https://doi.org/10.52131/jom.2024.0604.0135

*i*RASD Journal of Management

Volume 6, Number 4, 2025, Pages 218 - 233

Journal Homepage:
https://journals.internationalrasd.org/index.php/jom

Environmental Governance, Big Data Analytics, and SDG Performance: A PLS-SEM Analysis of SMEs in ASEAN Economies

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ARTICLE INFO

Article History:
Received: September 27, 2024
Revised: December 21, 2024
Accepted: December 25, 2024
Available Online: December 27, 2024

Keywords:
Big Data Analytics Capability
Environmental Governance
Green Innovation
Regulatory Pressure
SDG Performance

Funding:
This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ABSTRACT

This study examines the relationship between the performance of Sustainable Development Goals (SDGs) in Small and Medium Enterprises (SMEs) in ASEAN economies and Big Data Analytics Capability (BDAC), Environmental Governance Pressure (EGP), and Green Innovation (GI). It continues to explore the mediating role of Data-Driven Decision-Making (DDDM) and the moderating role of Regulatory Pressure (RP). A cross-sectional, quantitative approach was adopted; utilizing survey data collected from SMEs across various ASEAN countries. The direct, indirect and moderating effects of the constructions were analyzed using Partial Least Squares Structural Equation Modelling (PLS-SEM). The findings confirm that BDAC, EGP, and GI play essential roles in enhancing SDG performance, both directly and indirectly through DDDM. DDDM plays a pivotal mediating role in transforming digital and governance capabilities into sustainable outcomes. Moreover, RP has a positive direct effect on SDG performance; its moderating impact on the EGP–SP relationship is marginally significant. According to the study, SMEs need to develop analytics capabilities and integrate data-driven cultures to achieve their sustainability objectives. Policy makers should reinforce regulatory structures and bolster SMEs through incentives and institutional guidance to encourage green innovation and alignment with the SDGs. This study proposes an integrated model linking digital capabilities, environmental governance, innovation, and decision-making to sustainable performance in the SME context, with empirical evidence from emerging ASEAN economies.

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Citation: Saeed, M. (2024). Environmental Governance, Big Data Analytics, and SDG Performance: A PLS-SEM Analysis of SMEs in ASEAN Economies. IRASD Journal of Management, 6(4), 218–233. https://doi.org/10.52131/jom.2025.0604.0135

1. Introduction

Environmental governance has become a key cornerstone in promoting sustainable development and long-term environmental results over the last two decades. It includes the institutions, rules, and practices that define the ways societies interact with the environment, where it seeks to strike a balance between ecological conservation and the needs for economic and social aspirations (Hussain et al., 2021). With the recent increase in global awareness about climate change and erosion of the environment, both public and private sectors are facing increased pressure to adopt environmentally friendly strategies. It is a strategic resource for sustainable competitiveness (Aragòn-Correa et al., 2020; Bhatti et al., 2025).

The role of Small and Medium Enterprises (SMEs) in ASEAN economies is a topic that is getting remarkable consideration within this larger sustainability discourse. These enterprises are the backbone of national economic development in South East Asia, playing an important role in gross domestic products and employment. However, SMEs have often found it difficult to comply with the Sustainable Development Goals (SDGs), particularly environmental responsibility, which is because of resource limitations, capabilities, and technological preparedness (Abdulaziz-al-Humaidan et al., 2021; Wided, 2020). Therefore, integration of sustainability in the business models therefore calls not only for awareness and regulation in tandem but tools to work with data as well as capability to innovate.

New research recognizes transformative power of Big Data Analytics (BDA) in environmental governance and sustainable development promotion. BDA allows firms to capture, process, and analyze huge environmental data volumes that can be used to monitor emissions, optimize resource utilization, and improve decision-making (Ferraris et al., 2019; Garmaki et al., 2016). Specifically, in the case of Industry 4.0, BDA enables the proactive, predictive, and participatory governance mechanisms that extend beyond compliance towards supporting sustainable innovation (Bousdekis et al., 2021). Such digital capabilities are often underdeveloped in SMEs, which offers important avenues for enhancing the environmental performance and coordinating with global sustainability agendas (Bhatti et al., 2019; Noshad et al., 2019).

The coupling of big data analytics and environmental governance is particularly crucial to the accomplishment of the SDGs within the ASEAN region where economic growth and environmental sustainability should go hand in hand. New evidence indicates that digitalization and data-centric methods of governance can greatly improve environmental performance on organization and regional level (Fan et al., 2024; Guo & Shen, 2024). Additionally, the regulatory regime and the stakeholders' expectations are changing rapidly, which necessitates SMEs to adopt dynamic capacities that facilitate green innovation and sustainable results (Ahmed et al., 2024a; Ahmed et al., 2024b; Guo et al., 2022; Sun et al., 2025).

While academic interest keeps increasing, the gap in understanding interactions between environmental governance and big data analytics capabilities constitute a tool to affect SDG-related performance in SME context, especially ASEAN countries, still persists. The majority of the earlier research has been directed toward large firms, or separate national contexts, without an overall model to encompass digital readiness, forms of governance and sustainability results in SMEs.

This research gap has been filled by the current study which is designed to develop and empirically test a structural model which can link environmental governance, big data capabilities and performance in SDGs among the SMEs in the ASEAN economies. PLS-SEM Partial Least Squares Structural Equation Modeling (PLS-SEM) is employed to examine direct and indirect relationships between these constructs in this study as a way of presenting new insights on how SMEs can utilize digital and governance capabilities to promote their contribution to sustainable development. The study extends the theories of digital-environmental integration in emerging markets while offering empirical support to policymakers and the Small to Medium Enterprise leaders in the ASEAN market.

2. Literature Review

2.1. Big Data Analytics Capability and Data-Driven Decision-Making

Big Data Analytics Capability (BDAC) refers to an organization's capability to access, process and analyze huge amount of data to underpin informed and strategic decision-makers (Mikalef et al., 2019). In recent years, BDAC has been identified as a significant enabler for digital transformation and innovation, especially in fast moving business situations. Firms that invest in BDAC will be inclined to have data-driven culture, leading to higher efficiency and accuracy in decision-making (Wamba et al., 2017). These capacities are particularly relevant for SMEs attempting to be agile and competitive amid complexity of sustainability needs.

According to research, BDAC improves managerial decisions regarding the quality and timeliness based on providing firms with actionable insights (Sabharwal & Miah, 2021). This is supported by Mikalef et al. (2019) who advance that BDAC empowers firms to dynamically respond to environmental uncertainty allowing decision to be in consonance with long term strategic goal. If these insights are desired, this study puts forth the following:

H1: Big Data Analytics Capability (BDAC) has a positive and significant effect on Data-Driven Decision-Making (DDDM).

2.2. Big Data Analytics Capability and SDG Performance

There is an emerging connection between the sustainability outcomes, including the Sustainable Development Goal (SDG) performance, and BDAC. Companies that can effectively apply analytics are in a much better position to monitor emissions, manage resources, and report on environmental and social scores (Hao et al., 2019; Kiron, 2013; Ragmoun, 2022). Companies can create real-time dashboards for sustainability reporting and performance monitoring through BDAC; as such, corporate strategies can be aligned with the global development goals (Lassala et al., 2021). In addition, companies with high BDAC are also likely to score highly on environmental responsiveness and long-term value creation in form of innovation and risk mitigation (Rialti et al., 2019). Therefore, the given study enhances the following hypothesis:

H2: Big Data Analytics Capability (BDAC) has a positive and significant effect on SDG performance.

2.3. Data-Driven Decision-Making and SDG Performance

Data-Driven Decision-Making (DDDM) is one of the key managerial practices in which organizations leverage data insights to inform sustainability pursuits and operational effectiveness. Firms that institutionalize DDDM are likely to make their resource allocation and strategic planning compatible with environmental and social objectives (Kim et al., 2014). While sustainability problems are in the spotlight of such corporate concerns, DDDM proves to be an integration instrument of ecological aspects into ordinary business decisions. According to Peng et al. (2020), data-centric decision-making enhances the environmental governance performance, especially in areas facing complex environmental issues. Consequently, this study proposes:

H3: Data-Driven Decision-Making (DDDM) has a positive and significant effect on SDG performance.

2.4. Environmental Governance Pressure and Decision-Making

Environmental Governance Pressure (EGP) includes formal and informal norms, institutional prescriptions, and policy structures through which firm-level environmental conduct is guided (Hou et al., 2021; Wang, Gillani, Balsalobre-Lorente, et al., 2025). Nongovernmental organizations that operate in regulatory contexts that have their environmental standards well defined, tend to invest more in analytical systems to adhere to and react to governance requirements.

Zhou et al. (2021) argues that regulatory and community pressures will positively influence corporate responses in improved environmental monitoring and reporting systems. In consideration of these arguments, following is the proposed hypothesis:

H4: Environmental Governance Pressure (EGP) has a positive and significant effect on Data-Driven Decision-Making (DDDM).

2.5. Environmental Governance Pressure and SDG Performance

Environmental governance frameworks are crucial in terms of aligning firms to SDGs. High pressure for governance triggers adoption demand of ecological practices and reports, particularly industries that are at the risk of ecological risk (Tyler et al., 2023; Wang, Gillani, Sharif, et al., 2025). Once the governments and institutions create open and binding policies, firms are more likely to behave in a proactive manner and integrate the sustainability measures to their operations.

H5: Environmental Governance Pressure (EGP) has a positive and significant effect on SDG performance.

2.6. Green Innovation and Decision-Making

Green Innovation (GI) is the capacity of an organization to advance new products, processes, or practices to minimize the adverse impact on the environment (Karimi Takalo et al., 2021). Innovation initiatives in most cases need strong data support in the measuring of environmental benefits, risks and performance (Yang, Shafiq, Nazir, et al., 2024). Hence green innovation spurs efforts to intensify data-oriented practices pushing firms to embrace technologies that guide a sustainable decision-making process. Leveraging off these insights, the following hypothesis has been proposed.

H6: Green Innovation (GI) has a positive and significant effect on Data-Driven Decision-Making (DDDM).

2.7. Green Innovation and SDG Performance

The role of green innovation in sustainability performance is highly known in literature (Wang et al., 2024). According to Lassala et al. (2021), firms that care for green innovation can do more towards achieving environment and social goals compatible with the SDGs. New concepts in product design, recycling and renewable energy as well as eco-efficiency directly led to better sustainability indicators (Yang, Shafiq, Sharif, et al., 2024). Therefore, this study posits:

H7: Green Innovation (GI) has a positive and significant effect on SDG performance.

2.8. Regulatory Pressure and SDG Performance

Regulatory Pressure (RP) refers to coercive influence of government policies and compliance standards that determine corporate environmental behavior. Tyler et al. (2023) explain that SMEs usually address such pressure by integrating sustainability, enhancing waste disposal, and developing green capabilities. Strong regulatory regimes increase the chances of businesses to match their operations to the SDG priorities. Thus, the hypothesis is:

H8: Regulatory Pressure (RP) has a positive and significant effect on SDG performance.

2.9. Moderating Role of Regulatory Pressure

Environmental Governance Pressure may have different influences on the SDG performance depending on the level of regulation enforced. The pressure that governance has on the sustainability outcomes in countries or regions with more active regulatory institutions are expected to be accentuated (Zhou et al., 2021). This gives rise to the following moderation hypothesis:

H9: Regulatory Pressure (RP) positively moderates the relationship between Environmental Governance Pressure (EGP) and SDG performance.

2.10. The Mediating Role of Data-Driven Decision-Making

Researchers highlight the role of understanding mediating mechanisms in the digital-sustainability connection in recent studies. According to Mikalef et al. (2019), DDDM serves as a conduit whereby BDAC and other organizational capabilities realized performance outcomes. In the same way, governance structures and innovation exercises are more likely to generate sustainability advantages when moderated by powerful data-driven procedures (Hao et al., 2019). Based on this logic, following mediation hypotheses are proposed:

H10: Data-Driven Decision-Making (DDDM) mediates the relationship between Big Data Analytics Capability (BDAC) and SDG performance.

H11: Data-Driven Decision-Making (DDDM) mediates the relationship between Environmental Governance Pressure (EGP) and SDG performance.

H12: Data-Driven Decision-Making (DDDM) mediates the relationship between Green Innovation (GI) and SDG performance.

3. Data and Methodology

3.1. Research Design

This research involved quantitative, cross-sectional design in which the interrelations between Big Data Analytics Capability (BDAC), Environmental Governance Pressure (EGP), Green Innovation (GI), Data-Driven Decision-Making (DDDM), Regulatory Pressure (RP), and Sustainable Development Goal (SDG) performance for small and medium For model estimation was used the Partial Least Squares Structural Equation Modeling (PLS-SEM) technique as considering its applicability to complex models with both mediating and moderating effects, as well as studies with great predictive capacities.

3.2. Population and Sample

The target populations included small and medium enterprises (SMEs) in diverse industries through selected ASEAN countries such as Malaysia, Indonesia, Vietnam, Thailand and Philippines. These countries were selected because of an active SME sector, as well as the increasing focus on digital transformation and sustainability.

A purposive sampling technique was employed to ensure the inclusion of SMEs that had undertaken digital and sustainability-related initiatives. The key informants were mid- to senior-level managers responsible for data analytics, sustainability, innovation, or compliance functions. The study collected responses from 400 SMEs, ensuring adequate statistical power for PLS-SEM analysis.

3.3. Data Collection

Data was collected through a structured online survey, distributed via professional networks, chambers of commerce, and industry associations. The questionnaire consisted of multiple-item scales adapted from validated instruments in previous studies. Before full deployment, a pilot test was conducted with 30 SME managers to ensure clarity and relevance. Minor adjustments were made based on feedback.

3.4. Measurement Instruments

All constructs were measured using multi-item Likert scales ranging from 1 (“Strongly Disagree”) to 5 (“Strongly Agree”). The measurement items were adapted from established studies.

Table 1
Variables Name, Type and Description

Variable Name	Type	Description
SDG Performance (SDGP)	Endogenous (DV)	Measures how well SMEs align with and contribute to the UN SDGs.
Environmental Governance (EG)	Exogenous (IV)	Refers to the policies, regulations, and institutional frameworks guiding sustainable practices.
Big Data Analytics Capabilities (BDAC)	Exogenous (IV)	Represents the technological and analytical capabilities to harness big data.
Green Innovation (GI)	Exogenous (IV)	Captures the extent of public financial support for environmental sustainability in SMEs.
Data-Driven Decision Making (DDDM)	Mediator	Mediates the relationship between BDAC and SDG Performance (SDGP) by showing how data analytics translate into sustainable decisions.
Regulatory Pressure (RP)	Moderator	Moderates the relationship between Environmental Governance (EG) and SDG Performance (SDGP), enhancing or weakening the effect based on external compliance pressures.

Table 2
Variables Measurement

Variable	Code	Short Name	Measurement Item
Sustainable Performance (Abdulaziz-al-Humaidan et al., 2021)	SP1	Economic Efficiency	Our firm has improved profitability, reduced costs, and enhanced economic efficiency through sustainable practices.
	SP2	Environmental Impact	Our firm actively reduces waste, improves energy efficiency, and minimizes pollution to protect the environment.
	SP3	Social Responsibility	Our firm promotes employee well-being, ethical practices, and engages in community-oriented initiatives.
	SP4	Operational Excellence	Our firm has improved product quality, innovation, and customer satisfaction through sustainable initiatives.
	SP5	Overall Firm Success	Our firm has strengthened its market position, competitiveness, and growth through sustainability practices.
Environmental Governance Performance (Guo et al., 2022)	EGP1	Solid Waste Management	Our firm ensures high levels of solid waste consolidation across operations.
	EGP2	SO_2 Removal Rate	Our firm complies with industrial standards for removing sulfur dioxide emissions.
	EGP3	Urban Green Coverage	Our facilities contribute to enhancing green coverage in urban or built-up areas.
	EGP4	Non-Hazardous Waste Treatment	Our firm ensures the safe and non-hazardous treatment of domestic waste.
	EGP5	Sewage Treatment Efficiency	Our firm supports effective urban sewage treatment to minimize environmental harm.
Big Data Analytics Capabilities (Kim et al., 2014; Kiron, 2013; Wamba et al., 2017)	BDAC1	Data Infrastructure	Our firm has the infrastructure necessary to store and manage large volumes of data.
	BDAC2	Analytics Skills	Our employees possess the skills required to analyze big data effectively.
	BDAC3	Data Integration	We integrate data from various sources to improve our decision-making processes.
	BDAC4	Strategic Use of Analytics	We utilize big data analytics to support strategic business decisions.
Green Innovation (GI) (Karimi Takalo et al., 2021)	GI1	Eco-Friendly Products	Our firm has developed products that reduce environmental impact.
	GI2	Green Process Innovation	Our firm has improved production processes to reduce waste and emissions.
	GI3	Sustainable Technology Use	Our firm uses environmentally friendly technologies in its operations.
	GI4	Resource Efficiency Innovation	Our firm introduces innovations that reduce material and energy consumption.
Data-Driven Decision Making (DDDM) (Bousdekis et al., 2021)	DDDM1	Evidence-Based Culture	Our firm makes strategic decisions based on systematic data analysis.
	DDDM2	Real-Time Insights Use	Our firm uses real-time data to support key business decisions.
	DDDM3	Analytical Decision Tools	Our decision-making is supported by analytical tools and data visualization.

	DDDM4	Data Integration in Strategy	Data insights are consistently integrated into our strategic planning process.
Regulatory Pressure (RP) (Tyler et al., 2023)	RP1	Environmental Compliance Demand	Our firm faces increasing pressure to comply with environmental regulations.
	RP2	Regulatory Monitoring	Government agencies frequently monitor our environmental practices.
	RP3	Penalty Risk Awareness	Our firm is aware of penalties or sanctions for non-compliance with green laws.
	RP4	Policy Influence on Strategy	Environmental regulations significantly influence our strategic planning.

3.5. Common Method Bias Control

To mitigate the risk of common method bias (CMB), several procedural and statistical remedies were applied. Procedurally, respondents were assured of anonymity and confidentiality, and items were randomized to reduce response patterns. Statistically, Harman's single-factor test was performed, and the variance inflation factors (VIFs) were examined using full collinearity tests; all VIF values were below the recommended threshold of 3.3, suggesting no substantial CMB.

3.6. Data Analysis Strategy

Data was analyzed using SmartPLS 4, which is particularly suited for exploratory models, mediation and moderation testing, and studies with relatively smaller samples. The analysis followed a two-step approach: Measurement Model Assessment: Evaluating reliability, convergent validity (via AVE and outer loadings), and discriminant validity (via Fornell-Larcker and HTMT ratios). Structural Model Assessment: Testing hypothesized relationships through path coefficients, bootstrapped t-statistics (5,000 resamples), and p-values. Mediation was assessed using indirect effect significance, while moderation was examined through interaction terms. Model fit was evaluated using the Standardized Root Mean Square Residual (SRMR), with values below 0.08 indicating acceptable model fit.

4. Results

4.1. Convergent Validity Test

The convergent validity of the measurement model was evaluated using standard criteria, including item loadings, Cronbach's Alpha, Composite Reliability (CR), and Average Variance Extracted (AVE). All constructs showed or exceeded the values recommended (neither lower nor higher), meaning that the indicators are representative of their underlying latent variables. All item loadings were over 0.70 with values between 0.755 and 0.916, meaning all indicators strongly correlated with their corresponding construct. This indicates the items were well selected and indicates the dimensions they were designed to measure accurately.

Cronbach's Alpha values were between 0.868 and 0.933, which is indicative of high internal consistency of items contained in each construct. On the same note, the Composite Reliability values, which are 0.909-0.950, show that the constructs are highly reliable and that the measurement model is stable and consistent. AVE values of all constructs were also higher than 0.50, varying from 0.667 to 0.790. These large AVEs show that a large part of the variability of the indicators is explained by the construct and not by the error of measurements.

In conclusion, the measurement model presents high convergent validity. The high loadings, as well as high reliability for the internal consistency and substantial variance explained by each of the constructs add credibility to the conclusion that the indicators are valid and reliable. These findings have a firm basis for further analysis, including testing discriminant validity, as well as assessment of structural relationships in the model.

4.2. Fornell-Larcker Discriminant Validity

The Fornell-Larcker criterion was used to determine discriminant validity between the six constructs of the model: BDAC, DDDM, EGP, GI, RP, SP. The square roots of average variance extracted for each construct are placed on the diagonal of the matrix and compared to the inter-construct correlations in rows and columns. For all constructs, the diagonal values (square-roots of AVE) are greater than the off-diagonal correlation values in their respective rows and columns. For instance, the square root of AVE for BDAC is 0.868 that is greater than its highest correlation with any other construct (0.41 with SP). In a similar manner, SP has square root of AVE as 0.889 which is more than its highest correlation (0.604 with DDDM). This is a trend for all constructs. These findings establish that each construct is empirically separated from the others hence a discriminant validity in compliance with the Fornell-Larcker criterion. This implies the success of the measurement model in properly distinguishing the constructs which approves the validity of the structural model for testing other hypotheses and path analysis.

Table 3
Convergent Validity Test

Constructs	items	Loading	Alpha	CR	AVE
BDAC	BDAC1	0.887	0.891	0.924	0.754
	BDAC2	0.852			
	BDAC3	0.876			
	BDAC4	0.857			
DDDM	DDDM1	0.807	0.868	0.91	0.718
	DDDM2	0.838			
	DDDM3	0.898			
	DDDM4	0.845			
EGP	EGP1	0.843	0.876	0.909	0.667
	EGP2	0.831			
	EGP3	0.755			
	EGP4	0.872			
	EGP5	0.778			
GI	GI1	0.867	0.89	0.923	0.751
	GI2	0.902			
	GI3	0.835			
	GI4	0.861			
RP	RP1	0.916	0.908	0.933	0.778
	RP2	0.884			
	RP3	0.883			
	RP4	0.843			
SP	SP1	0.911	0.933	0.95	0.79
	SP2	0.9			
	SP3	0.896			
	SP4	0.857			
	SP5	0.88			

Table 4
Fornell Larcker

	BDAC	DDDM	EGP	GI	RP	SP
BDAC	0.868					
DDDM	0.294	0.847				
EGP	-0.002	0.263	0.817			
GI	-0.066	0.299	0.056	0.866		
RP	0.066	0.011	0.106	-0.042	0.882	
SP	0.41	0.604	0.414	0.199	0.14	0.889

4.3. Heterotrait-Monotrait Ratio: Discriminant Validity Assessment

To measure the discriminant validity of the six constructs of the model, the HTMT ratio was applied. BDDC, DEGD, EGP, GI, RP and SP. Based on the results, all HTMT values are under the most conservative cut-off point of 0.85 with the highest value being at 0.669 (between DDDM and SP). This means that the construct pairs are empirically different from one another, and they are not showing troublesome degrees of overlap. The low HTMT values further reinforce the conclusion that the constructs measure different concepts, even when moderately correlated. Therefore, the analysis confirms that discriminant validity is well established across all constructs, using the HTMT criterion. This supports the robustness of the measurement model and gives confidence in proceeding to the structural model evaluation and hypothesis testing.

Table 5
HTMT Ratio

	BDAC	DDDM	EGP	GI	RP	SP
BDAC						
DDDM	0.333					
EGP	0.052	0.289				
GI	0.074	0.335	0.102			
RP	0.078	0.064	0.107	0.066		
SP	0.445	0.669	0.446	0.217	0.141	

4.4. Cross Loading

The cross loadings table confirms the presence of discriminant validity at the item level, as each indicator loads highest on its intended construct compared to all other constructs. For example, all BDAC items (BDAC1 to BDAC4) show strong loadings on the BDAC construct and much lower loadings on other constructs, indicating they reliably measure big data analytics capability. Similarly, DDDM indicators (DDDM1 to DDDM4) load highest on the DDDM construct, despite showing moderate cross-loadings on SDG performance, which is expected due to their theoretical relationship. EGP, GI, RP, and SP indicators also demonstrate the same pattern—each item loads more strongly on its own construct than on any other, with no problematic overlaps. Overall, the results confirm that each construct is measured by distinct items, supporting discriminant validity across the measurement model.

Table 6
Cross Loading

	BDAC	DDDM	EGP	GI	RP	SP
BDAC1	**0.887**	0.272	-0.023	-0.053	0.031	0.348
BDAC2	**0.852**	0.267	0.032	-0.093	0.147	0.389
BDAC3	**0.876**	0.232	-0.015	-0.057	-0.002	0.319
BDAC4	**0.857**	0.247	-0.004	-0.024	0.039	0.359
DDDM1	0.225	**0.807**	0.201	0.256	0.091	0.489
DDDM2	0.214	**0.838**	0.267	0.269	-0.02	0.504
DDDM3	0.27	**0.898**	0.242	0.278	-0.023	0.534
DDDM4	0.288	**0.845**	0.179	0.208	-0.005	0.519
EGP1	0.028	0.152	**0.843**	0.05	0.029	0.309
EGP2	-0.002	0.26	**0.831**	0.048	0.184	0.359
EGP3	-0.045	0.149	**0.755**	-0.001	-0.001	0.278
EGP4	0.035	0.28	**0.872**	0.055	0.09	0.424
EGP5	-0.046	0.19	**0.778**	0.07	0.097	0.279
GI1	-0.066	0.251	-0.053	**0.867**	-0.003	0.18
GI2	-0.029	0.294	0.116	**0.902**	0.008	0.199
GI3	-0.025	0.201	0.033	**0.835**	-0.038	0.147
GI4	-0.107	0.276	0.084	**0.861**	-0.12	0.158
RP1	0.102	0.008	0.126	-0.019	**0.916**	0.163
RP2	0.043	0.003	0.049	-0.039	**0.884**	0.09
RP3	0.046	0.041	0.103	-0.041	**0.883**	0.125
RP4	0.005	-0.03	0.069	-0.07	**0.843**	0.079
SP1	0.375	0.55	0.371	0.149	0.13	**0.911**
SP2	0.413	0.569	0.38	0.18	0.138	**0.9**
SP3	0.372	0.576	0.321	0.183	0.084	**0.896**
SP4	0.35	0.496	0.404	0.143	0.125	**0.857**
SP5	0.301	0.485	0.365	0.235	0.145	**0.88**

4.5. Measurement Model

The measurement model in the diagram demonstrates that all constructs exhibit strong reliability and validity. Each latent construct—BDAC, EGP, GI, RP, DDDM, and SP—is measured by multiple indicators, all of which have high outer loadings (ranging from 0.755

to 0.916), well above the commonly accepted threshold of 0.70. This confirms indicator reliability.

Additionally, the constructs are clearly defined and distinct, with no signs of cross-loading issues. The consistent and high indicator loadings suggest strong internal consistency reliability and convergent validity. For example, BDAC is measured by four indicators (BDAC1–BDAC4), each loading above 0.85, and SP (Sustainable Performance) is measured by five indicators (SP1–SP5), all loading above 0.85 as well. Overall, the model meets the requirements for a robust measurement model, showing that each construct is well represented by its indicators and is suitable for structural model analysis.

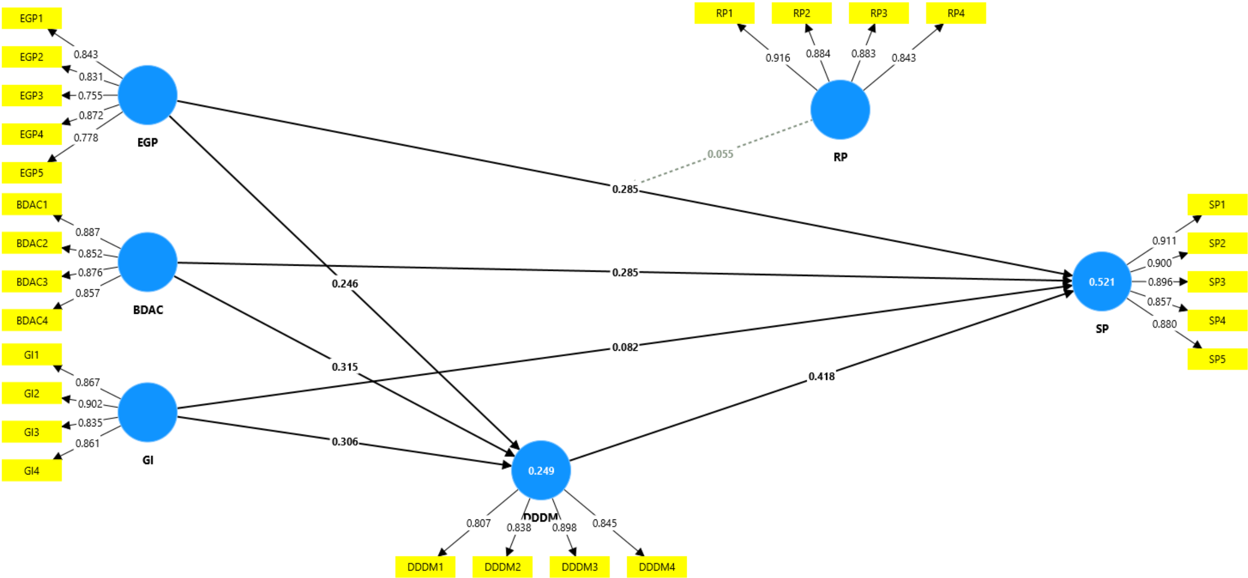

Figure 1: Measurement Model

4.6. Path Analysis

The results of path analysis indicate that the given model consists of all statistically significant main relationships. Big Data Analytics Capability (BDAC) positively influence DDDM and SP significantly, meaning that organizations with strong analytics capability are able to make informed decisions, and sustainability goals. DDDM itself has a substantial and robust positive impact on SP, which means that it is an important determinant of sustainability outcomes. Environmental Governance Pressure (EGP) works in a positive way for DDDM and SP indicating that external governance exists in influencing the sustainability practices. Green Innovation (GI) also greatly influences the DDDM and influences SP in a not less significant manner. It has a positive and significant direct impact of RP on SP. The interaction term between RP and EGP is just significant, meaning a possible and weak moderating effect. In addition, all the indirect effects through DDDM are significant signifying that DDDM mediates the relations between BDAC, EGP, GI, and SP. Overall, the results support the idea that data capabilities, governance, and innovation all contribute to improving the sustainability performance with data-driven decision-making as the major mediating mechanism.

Table 7
Path Analysis

	Original sample	STDEV	T statistics	P values
BDAC -> DDDM	0.315	0.042	7.542	0.000
BDAC -> SP	0.285	0.035	8.206	0.000
DDDM -> SP	0.418	0.037	11.289	0.000
EGP -> DDDM	0.246	0.042	5.844	0.000
EGP -> SP	0.285	0.035	8.135	0.000
GI -> DDDM	0.306	0.037	8.208	0.000
GI -> SP	0.082	0.034	2.400	0.016
RP -> SP	0.093	0.033	2.856	0.004
RP x EGP -> SP	0.055	0.031	1.777	0.076
BDAC -> DDDM -> SP	0.132	0.023	5.760	0.000
EGP -> DDDM -> SP	0.103	0.021	4.974	0.000
GI -> DDDM -> SP	0.128	0.020	6.359	0.000

4.7. Structural Model

Structural model indicates that all major hypothesized paths are statistically significant with great support from t-values displayed against each of the paths. BDAC, EGP, and GI exert positive impacts on DDDM that significantly exert positive impact on SP. In addition, BDAC, EGP, GI, and RP have also direct positive influences on SP. The interaction effect of RP on the relationship between EGP and SP is marginally significant; therefore, there is a potential moderating role. The model validates that data capabilities, governance pressures, and innovation are directly and indirectly related to the SDG performance due to better decision-making processes.

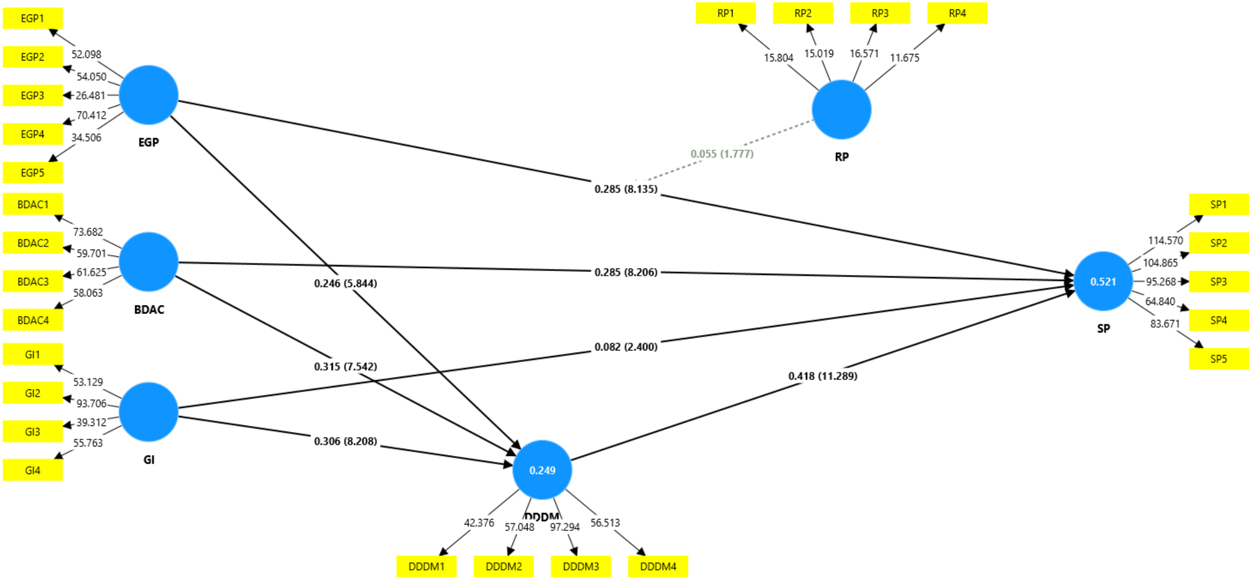

Figure 2: Measurement Model

4.8. Discussion

The results of this study provide helpful insights into how environmental governance (EG), big data analytics capability (BDAC), and green innovation (GI) affect SME-related Sustainable Development Goal (SDG) performance in the setting of ASEAN economies. The results provide strong support for the proposed model and coincide with theoretical expectations and past empirical research.

First, the strong effect that BDAC has on DDDM and SDGs performance suggests that digital capabilities are critical in advancing sustainability. The results of this study are consistent with studies by (Mikalef et al., 2017; Wamba et al., 2017), who indicated that BDAC increases firm agility, knowledge management, and strategic alignment, which are thus supportive of sustainability results. In addition, the positive relationship between BDAC and DDDM confirms the hypothesis that the analytics capabilities are contributing to the generation of insights that define more efficient and timely decisions for the SMEs (Kiron, 2013; Sabharwal & Miah, 2021). Like (Hao et al., 2019), our results show that BDAC is a technological resource as well as strategic platform for sustainable innovation.

The important mediating role part of DDDM is further confirmed because of its strong impact on SDG performance. Systematic use of data for driving decisions by organizations puts them at an advantage of adopting environmental and social goals. This outcome is coherent with (Kim et al., 2014), where it was reported that data-driven strategies enhance the internal efficiency and external accountability. Our findings are also in line with the findings by (Rialti et al., 2019) that their DDDM links technological capabilities to organizational performance both conventionally and in terms of sustainability measures.

Environmental governance pressure (EGP) has become a major factor toward DDDM and SDG performance. It is supportive of the view that governance frameworks, by way of regulations, institutional support, and stakeholder engagement, determine corporate environmental behavior. Close patterns have been reported in earlier studies by (Hou et al., 2021; Peng et al., 2020), where the quality of governance and enforcement is positively attributed to sustainability endeavors in Chinese regions. The positive link between EGP and

DDDM implies that governance mechanisms stimulate firms in taking systemic and data-based compliance and performance monitoring systems. This supplements the findings of (Zhou et al., 2021) according to which the pressures of community and regulation influence corporate environmental responses as a whole.

Green innovation (GI) was established to be highly significant for DDDM, and, to a slightly lesser extent, SDG performance. This means that innovation fosters the call for improved information systems to direct and measure sustainable efforts. The high correlation between GI and DDDM confirms the findings of (Karimi Takalo et al., 2021), which states that green innovation is not only a tech-shift but a strategic decision-making process that significantly depends on data's availability and interpretation. The indirect effect of GI on SDG performance had significant effects, which highlights the need for effective implementations mechanisms. Firms which carry out innovation but do not have supporting analytics may fail to reap entire sustainability advantages.

Regulatory pressure (RP) was also found to exert a positive direct influence on SDG performance, thereby restating the value of formal institutional arrangements, in terms of stimulating sustainability compliance. It goes in with what (Tyler et al., 2023) had revealed as the regulatory and market pressures force the SMEs to implement proactive environmental practices. However, the RP acted as a slightly significant moderator in the relationships between EGP and SDG performance. This implies that although there is a role of RP in enhancing the governance-performance relationship, its effect may differ as a result of contextual or firm-level conditions like size, sector, or digital maturity.

Notably, the current study found support for the fact that DDDM mediates the relationships between BDAC and EGP and GI with SDG performance. These findings concur with dynamic capabilities view put forward by (Mikalef et al., 2019), where in organizations, resources (such as data infrastructure, innovative capacity) are not sufficient as they need to be integrated and reconfigured through informed choices to attain superior results. The mediating role of DDDM indicates that technology and governance are not enough unless it becomes part and parcel of the organizational processes that should facilitate strategic as well as operational decision-making.

The results are also consistent with the broader evidence that the SDG alignment can improve firm performance, especially, in case sustainability is incorporated into central strategic procedures (Lassala et al., 2021; Ramos et al., 2022). For the context of ASEAN SMEs, this study identifies that the attainment of goals of the SDGs is not simply a case of compliance with policy and an investment in technology but also necessitates the development of decision-making cultures based on data and sustainability principles.

In general, this research augments the literature that synthesizes digital transformation, governance, and innovation in sustainability discourse. It further verifies that BDAC, EGP, GI are crucial in SDG delivery, but their effectiveness is enhanced when mediated through robust internal decision-making processes. The results have practical implications for SME managers and policymakers in ASEAN economies, as an instrument to improve the analytics capacity and the supportive regulatory environment should be supplemented by initiatives to create data-driven cultures in organizations. Such a holistic approach is fundamental for SMEs to manage to move from compliance-type of sustainability to innovation-led and performance oriented sustainable development.

5. Conclusion

This study gives a detailed insight on how environmental governance; big data analytics capabilities and green innovation affect SDG performance in SMEs operating in ASEAN. The findings show that BDAC, EGP, and GI play critical roles, primarily as enablers of sustainability performance through data-driven decision-making processes and, at the same time as, a direct enabler of sustainability performance. The mediation function of DDDM is most interesting since it transforms the inputs of technology and institutions as into tangible sustainability results. Moreover, Regulatory Pressures have direct positive relation with SDG performance but is only marginally significant in relation to EGP–SP moderating role, indicating the complex regulatory environments in emerging economies. The findings indicate that the efficiency of environmental governance is increased when coupled with internal capability of the organization in form of analytics and innovation.

Theoretically, this work adds to the literature by bringing the two dichotomies (dynamic capabilities theory and environmental governance, and innovation perspectives), into focus. In a practical sense, it offers a road map to the SME managers and policymakers to synchronize digital transformation efforts with sustainability goals. Future researches are called to extend this model with the use of longitudinal data, cross-country comparisons, and more of mediators or moderators to provide a more comprehensive account of digital sustainability in the SME.

5.1. Theoretical Implications

The present study contributes to the literature of sustainability, big data analytics, and environmental governance, in particular in relation to SMEs in emerging ASEAN economies, with several theoretical contributions. First, it extends the dynamic capabilities theory by establishing that Big Data Analytics Capability (BDAC) and Green Innovation (GI) influence the Sustainable Development Goal (SDG) performance not only via the direct routes but also through their mediation role in the Data- Driven Decision Making (DDDM). This emphasizes the role of intra-organizational processes towards the conversion of external capabilities into measurable outcomes, continuing the previous findings of (Mikalef et al., 2019; Wamba et al., 2017).

Second, the inclusion of the Environmental Governance Pressure (EGP) and Regulatory Pressure (RP) in the framework provides the connection between governance and technological capability approaches. Although previous studies have mostly studied these domains separately, our integrative model offers a more joined-up view of a relationship between formal governance structures and how these influence the outcomes toward sustainability. This adds to the body of literature of institutional influence in environmental management (Hou et al., 2021; Zhou et al., 2021).

Third, the marginal significance of the moderating effect of RP on EGP–SP association points to the necessity of developing the theoretical assumptions concerning regulatory effectiveness. It states that not all governance pressures produce the same outcomes in different cases and shows the complexity of the institutional arrangement in emerging economies, where the enforcement capability and firm responsiveness are diverse. Overall, this study proposes a multi-dimensional and empirically assessed paradigm that future researchers can consider employing to better delve into the interaction between the governance, technology, and organizational behavior in the advancement of sustainability.

5.2. Practical Implications

The findings provide useful information to SME managers, policymakers, and sustainability practitioners in the ASEAN economies. For small and medium-sized enterprise managers the results emphasize how important it is to put money in big data analytics infrastructure and talent. Aside from digital tools, SMEs need to understand and act on data and incorporate it into the operational culture of data-driven decision-making. Smaller firms can overcome capability gaps by means of training programs and partnerships with providers of analytics.

While, on the other hand, the policymakers should understand the stimulating potential of environmental governance frameworks of innovation and performance. Improving institutional support, transparency, and enforcement can incentivize firms to come closer to targets of SDG. Specifically, the regulatory pressure that calls for compliance should be intended to promote active and innovative-oriented actions toward sustainability, especially in the SMEs that frequently have to work under resource constraints.

The study also makes recommendations, on the need to have public-private partnerships to increase SME readiness to digital sustainability. This consists of incentives for green innovation, subsidies for the adoption of technologies, and establishment of regulatory sandboxes for conducting sustainability focused innovation experiments. Government-driven interventions to endorse digital literacy and sustainability reporting among SMEs could have a substantial impact on regional accomplishment to SDGs.

5.3. Limitations and Future Research

While they are strong, there are some limitations to this study which must be recognized. First, the utilization of cross-sectional data reduces the possibility of making causal inferences. Longitudinal studies would be relevant to monitor changes in digital and sustainability capabilities through time. Second, although the focus of the study is SMEs in ASEAN economies, the country- specific institutional and cultural differences might affect the results. Future studies can use a multi-country comparative design so that one can explore such variations in depth.

Third, the current study measured performance with regards to self-reported perceptions of SDG alignment; while that is legitimate, it does not determine actual sustainability outcomes. Further research would be possible to include the objective performance data (e.g., emissions levels, audit scores, or SDG-aligned certifications) to support and extend these findings. Also, the qualitative studies might reveal more about the ways in which analytics and governance shape decision-making processes in diverse contexts of SME.

Finally, other mediating and moderating variables such as organizational culture, leadership commitment or technological readiness should be examined in future research to determine if they would impact on the observed strength or direction of the relationships. The extension of the model to incorporate views of customers and stakeholders might also provide a greater insight into how SMEs engage in sustainable transformation.

Authors Contribution
Muhammad Saeed: Sole author in the paper.

Conflict of Interests/Disclosures
The authors declared no potential conflicts of interest regarding the article's research, authorship, and/or publication.

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