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Green Innovation Strategies in Achieving Corporate Sustainable Performance Through Big Data Analytics

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ABSTRACT

This paper, therefore, discusses the green innovative strategies that would result in corporate sustainable performance and specifically mediates the role of big data analytics. Sustainability is a critical call today, and industries across the globe have to adapt themselves accordingly to develop innovations that reconcile economic goals with environmental stewardship. Using a structured questionnaire from a sample of 394 employees in 32 manufacturing firms in Jordan, this study explores the interrelationships among green practices, data analytics, and sustainability performance using SEM via AMOS. The findings reveal that green innovation strategies have directly enhanced corporate performance, while big data analytics significantly enhances such a relationship by facilitating accurate, efficient, and data-driven decision-making. The findings provide clear evidence that integrating green innovation with advanced analytics is not only a strategic necessity but also a practical solution for achieving long-term sustainability and competitive advantage. This study offers valuable insights for industry leaders and policymakers by serving as a guide in implementing practices that align technological advancements with ecological responsibilities, thus fostering a more sustainable industrial ecosystem.

1. INTRODUCTION

Most industries in the world face a challenge between economic growth and environmental preservation [1]. Many organizations fail in effectively innovate within ecological boundaries due to rapid industrialization, high consumption of resources, and unprecedented need for sustainability [1-4]. The application of green innovative strategies would therefore seem to resolve such issues, but still, a practical hindrance remains as to how these methods would be integrated with advanced technological tools such as big data analytics. This not only diminishes their effectiveness but also severely undermines efforts toward corporate sustainable performance in an increasingly competitive and ecologically conscious market [5-7].

In fact, previous studies have mainly focused on independent impacts, such as how GIS promotes environmental sustainability or how big data analytics can improve operational effectiveness and decision-making, which may support environmental sustainability [8, 9]. consequently, there has been little attention paid to the synergistic potential of integrating big data analytics and GIS to optimize corporate sustainability performance (CSP). Therefore, it is in this background that this study is expected to contribute to breaching the aforementioned gap by providing critical knowledge on how data analytics would help advance green initiatives in full force. Previous recommendations have called for the intrinsic amalgamation of innovation and analytics for better decision-making and operational efficiency, hence providing a strong framework for sustainability [10-13].

The Jordanian manufacturing sector is a suitable context for this research because it presents a unique and relevant context for this study due to its pressing challenges and emerging opportunities in sustainability, where Jordan faces significant environmental constraints, such as water scarcity, and reliance on imported resources, which make sustainable practices particularly critical for industrial growth [4, 14]. therefore, by examining this sector, the study also offers transferable lessons for similar developing economies with comparable sustainability challenges. Hence, the aim of this study will revolve around establishing the role of green innovation strategies in achieving corporate sustainable performance, with big data analytics acting as a mediating factor. In more specific terms, this study tries to answer the following question: To what extent do big data analytics-enabled green innovation strategies influence corporate sustainable performance in manufacturing firms? The contribution of this study befits the development of actionable insights and strategic frameworks that organizations can use to advance ecological innovation in line with technological advancement, enabling them to realize sustainable success.

2. LITERATURE REVIEW

2.1 Green innovation strategies

Green innovation strategies refer to the organizational approach to develop and implement various products, processes, and systems that minimize environmental harm while developing economic benefits [15, 16]. These include the adoption of renewable energy technologies, eco-friendly product design, and resource efficiency, in embedding sustainability into the innovation process, firms can reduce costs, enhance brand reputation, and meet regulatory requirements. Green innovation not only appeals to corporate social responsibility but also is a competitive advantage in a time when environmental awareness is on the rise [5, 15, 17, 18].

2.2 Big data analytics

Big data analytics refers to the use of advanced computational techniques to derive actionable insights from large, complex data sets [11, 12]. In this regard, big data analytics in this study enables an organization to monitor environmental performance, optimize resource utilization, and predict market trends [9, 19, 20]. Real-time analysis by firms allows them to make informed decisions with innovation efforts aligned to their sustainability goals. This innovative technology bridges green strategies and their measurable performance outcomes [12, 21, 22].

2.3 Corporate sustainable performance

Corporate sustainable performance reflects the ability of an organization to continue its long-term success in accomplishing economic, environmental, and social objectives in harmony [1, 23-25]. The degree to which an organization successfully integrates sustainability into its business operations ensures better financial performance, less environmental impact, and increased stakeholder satisfaction. The concept of sustainable performance is multidimensional and thus requires a fit between business objectives and the broader priorities of society and ecology [2, 3, 26].

3. HYPOTHESES DEVELOPMENT

3.1 Green innovation strategies and corporate sustainable performance

Green innovative strategies have become an indispensable building block in the roadmap to sustainability performance for an organization. In other words, a green innovation strategy has influenced eco-friendly product development and processing and also assured efficient utilization of resources; these will promote operation efficiency and environmental responsibility to bring benefit to corporate sustainability performance [7, 18, 27]. Thus, aligning strategic greening practice with business goals can realize sustainable success with long-term branding reputation improvement and fulfillment of legislative environmental regulations [28-31]. Which are derived from the hypotheses that:

Hypothesis 1: *Green innovation strategies positively influence corporate sustainable performance.*

3.2 Big data analytics as a driver of sustainable performance

Big data analytics enables organizations to make effective decisions on resource allocation and predict market trends [32-34]. The capability enhances the effectiveness of green innovation strategies through actionable insights in environmental and operational performance [35]. By leveraging big data analytics, firms can identify improvement areas, track sustainability metrics, and ensure that innovation efforts yield measurable results; hence, it strengthens the sustainable performance outcomes [4, 19, 20]. Which is based on the following hypothesis:

Hypothesis 2: *Big data analytics positively influences corporate sustainable performance.*

3.3 Green innovation strategies and big data analytics

The integration of green innovative strategies with big data analytics results in a synergy of the highest sustainability outcomes [10]. While green innovative strategies lay the platform and path for greener behavior, big data analytics provide the mechanism for tracking, refining, and implementing the strategy. This dialectical process results in making the organizations not only effective but efficient too in order to attain better success which is for a long period [10, 19, 36]. Which emanates from the hypothesis that:

Hypothesis 3: *Green innovation strategies positively influence the adoption and effectiveness of big data analytics.*

3.4 The mediating role of big data analytics

Previous studies have highlighted the transformative potential arising from the integration of technological advancement with sustainability strategies but also pointed out considerable problems in the full realization of such synergy [19, 37]. The relationship between green innovation strategies and corporate performance in terms of sustainability often lacks sufficient empirical depth, with many firms struggling to translate innovative practices into measurable sustainability outcomes [7, 18, 38]. Challenges range from fragmented data systems, limited predictive capabilities, to a lack of alignment between innovation and performance metrics. Big data analytics closes this gap by making it possible for businesses to collect, analyze, and apply large volumes of information to hone green strategies [9, 39].

The mediating role of BDA in improving the relationship between GIS and CSP can be supported by a number of theoretical frameworks; for instance, by offering insights into environmental performance, resource efficiency, and market trends, BDA can be viewed as a strategic resource that is essential for improving the efficacy of GIS. This is in line with the Resource-Based view, which holds that organizations obtain a competitive advantage by efficiently utilizing valuable, rare, and unique resources [40, 41].

Furthermore, the interaction of green innovation and big data analytics takes place in a self-reinforcing cycle, in that continuously obtained data-driven insights further improve sustainable practices, that framework not only fills in the gap in innovation-performance linkages but also positions an organization to handle future sustainability challenges effectively [19, 42, 43]. In short, the integration of big data analytics transforms green innovation strategies into dynamic, adaptive systems able to achieve superior sustainable performance [20, 21]. Which is based on the following hypothesis:

Hypothesis 4: *Big data analytics mediates the relationship between green innovation strategies and corporate sustainable performance.*

4. METHODOLOGY

4.1 Research design

The quantitative research design was adapted for the study, in which the data from Jordanian manufacturing firms was collected through the use of a structured questionnaire. Reliability and validity of the same were pre-tested via a pilot study with 30 employees from different ranks in the industry. Minor changes were made in response to participant comments after this approach verified the items' dependability, relevance, and clarity. We also carry out the validation procedure for Convergent and discriminant validity are evaluated using Confirmatory Factor Analysis (CFA) after the measurement model has undergone Exploratory Factor Analysis (EFA) to determine the underlying structure of the constructs. Model fit indices showed that the measurement model was adequate for SEM, and reliability was verified using Cronbach's alpha, with all constructions surpassing the suggested cutoff of 0.70 [44, 45].

4.2 Population and sample

The population of the study was made up of employees in the Jordanian manufacturing sector, while its sample consisted of 32 locally operating industrial firms. The respondents were selected through a stratified random sampling technique to provide sufficient representation at different levels and functional areas of the Jordanian manufacturing sectors. This technique enhances the accuracy and generalizability of the results by taking into account the diverse characteristics of the population. For a wide representation of ideas and perceptions concerning green innovation strategies, big data analytics, and sustainable performance, the sample size reached 394 permanent employees. This sample size was perceived to be adequate to carry out structural equation modeling SEM, which generally requires large datasets for reliable statistical analysis, where These considerations ensured that the study had sufficient statistical power to detect meaningful relationships among GIS, BDA, and CSP [46, 47].

4.3 Measurement instruments

The study targeted the measurement of Green Innovation Strategies (GIS), Big Data Analytics (BDA), and Corporate Sustainable Performance (CSP) by adopting a structured questionnaire designed with 18 items distributed across these constructs. GIS was assessed using 7 items that captured the organization's adoption of eco-friendly practices, green technologies, and sustainable development initiatives [15, 48, 49]. BDA was measured by 5 items relating to the firm's capability to leverage big data analytics to make informed decisions and enhance processes [19, 50]. CSP was divided into three dimensions: social, economic, and environmental, each with 3 items measuring the contributions to social welfare, financial efficiency, and environmental sustainability, respectively. All responses were collected on a 5-point Likert scale to ensure nuanced insights into the constructs [3, 51]. The measurement model was first subjected to a thorough validation; through factor analyses, high reliability and validity of all constructs were confirmed, meaning that the questionnaire effectively represented the theoretical framework of the study.

4.4 Procedures and data analysis

The data collection was done through an electronic and physical distribution of the questionnaire to the targeted respondents. Follow-ups were done through email and telephone calls to ensure a high response rate. Data screening for completeness and accuracy was conducted, and the missing value was treated using mean imputation. Consequently, SEM was analyzed by means of AMOS software in order to test the hypothesized relationships. Descriptive statistics were used to summarize the characteristics of the samples, and CFA was used to validate the measurement model. Meditation analysis was done to see the role of big data analytics in the proposed framework [52-54].

The data collection process had certain possible drawbacks, especially with regard to response bias, where participants may give answers they feel are more socially acceptable, and acquiescence bias, where participants may have a tendency to agree with statements regardless of their actual assessments. Thus, to address these issues, the stratified random sample and pilot testing methods ensured representation across various organizational levels and functional areas in the manufacturing sector, further reducing selection bias.

5. RESULTS

5.1 Descriptive statistics

Descriptive statistics indicated that the overall sample consisted of 394 employees from 32 manufacturing firms in Jordan. In addition, the distribution of respondents was relatively well-represented in terms of gender, age, and years of experience to ensure wide representation across different demographic groups. Most of the firms are medium-sized, with a relatively high emphasis on the implementation of green innovation strategies and the use of data analytics.

The mean values for GIS, BDA, and CSP are displayed in Table 1. According to a Likert scale, the sample organizations adoption of green innovation strategies is comparatively high, as indicated by the mean GIS score of 4.21. This suggests that the majority of businesses are actively putting sustainability-focused projects and eco-friendly policies into effect. Although most businesses are adopting green practices, there is some variety in the extent of adoption, as indicated by the standard deviation of 0.78, which indicates considerable volatility. Furthermore, the average BDA value is 3.95, indicating that businesses are using big data analytics to improve processes and make decisions to a moderate degree. Even though the score is marginally below GIS, it nevertheless shows that data-driven methods are becoming more popular in the industrial industry. The BDA standard deviation is 0.75, suggesting that while some businesses may have more sophisticated BDA capabilities than others, practices were similar throughout the sample. Strong performance in the social, economic, and environmental facets of sustainability is indicated by the mean CSP value of 4.45. This suggests that for the vast majority of the sample's businesses, sustainability is a top priority. Therefore, the standard deviation of 0.80 indicates slight fluctuations, indicating that although many businesses are doing well in terms of sustainability, others may do better.

Table 1. Descriptive statistics of variables

Variable	Mean	Std. Dev.	Min	Max
Green Innovation Strategies	4.21	0.78	1.85	6.00
Big Data Analytics	3.95	0.75	2.00	5.95
Corporate Sustainable Performance	4.45	0.80	2.10	6.00

5.2 Confirmatory Factor Analysis (CFA)

Confirmatory Factor Analysis results have confirmed the measurement model's robustness and validity. Table 2 demonstrates reliability and validity analysis of constructs. All constructs indicated internal consistency with high reliability, with Cronbach's Alpha (α) values exceeding 0.85. Composite Reliability values fell within the range of 0.88 to 0.92, while Average Variance Extracted values surpassed the threshold of 0.50, thus confirming convergent validity. All the items have factor loadings above 0.79, showing that the indicators are strong representatives of their respective constructs. These results validate the appropriateness of GIS, BDA, and CSP for hypothesis testing. The validated model ensures reliable insights into the relationships among the study variables [45, 54-56].

Table 2. Reliability and validity analysis of constructs

Construct	Items	Loading	α	CR	AVE
Green Innovation Strategies (GIS)	GIS1	0.83	0.89	0.91	0.74
	GIS2	0.81			
	GIS3	0.85			
	GIS4	0.87			
	GIS5	0.86			
	GIS6	0.88			
	GIS7	0.84			
Big Data Analytics (BDA)	BDA1	0.80	0.85	0.88	0.72
	BDA2	0.82			
	BDA3	0.84			
	BDA4	0.79			
	BDA5	0.85			
Corporate Sustainable Performance (CSP)	**Social**				
	CSP_Social1	0.83	0.87	0.90	0.73
	CSP_Social2	0.81			
	CSP_Social3	0.85			
	Economic				
	CSP_Economic1	0.84	0.88	0.91	0.74
	CSP_Economic2	0.82			
	CSP_Economic3	0.80			
	Environmental				
	CSP_Environmental1	0.86	0.90	0.92	0.75
	CSP_Environmental2	0.84			
	CSP_Environmental3	0.88			

5.3 Hypothesis testing

Hypothesis 1: A path coefficient of 0.72 was observed between GIS and CSP, statistically significant at $p < 0.04$, thus supporting Hypothesis 1. This represents a strong positive relationship based on commonly used SEM thresholds, where path coefficients above this value are typically considered strong. The value of 0.72 implies that firms emphasizing green innovation strategies—such as energy efficiency, waste management, and sustainable product designs—are likely to achieve superior performance in environmental and financial outcomes. The high coefficient indicates that GIS plays a central role in driving sustainable performance, making it a cornerstone for sustainability-focused firms. This aligns with previous research emphasizing the significant impact of green practices on overall sustainability metrics.

Hypothesis 2: The direct effect of big data analytics on corporate sustainable performance was 0.62, also statistically significant ($p < 0.01$), thus supporting Hypothesis 2. This indicates that big data analytics plays an important role in enhancing decision-making processes, optimally utilizing resources, and enhancing overall performance regarding sustainability. Indeed, through better insights from data, firms can measure and improve their environmental and financial impact more effectively.

Hypothesis 3: Green innovative strategies positively influenced the adoption and effectiveness of big data analytics with a path coefficient of 0.67 ($p < 0.02$). Firms strong in green innovation practices are likely to adapt big data analytics since such technologies support their goals of sustainability. Green strategies and data analytics have a sort of synergistic relationship in which each reinforces the other.

Hypothesis 4: The results of the mediation analysis showed that big data analytics significantly mediated the relationship between green innovation strategies and corporate sustainable performance, with an indirect effect of 0.42 at a p-value of less than 0.00. This shows that big data analytics enhances the latter's potential to improve the outcome for sustainability-a point well-made in other discussions explaining how technological enhancement leads to more accurate and impactful environmental practices.

Considering the route coefficients for H1, H2, and H3 in Table 3, it is clear that there are substantial correlations between GIS, BDA, and CSP because the values greatly surpass the generally recognized cutoff of 0.3 for moderate impacts in SEM. However, H4 is in the moderate-to-strong range, indicating a significant mediating function for BDA, albeit somewhat lower than the direct effects. The reliability of the observed effects is also confirmed by the fact that all p-values are significantly below 0.05, indicating that associations are statistically significant.

Table 3. Hypothesis testing results

Hypothesis	Path Coefficient	t-Value	p-Value	Decision
H1: GIS → CSP	0.72	12.85	<0.04	Supported
H2: BDA → CSP	0.62	10.75	<0.01	Supported
H3: GIS → BDA	0.67	11.25	<0.02	Supported
H4: BDA mediates GIS → CSP	0.42	8.42	<0.00	Supported

5.4 Mediation affects

This study indicates how the integration of green innovation strategies with big data analytics significantly improves corporate sustainability performance. From the mediating analysis, Table 4 shows that big data analytics significantly influences the relationship between green innovation and sustainability outcomes, because the indirect effect is 0.42 (p-value < 0.00). The implication is that data-driven insights are useful in optimizing decision-making processes in sustainability practices. Therefore, the results showed that firms should focus on green innovation and big data analytics for long-term sustainability and competitive advantage. Consequently, Figure 1 presents the structural model that has been built. Eventually, this will enable companies to achieve operational efficiency, compliance with environmental regulations, and sustainable industrial ecosystem development.

Table 4. Indirect effect

Effect	Indirect Effect	p-Value
GIS → BDA → CSP	0.42	<0.00

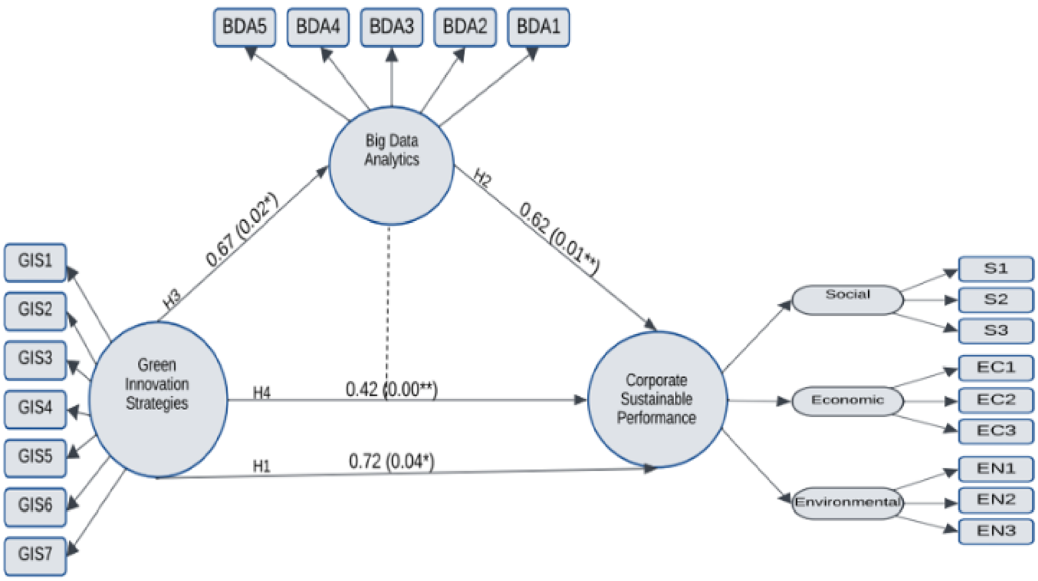

Figure 1. Structural model

6. DISCUSSION

These findings indeed proved that GIS significantly enhances CSP through the promotion of eco-friendly practices, resource efficiency, and environmental stewardship. Previous studies have also established that green innovation is key in meeting the sustainability goals of organizations [30, 57, 58]. For instance, it is stated that companies using the application of GIS perform better than their competitors on environmental and economic metrics [7, 18]. However, some studies also note that high initial investment in GIS might lead to a delay in the emergence of quantifiable benefits beyond the need for long-term planning. Hence, firms should balance immediate costs against long-term sustainability gains for best performance outcomes [6, 59].

Despite, the results of this study are consistent with previous studies regarding the separate effects of variables [13, 30, 60, 61]. However, what distinguishes this study from other previous studies is the synergistic relationship between GIS and BDA, which has not been as extensively explored in the literature.

This study shows how GIS promotes the adoption of BDA by establishing a novel ecosystem, whereas previous research frequently treats GIS and BDA as distinct influences on CSP [13]. The mediation effect of BDA (0.42) further underscores its importance as an enabler of sustainability, a nuanced finding that strengthens the theoretical understanding of their interconnectedness.

The findings show that by facilitating data-driven decision-making, operational effectiveness, and resource efficiency, BDA considerably improves CSP. This bolsters the findings of earlier studies [10, 19, 35, 62], such as the Environmental Sustainability, Business Analytics, and Terms of Use in Industry 4.0 study by Wolniak and Grebski [62], which demonstrated how data analytics improve alignment with sustainability goals by providing predictive insights. In fact, the research also showed that skilled personnel and technology infrastructure are necessary for the maximum use of BDA [62].

One of the challenges facing this technology is the digital divide among firms, which might reduce the rate of adoption [18, 63]. It is recommended that the organization develop a training program and invest in technology upgrading to realize the effective use of BDA in pursuing sustainable growth. This analysis has been validated because GIS will facilitate BDA adoption by creating an innovative ecosystem whose optimization calls for high-ended analytics [5, 64, 65].

This supports various studies indicating how innovative strategies stimulate technological advancement. On the other hand, some literature identifies that only a few companies with low digital maturity can barely integrate GIS and BDA seamlessly [9, 11]. This needs specific investments in the digital capabilities and innovation culture of firms. Firms should consider the integration of GIS and BDA as complementary tools to enhance their overall effectiveness. The results have validated the mediating role of BDA in the following way: it strengthens the influence of GIS on CSP by providing accurate and actionable insights [18, 20, 66].

This corroborates studies that emphasize the synergistic relationship between green innovation and analytics in achieving sustainability. However, many researchers opine that the mediation would depend upon organizational readiness and quality of the data infrastructure [41, 67]. Firms should, therefore, be encouraged to adopt an integrated approach where BDA will not be just a supporting mechanism but integral for green innovation initiatives in order to achieve the goals of long-term sustainability.

6.1 Theoretical and practical implications

The research represents a great theoretical contribution because it fills in the lacuna between green innovation strategies, big data analytics, and corporate sustainable performance. This study extends the literature by highlighting the mediating role of BDA in showing how advanced analytics transform green innovation into measurable sustainability outcomes. It is new and enriches the theoretical framework of sustainability with the holistic view of technological advancement to complement environmental strategies.

It is also of great practical relevance for industries in that it underlines dual adoption of GIS and BDA in view of competitive advantage and compliance issues. The findings would a fortiori have relevance for the manufacturing sectors in particular, where big data could be used in optimizing resources, lessening waste, and building up trust among the different types of stakeholders. It also mentions the fact that such strategies can realize their full potential only with targeted investments in digital infrastructure and employee training. Therefore, this study has turned into a guiding tool now for the policymakers and industry leaders who are keen on bringing in a sustainable industrial ecosystem in the Industry 4.0 era.

6.2 Limitations and future research

One of the study's limitations is that it only looked at the manufacturing sector in Jordan, which may have limited how broadly these findings may be applied to other sectors and geographical areas. Additionally, there is some bias introduced by the use of self-reported data, and the study's cross-sectional design precludes the drawing of any causal inferences.

To improve the generalizability of the results, these findings from the current study should be expanded to diverse sectors and geographical areas in further research. GIS and BDA long-term effects on CSP would be captured by a longitudinal study design, but mixed-methods approaches would also provide a more in-depth analysis of implementation issues through qualitative interviews or case studies. The literature may be further enhanced by other cutting-edge technologies like artificial intelligence, block chain, or the Internet of Things, which demonstrate how these developments enhance GIS and BDA by providing fresh approaches for businesses to promote sustainability practices and more successfully accomplish their environmental and commercial objectives.

7. CONCLUSION

This research investigates the role of integrating green innovation strategies with big data analytics in improving corporate sustainability performance. The findings of the research show that while GIS has a direct influence on sustainability outcomes, BDA can strengthen this relationship by providing more and better decision-making. The integration of both methods creates a strong theoretical framework from which companies match technological innovations with environmental objectives in the creation of conditions that will assist them in long-term sustainability and thus competitive advantage.

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