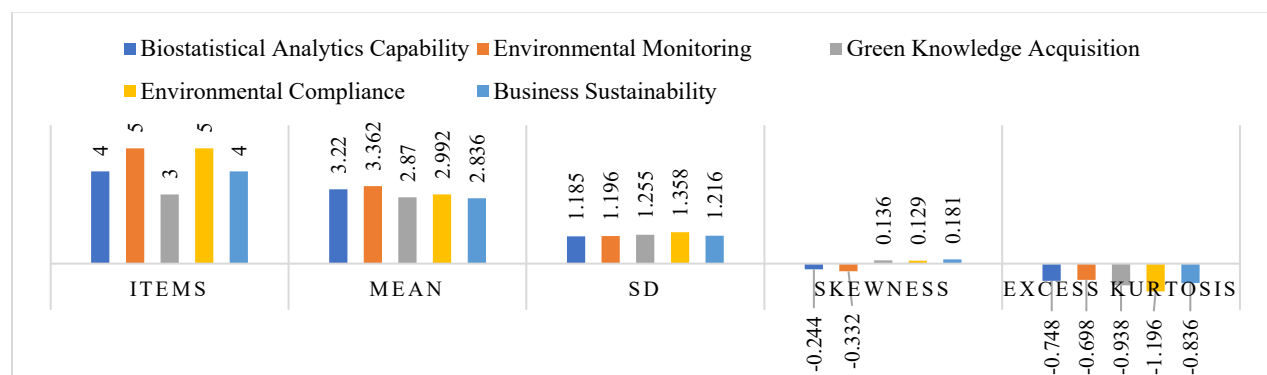
The data were gathered by a structured questionnaire with the measurement items of the questionnaire taken from the previous studies. The questionnaire aimed to collect the respondents' evaluation of analytical capacity, environmental monitoring, green knowledge acquisition, environmental compliance, and business sustainability. The respondents were chosen based on their knowledge of the organizational practices. Questionnaires returned were checked for completeness and usability prior to statistical analysis.

Descriptive statistics for the five constructs of the study are shown in Table 1. The highest mean ($M = 3.362$) was for environmental monitoring, followed by biostatistical analytics capability ($M = 3.220$). Green knowledge acquisition ($M = 2.870$) and business sustainability ($M = 2.836$) had the lowest mean. There was variation in respondents' assessments, with standard deviations ranging from 1.185 to 1.358. Skewness values ranged from -0.332 to 0.181 , while excess kurtosis ranged from -1.196 to -0.698 . The values suggest near-symmetrical distributions with little skewness. In general, the descriptive statistics suggest no significant deviations from the distributional symmetry. The descriptive statistics presented in Table 1 are shown in the graph in Figure 2.

Table 1: Descriptive Statistics

Variable	Items	Mean	SD	Skewness	Excess Kurtosis
Biostatistical Analytics Capability	4	3.220	1.185	-0.244	-0.748
Environmental Monitoring	5	3.362	1.196	-0.332	-0.698
Green Knowledge Acquisition	3	2.870	1.255	0.136	-0.938
Environmental Compliance	5	2.992	1.358	0.129	-1.196
Business Sustainability	4	2.836	1.216	0.181	-0.836

Note: SD = standard deviation. Values are aggregated across the items within each variable.

**Figure 2:** Representation of Descriptive Statistics

5. Findings

The convergent validity and reliability of the measurement model are evaluated in Table 2. Indicator loadings were between 0.827 and 0.954, which is greater than the recommended threshold of 0.70 (Aljumah et al., 2026; Sarstedt et al., 2022). The Cronbach's alpha values were between 0.908 and 0.942 and the rho_A values were between 0.908 and 0.942, which identified that the internal consistency of the questionnaire was good. The composite reliability scores ranged from 0.931 to 0.956, and the average variance extracted (AVE) scores ranged from 0.731 to 0.878. Convergent validity was supported by all AVE values being above the recommended minimum of 0.50. Overall, the results show acceptable measurement quality.

Table 2: Measurement Model Assessment

Construct	Indicator	Loading	Cronbach's α	rho_A	CR	AVE
Biostatistical Analytics Capability	BioAC1	0.873	0.912	0.913	0.938	0.792
	BioAC2	0.903				
	BioAC3	0.901				
	BioAC4	0.883				
Business Sustainability	BusS1	0.878	0.924	0.925	0.946	0.814
	BusS2	0.905				
	BusS3	0.923				
	BusS4	0.903				
Environmental Compliance	EnvC1	0.827	0.942	0.942	0.956	0.812
	EnvC2	0.922				
	EnvC3	0.921				
	EnvC4	0.926				
Environmental Monitoring	EnvC5	0.906	0.908	0.908	0.931	0.731
	EnvM1	0.864				
	EnvM2	0.868				
	EnvM3	0.861				
Green Knowledge Acquisition	EnvM4	0.828	0.930	0.932	0.955	0.878
	EnvM5	0.853				
	GreKA1	0.934				
	GreKA2	0.954				
	GreKA3	0.922				

Note. α = Cronbach's alpha; rho_A = Dijkstra–Henseler reliability; CR = composite reliability; AVE = average variance extracted. Factor loadings for Green Knowledge Acquisition were not provided in the supplied table.

The heterotrait–monotrait ratio (HTMT) values for assessing discriminant validity are shown in Table 3. The results reported are between 0.037 and 0.842, with the highest value being between environmental compliance and green

knowledge acquisition (HTMT = 0.842). The other values are also less than 0.85. Therefore, the findings indicate discriminant validity based on the criterion of 0.85, but the environmental compliance and green knowledge acquisition relationship is relatively close to the criterion. The results indicate that the constructs are empirically distinguishable based on the reported HTMT estimates.

Table 3: Discriminant Validity

Variable	BioAC	BusS	EnvC	EnvM	GreKA
Biostatistical Analytics Capability					
Business Sustainability	0.06				
Environmental Compliance	0.037	0.823			
Environmental Monitoring	0.812	0.162	0.157		
Green Knowledge Acquisition	0.055	0.737	0.842	0.126	

The HTMT results shown in Table 3 are presented in a visual format in Figure 3. The relatively high scores for environmental compliance and green knowledge acquisition are in line with their relatively close conceptual relationship. However, the reported values are still less than the criterion of 0.85. Therefore, the figure visually represents the reported evidence for discriminant validity.

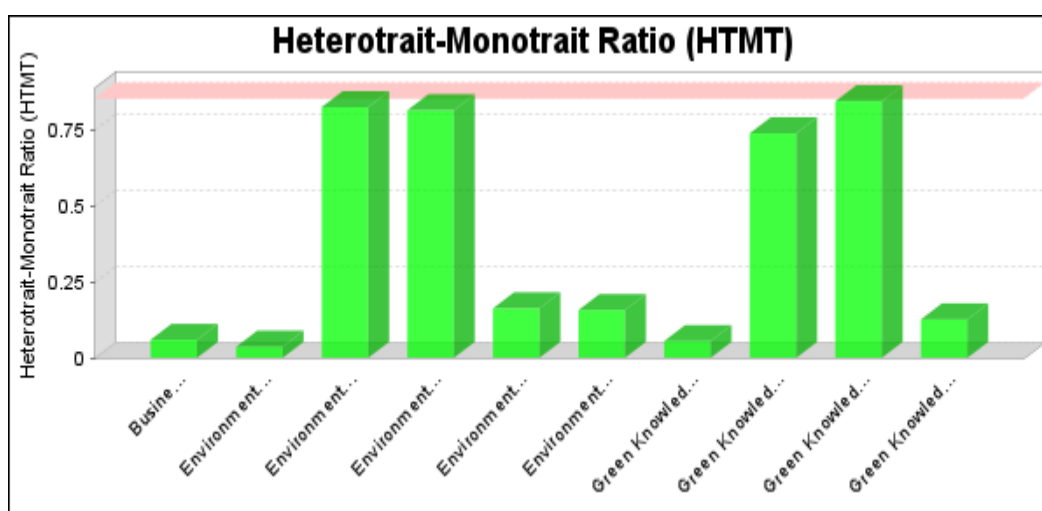


Figure 3: Representation of Discriminant Validity

The direct relationships between the study constructs were estimated and are presented in Table 4. Environmental monitoring is positively affected by biostatistical analytics capability ($\beta = 0.740$, $t = 31.215$, $p < 0.001$), supporting H1. The relationship between biostatistical analytics capability and green knowledge acquisition is not statistically significant ($\beta = 0.008$, $t = 0.110$, $p = 0.913$); consequently, the H2 is not supported. The ability to conduct biostatistical analytics is positively and significantly related to environmental compliance ($\beta = 0.117$, $t = 2.110$, $p = 0.035$), which supports H3. Environmental monitoring ($\beta = 0.141$, $t = 2.366$, $p = 0.018$) and green knowledge acquisition ($\beta = 0.778$, $t = 36.285$, $p < 0.001$) also positively affect environmental compliance, thus supporting H4 and H5, respectively. Lastly, environmental compliance has a positive effect on business sustainability ($\beta = 0.769$, $t = 36.674$, $p < 0.001$), which is in support of H6.

Table 4: Path Coefficient (Direct Effect)

	β	STDEV	T Statistics	P Values
Biostatistical Analytics Capability -> Environmental Compliance	0.117	0.056	2.11	0.035
Biostatistical Analytics Capability -> Environmental Monitoring	0.74	0.024	31.215	0
Biostatistical Analytics Capability -> Green Knowledge Acquisition	0.008	0.073	0.11	0.913
Environmental Compliance -> Business Sustainability	0.769	0.021	36.674	0
Environmental Monitoring -> Environmental Compliance	0.141	0.06	2.366	0.018
Green Knowledge Acquisition -> Environmental Compliance	0.778	0.021	36.285	0

Table 5 tests the mediating effects of environmental monitoring and green knowledge acquisition between biostatistical analytics capability and environmental compliance. The indirect effect is positive and significant ($\beta = 0.105$, $t = 2.353$, $p = 0.019$) and thus, H7 is supported. This result suggests that environmental monitoring is one of the major avenues by which biostatistical analytics capability can help to achieve environmental compliance. The indirect effect mediated by green knowledge acquisition is not statistically significant ($\beta = 0.006$, $t = 0.110$, $p = 0.913$). Hence, H8 is not

supported. The distribution of estimated indirect effects between biostatistical analytics capability and environmental compliance are shown in Figure 4.

Table 5: Path Coefficient (Direct Effect)

	β	STDEV	T Statistics	P Values
Biostatistical Analytics Capability -> Environmental Monitoring -> Environmental Compliance	0.105	0.044	2.353	0.019
Biostatistical Analytics Capability -> Green Knowledge Acquisition -> Environmental Compliance	0.006	0.057	0.11	0.913

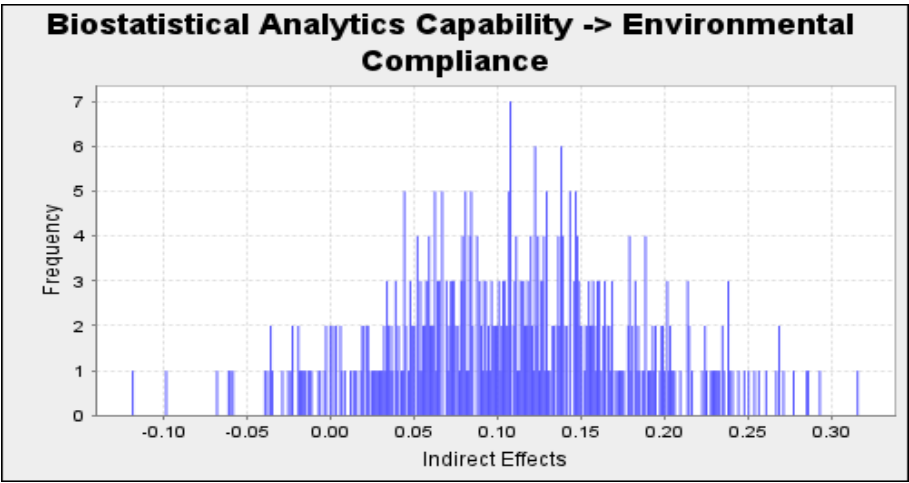


Figure 4: Indirect Effect Histogram

6. Discussion and Conclusion

This study investigated the role of biostatistical analytics capability in enhancing environmental compliance and business sustainability, emphasizing the mediating roles of environmental monitoring and green knowledge acquisition. Majorly, results support the proposed relationships among the biostatistical analytics capability, environmental monitoring, green knowledge acquisition, environmental compliance, and business sustainability. Biostatistical analytics capability positively affects environmental monitoring, supporting H1 ($\beta = 0.740$, $p < 0.001$). This finding indicates that analytical skills can be used to create systematic environmental management, identifying variations in operations, monitoring environmental indicators and identifying potential issues. This is in line with [Gupta and George \(2016\)](#) who highlighted that organizational resources and routines that support the capability of big data analytics can yield useful insights and enhance firm performance. Likewise, [Henri and Journeault \(2008\)](#) highlighted the importance of environmental performance indicators for compliance monitoring and managerial decision making. The relationship between biostatistical analytics capability and green knowledge acquisition is not significant ($\beta = 0.008$, $p = 0.913$), thus, H2 is rejected. This finding implies that analytical skills are not sufficient for firms to acquire environmental knowledge, unless they have complementary learning practices and knowledge-management routines.

Moreover, biostatistical analytics capability has a positive effect on environmental compliance ($\beta = 0.117$, $p = 0.035$), which supports H3. While statistically significant, this comparatively low coefficient suggests that analytical ability does not have a direct relationship with compliance that is very strong. This finding underscores the need to move from an analytical to an operational resource, rather than depending on the analytical resources alone. Environmental monitoring also supports H4 with a positive relationship with environmental compliance ($\beta = 0.141$, $p = 0.018$). This result aligns with the results of a review conducted by [Gray and Shimshack \(2011\)](#) which found that environmental monitoring and enforcement can lower the likelihood of future regulatory violations and emissions. The results of these studies collectively support the notion that analytical skills are more useful in environmental management when coupled with systematic monitoring and corrective action.

Additionally, the green knowledge acquisition is positively related to environmental compliance ($\beta = 0.778$, $p < 0.001$) and thus supports H5. Similarly, previous studies highlighted the positive relationship between green knowledge acquisition and environmental compliance ([Baquero, 2025](#); [Truong et al., 2025](#)). The result suggests that technical, market and product-related environmental knowledge could be a source of information for firms to grasp their responsibilities and to find suitable compliance actions. It supports the work of [Wang et al. \(2020\)](#) who concluded that green knowledge acquisition is a partial mediator between green learning orientation and green innovation. While their study was on innovation and not

compliance, both findings point to the need for environmental knowledge. Therefore, the relationship between green knowledge acquisition and environmental compliance has valuable importance for manufacturing companies (Truong et al., 2024).

Furthermore, business sustainability is positively related to environmental compliance ($\beta = 0.769$, $p < 0.001$), which supports H6. This finding indicates that environmental needs could be a factor in long-term growth, competitiveness and strategic continuity. It aligns with the study by Truong and Nguyen (2024), which investigated environmental compliance and innovation as the linkage between organizational capabilities and business performance. The finding also supports (Hart, 1995) natural-resource-based view that environmental management skills can be sources of sustained competitive advantage. Likewise, Porter and Linde (1995) maintained that properly crafted environmental requirements can encourage innovation and enhance the productivity of resources.

Lastly, mediation analysis shows that environmental monitoring significantly mediates the relationship between biostatistical analytics capability and environmental compliance (indirect effect $\beta = 0.105$, $p = 0.019$), which supports H7. The direct relationship is also important, and the results are consistent with partial mediation. The indirect effect of green knowledge acquisition is not significant ($\beta = 0.006$, $p = 0.913$), therefore, H8 is rejected. This is in line with the results of the insignificant relationship between analytics capability and green knowledge acquisition, although there is a strong relationship between knowledge acquisition and compliance. Overall, the results suggest that the environmental monitoring mechanism is the one that is more strongly supported as contributing to compliance via biostatistical analytics capability. Hence, companies can gain from the use of analytical tools together with structured monitoring processes, and from the reinforcement of their own organizational practices for the acquisition of environmental knowledge.

7. Implications of the Study

7.1 Theoretical Implications

This study helps to understand the role of biostatistical analytics capability in the environmental management mechanism for environmental compliance and business sustainability, which is a part of the natural-resource-based view (NRBV). First, there is a strong connection between biostatistical analytics capability and environmental monitoring, which means that analytical resources can be converted into structured environmental oversight. Second, the results reveal that environmental monitoring is an important mediator between analytics capability and environmental compliance, underscoring the need for operational routines to unlock the value of analytics resources. Third, the insignificant correlation between analytics capability and green knowledge acquisition contradicts the notion that analytical capability is a prerequisite to environmental learning. The proposed mediating role of green knowledge acquisition is not supported, even though this is a strong predictor of environmental compliance. This separation deepens the comprehension of analytical skills and knowledge-based resources in environmental management. Lastly, the positive link between environmental compliance and business sustainability reinforces the NRBV position that environmental management can be a source of long-term competitiveness for organizations.

7.2 Practical Implications

The findings have several practical implications for manufacturing companies aiming to enhance their environmental compliance and business sustainability. First, managers need to build the capacity of biostatistical analytics by providing adequate analytical tools, employee training, and systematic use of data. However, the results indicated that analytical skills should be linked directly to environmental monitoring activities and not considered as a separate technological investment. Companies can set up measurable environmental metrics, review operational data regularly, detect deviations and take corrective measures. Second, managers need to establish formal procedures for learning green knowledge from technical experts, regulatory bodies, suppliers, customers and environmental professionals. Since green knowledge acquisition is highly predictive of environmental compliance, firms should make sure that the knowledge relevant to environmental issues is used in operating procedures and environmental decisions. Third, organizations need to embed compliance goals into long-term plans, and know that environmental compliance is positively correlated with business sustainability. Senior management should periodically review environmental risks, evaluate progress and allocate responsibilities. These actions can contribute to the development of more systematic environmental practices, but the relationships between the actions and performance do not ensure performance in all organizational contexts.

8. Limitations and Future Directions

The study has some limitations that provide avenues for future research. Firstly, the cross-sectional design does not allow for causal interpretation, consequently longitudinal studies could investigate how the relationships change over time.

Second, purposive sampling may limit generalizability; larger and more diverse samples across manufacturing industries and geographical areas are needed in future research. Third, biostatistical analytics capability measures focus on learning and using tools rather than on actual organizational capabilities. Measures of actual analytical resources, skills, and routines should be developed or validated for future studies. Fourth, conceptually similar items are included in environmental monitoring and environmental compliance, which may impact the discriminant validity. These measures need to be improved and alternative models of measurement should be tested. Lastly, the mediation via green knowledge acquisition was not supported. Organizational learning, knowledge-sharing practices, and environmental management systems may be other mechanisms that could be explored in future research, with bootstrapped indirect effects and confidence intervals used to robustly assess mediation.

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