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RESEARCH ARTICLE

The Influence of Aggressive Low Carbon Innovation on Firm's ESG Performance at Energy Industry: The Role of Green Knowledge Management, Green Market Orientation, and Management Commitment

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ABSTRACT

This study examines the impact of Aggressive Low Carbon Innovation on Firm's ESG Performance at Pertamina group: The Role of Green Knowledge Management, Green Market Orientation, and Management Commitment. Using a quantitative approach and a correlational research design, data were collected cross-sectionally from 210 top management respondents at Pertamina group. Structural Equation Modeling-Partial Least Squares (SEM-PLS) was applied to analyze the complex relationships between variables, including direct and indirect effects. The direct influence findings show that all independent variables—Green Knowledge Management, Green Market Orientation, and Management Commitment—significantly impact Aggressive Low Carbon Innovation and Firm's ESG. The indirect influence findings indicate that Aggressive Low Carbon Innovation mediates the effect of Green Knowledge Management, Green Market Orientation, and Management Commitment on Firm's ESG. This research concludes that low-carbon innovation significantly enhances a company's ESG performance, supported by green knowledge management, green market orientation, and management commitment. It strengthens the environmental, social, and governance aspects of ESG, helping companies meet sustainability regulations and gain competitive advantages. Recommendations include ensuring strong leadership commitment, developing effective knowledge management, aligning with green market trends, and integrating low-carbon innovation into sustainability strategies. Transparency in ESG reporting, collaboration, government incentives, employee training, and regular monitoring are essential to drive green innovation and maintain the relevance of ESG strategies.

INTRODUCTION

In recent decades, sustainability issues have become a major focus in the energy sector. This aligns with the growing global awareness of climate change and the importance of transitioning to a low-carbon economy. Governments, stakeholders, and society urge companies to reduce their negative environmental impacts while maintaining their business competitiveness. In the face of these increasing challenges, the concept of green innovation has emerged as a solution that combines operational efficiency with a positive environmental impact (Chen et al., 2015). Pertamina, as one of the largest energy companies in Indonesia, faces significant challenges in reducing carbon emissions and supporting the energy transition toward a low-carbon economy. As the largest carbon emitter in Indonesia, Pertamina has an obligation to comply with domestic environmental regulations and global commitments, such as the Paris Agreement, which aims to limit global warming to below 2°C above pre-industrial levels (IEA, 2022). In response to this challenge, Pertamina has committed to achieving Net Zero Emission (NZE) by 2060, in line with the target announced at COP26, as part of

Indonesia's efforts to mitigate the impacts of climate change (Pertamina, 2022).

To meet this commitment, Pertamina, as a energy company with 11 subsidiaries, has established a dual growth strategy, which focuses not only on strengthening its fossil energy business but also on developing low-carbon business (low carbon business). In this strategy, Pertamina concentrates on developing the carbon market, renewable energy, and carbon capture and storage (CCS/CCUS) technologies (Pertamina, 2022). Figure 1 in Pertamina's annual report illustrates the company's efforts in supporting this green energy transition.

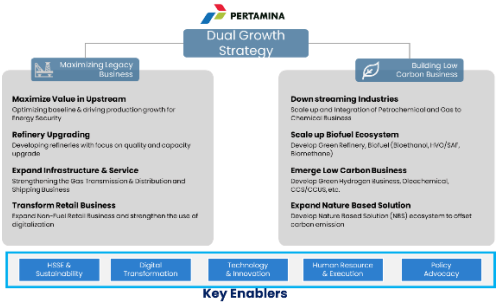

Figure 1: Pertamina's dual growth strategy

A major focus in the development of low-carbon business is the carbon market, which allows companies and individuals to offset carbon emissions through the trade of carbon credits. These carbon credits are generated from projects focused on emission reduction through both technological solutions and nature-based solutions. There are two main types of carbon markets: voluntary markets, where parties purchase carbon credits voluntarily, and regulatory markets, driven by international commitments such as the Paris Agreement (WEF, 2023; IEA, 2023). By utilizing this mechanism, Pertamina has the potential to strengthen its efforts in reducing carbon emissions in Indonesia.

The development of renewable energy has become a key pillar in the energy transformation in Indonesia. Renewable energy, which includes renewable natural resources such as solar, wind, and biomass, plays an important role in reducing the company's carbon footprint. Investment in renewable energy also allows companies to meet increasingly stringent sustainability standards and strengthen their reputation in terms of social and environmental responsibility (IRENA, 2020). Pertamina itself already has a fairly extensive renewable energy portfolio, with a generation capacity of over 700 MW from various sources such as geothermal, biomass, and solar energy.

Figure 2: Pertamina's renewable energy portfolio

Pertamina also focuses its efforts on carbon capture and storage (CCS/CCUS) technologies. These technologies are designed to capture carbon dioxide (CO_2) emissions generated by industrial activities and store them to prevent their release into the atmosphere. CO_2 can be captured through various technologies, and its utilization can produce new environmentally friendly products, such as CO_2-based concrete (Connick & Benson, 2014; Boot-Handford et al., 2014). By developing this technology, Pertamina has the potential to reduce a significant amount of carbon emissions, which will contribute to achieving the NZE target set by the Indonesian government by 2060.

The increasing global concern over environmental sustainability has heightened the significance of firms' environmental, social, and governance (ESG) performance, particularly in the energy sector,

where carbon emissions and environmental impact remain critical issues. Green Knowledge Management (GKM) emerges as a strategic approach that enables firms to acquire, disseminate, and apply environmentally relevant knowledge to enhance their sustainable practices. Organizations that effectively integrate GKM tend to develop a deeper understanding of eco-friendly production, resource efficiency, and regulatory compliance, which consequently fosters superior ESG performance. Research by Afifah et al. (2024) and Tabah et al. (2023) highlights that Green Knowledge Management (GKM) plays a crucial role in enhancing a company's ESG performance. GKM enables companies to integrate knowledge related to environmental management and the application of environmentally friendly technologies. This knowledge is vital in supporting aggressive green innovation and driving the development of more sustainable products and processes. GKM can improve operational efficiency and support more strategic decision-making (Guang-lin & Tao, 2023; Liu et al., 2016).

Firms that embrace Green Market Orientation (GMO) proactively respond to stakeholders' expectations by aligning their strategic objectives with sustainability principles. GMO encourages companies to understand market needs related to sustainability and adopt low-carbon technologies. GMO also contributes to a company's social and environmental performance, which, in turn, will improve ESG performance. Research by Du and Wang (2022) and Borah et al. (2021) shows that companies with strong green market orientation are more capable of developing environmentally friendly innovations and contributing to reducing their carbon footprint. By prioritizing green consumer demands and regulatory shifts, firms with a strong GMO stance cultivate a competitive advantage while simultaneously mitigating environmental risks.

Management commitment plays a pivotal role in driving Aggressive Low Carbon Innovation (ALCI) and enhancing a firm's ESG performance, particularly in the energy sector, where sustainability challenges are inherently complex and resource-intensive. A strong commitment from top management establishes a clear strategic vision that prioritizes low-carbon innovation as a core organizational objective rather than a peripheral initiative (Adebayo, 2024). Firms with dedicated leadership are more likely to allocate substantial financial and human capital resources toward the development and implementation of advanced energy-efficient technologies, renewable energy integration, and carbon reduction strategies (Sideri, 2023). Managerial commitment fosters an organizational culture that encourages risk-taking and long-term investments in sustainability-driven innovation, ensuring that aggressive low-carbon initiatives are continuously refined and scaled. The direct impact of this commitment extends to ESG performance, as firms that embed sustainability principles into their corporate governance structures and operational frameworks are better positioned to meet regulatory requirements, enhance transparency, and gain investor confidence (Clementino & Perkins, 2020). Firms that actively pursue ALCI under strong managerial leadership are more capable of achieving significant reductions in carbon footprints, thus improving their environmental performance and overall ESG ratings. In a sector increasingly scrutinized for its environmental impact, management commitment serves as the catalyst that transforms sustainability aspirations into tangible outcomes, reinforcing the firm's long-term viability, stakeholder trust, and competitive advantage in a rapidly evolving regulatory and market landscape (Veenstra & Ellemers, 2020).

The role of Green Knowledge Management, Green Market Orientation, and Management Commitment in ESG performance is further reinforced when firms adopt an innovation-driven approach, particularly through Aggressive Low Carbon Innovation (ALCI). ALCI reflects the degree to which firms actively pursue radical technological advancements and process improvements that significantly reduce carbon emissions. By aggressively investing in renewable energy, energy-efficient technologies, and carbon capture solutions, firms not only enhance their sustainability credentials but also strengthen their ESG ratings (Lee & Rhee, 2023). The mediating role of ALCI suggests that firms possessing extensive green knowledge and a strong market-driven sustainability orientation can effectively translate these capabilities into concrete environmental innovations (Treepongkaruna, 2024). Such innovations serve as a bridge that transforms organizational sustainability awareness into measurable ESG outcomes, highlighting the crucial interplay between knowledge management, market orientation, and managerial dedication (Liu, 2023). Firms within the energy sector must foster an ecosystem conducive to aggressive innovation, ensuring that their sustainability objectives are not merely theoretical but actively materialized through transformative

low-carbon strategies (Sideri, 2023).

Given the growing pressure from investors, regulatory bodies, and consumers for firms to demonstrate tangible sustainability efforts, the integration of Green Knowledge Management, Green Market Orientation, and Management Commitment into ESG performance frameworks becomes imperative (Liu, 2023). Without the intermediary function of Aggressive Low Carbon Innovation, the potential of these antecedents may remain underutilized. Firms that merely possess sustainability knowledge or espouse a market-driven green focus but lack the commitment to invest in aggressive innovations may struggle to achieve substantial ESG advancements (Ying, 2024). The dynamic interactions among these variables underscore the necessity for a holistic sustainability strategy where firms proactively harness their knowledge assets, market intelligence, and leadership dedication to drive aggressive innovations that reshape their operational landscape (Widodo et al., 2022). Within the energy sector, where emissions-intensive activities prevail, the adoption of such an integrative approach is not only a matter of corporate responsibility but also a strategic imperative to secure long-term resilience and competitiveness in a rapidly evolving regulatory and market environment (Torre et al., 2020).

Research by Yusr et al. (2020) shows that green innovation capability is a key factor in supporting the long-term sustainability of a company. Green innovation capability includes a company's ability to produce products and processes that are not only resource-efficient but also environmentally friendly, such as reducing emissions and improving energy efficiency. This capability is especially important in the context of Pertamina's development of low-carbon business, which requires innovative solutions to reduce environmental impacts while maintaining competitiveness. On the other hand, research by Weinzimmer et al. (2023) states that strategic aggressiveness plays an important role in a company's decision-making to achieve competitive advantage quickly. By adopting bolder and more proactive strategies, companies like Pertamina can accelerate the implementation of sustainability initiatives and innovate in reducing carbon emissions. In this regard, strong managerial commitment is also a critical factor in ensuring the effective implementation of these initiatives. Managerial commitment ensures that sustainability policies are consistently applied throughout the organization, which will contribute to improving ESG performance (Ahmad et al., 2024). Therefore, it is important for Pertamina to have a solid green market orientation as part of its business strategy. This study proposes a model that combines Green Knowledge Management (GKM), Green Market Orientation (GMO), and managerial commitment (Management Commitment), mediated by aggressive low-carbon innovation, to improve the company's ESG performance, particularly at Pertamina group. Companies that successfully manage green knowledge, adopt a strong green market orientation, and have a solid managerial commitment will have a competitive edge in facing sustainability challenges and energy transition in Indonesia.

The primary objective of this research is to develop and evaluate a hybrid Transformer-RNN model specifically designed for Multilabel classification of Thai banking documents. By leveraging Transformer's capability to capture contextual nuances and RNN's proficiency in handling sequential dependencies, this study aims to address the challenges posed by the Thai language and the specific requirements of banking texts. By achieving these objectives, this research seeks to contribute to advancements in Thai text classification methodologies and provide a robust framework applicable to other domain-specific multilabel classification tasks.

LITERATURE REVIEW

Theoretical framework

Dynamic Capability Theory, introduced by Teece, Pisano, and Shuen (1997), focuses on how companies can maintain a competitive advantage in a constantly changing business environment. This theory offers a conceptual framework for understanding how firms can adapt, transform, and reconfigure their resources to respond to external changes. Dynamic capability is defined as a company's ability to integrate, build, and reconfigure both internal and external competencies to meet the challenges of a shifting environment. This capability is critical for innovation and adaptation, helping firms remain competitive in dynamic and unstable markets. The theory is based on three key elements: sensing, which refers to a company's ability to identify and understand changes in the external environment, including recognizing new opportunities, evolving

technologies, and shifts in customer needs; seizing, which involves capitalizing on these identified opportunities quickly and effectively through strategic decisions and resource allocation; and reconfiguring, the continuous process of adjusting organizational assets, business processes, and operational models to align with market dynamics and technological advancements (Nonaka & Takeuchi, 1995).

This theory is particularly relevant in the context of aggressive low carbon innovation and its impact on a firm's Environmental, Social, and Governance (ESG) performance. For Pertamina group, dynamic capability plays a crucial role in enabling the company to effectively manage and implement green innovations, respond to sustainability challenges, and enhance its ESG performance (Chu et al. 2017; Shahzad et al. 2024). As the energy sector faces increasing environmental pressures, Pertamina's ability to sense emerging trends in green technologies, seize opportunities for low-carbon innovation, and reconfigure its operational strategies is vital (Kirca et al., 2005; Wei et al., 2014). This process is further supported by green knowledge management and green market orientation, as these factors help the company adopt sustainable practices and innovate in ways that align with its environmental goals. Additionally, management commitment ensures the consistent implementation of sustainability initiatives, creating a strong foundation for continuous improvement in ESG performance (Chen, 2006; Lopez & Soto, 2010).

Empirical studies and research gap

This study proposes a model to explore the impact of aggressive low-carbon innovation (ALCI) on firm's ESG performance (FESGP) at Pertamina group, integrating three key factors: green knowledge management (GKM), green market orientation (GMO), and management commitment (MC). While focusing on a highly relevant topic within the context of sustainability and green innovation, several aspects of this study still require further exploration and clarification to provide more significant contributions to theory and practice. Previous research has shown that GKM and GMO play essential roles in supporting sustainability and competitive advantage (Inkinen, 2016; Fraj et al., 2011), with ALCI serving as a mediator for driving aggressive low-carbon innovation to achieve long-term sustainability goals (Chen & Chang, 2013). This study seeks to synthesize these concepts and offer insights on how companies can not only adopt environmentally friendly practices but also innovate aggressively to maintain competitiveness in an increasingly environmentally conscious market.

However, while previous studies have focused on the relationship between GKM and green technology innovation or sustainable performance in sectors such as construction (Khan et al., 2024; Parekh et al., 2024), there remains a significant gap in the context of large energy sectors like Pertamina group. Prior research tends to be more general, often not specific to industries with high pollution and significant environmental impact. Moreover, studies on ALCI as a more aggressive approach to reducing carbon footprints and its impact on ESG performance have been relatively unexplored, especially in large energy companies. This study aims to fill that gap by delving deeper into how ALCI, driven by GKM, GMO, and MC, influences Pertamina's ESG performance. Additionally, this research expands the understanding of how aggressive low-carbon innovation can become a crucial strategy for the energy sector in achieving sustainability and leading the transition to a green economy. This opens opportunities for further studies comparing this model with other sectors or companies, and testing whether this approach can be applied more broadly or is only relevant for large companies like Pertamina (Soewarno et al., 2020).

Hypothesis framework

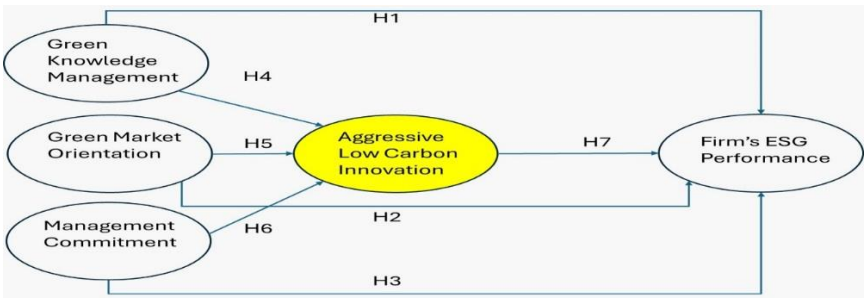

Figure 3: Hyphothesis framework

H1: Green Knowledge Management (GKM) affects Firm ESG Performance

H2: Green Market Orientation affects Firm's ESG Performance

H3: Management Commitment affects Firm's ESG Performance

H4: Green Knowledge Management affects Aggressive Low Carbon Innovation

H5: Green Market Orientation affects Aggressive Low Carbon Innovation

H6: Management Commitment affects Aggressive Low Carbon Innovation

H7: Aggressive Low Carbon Innovation affects Firm's ESG Performance

Operational definition of research variables

The operational definition table outlines the variables, indicators, and measurement items used in this study to ensure clarity and consistency in data collection and analysis. Each variable is broken down into specific indicators that reflect its theoretical construct, measured using a set number of items derived from validated sources. These variables include Green Knowledge Management (X1), Green Market Orientation (X2), and Management Commitment (X3), which are considered independent variables. Aggressive Low Carbon Innovation (Z) serves as a mediating variable, while the dependent variable is Firm's ESG Performance (Y). The measurement items, adapted from credible and recent literature, were designed to ensure the validity and reliability of the constructs, using a structured questionnaire with 15 items per variable to capture the multifaceted nature of these concepts.

Table 1: Operational definition of research variables

No	Variable	Indicator	Item (n)	Source
X1	Green Knowledge Management	1. Green Knowledge creation 2. Green Knowledge acquisition 3. Green Knowledge application 4. Green Knowledge Sharing Across Departments 5. Access to Green Practices Information 6. Promoting Green Knowledge Exchange	15	Mingqiang et al. (2024) & Ali, Nawaz, Khan., Khalid, Mehmood., Ho, Kwong, Kwan. (2024)
X2	Green Market Orientation	1. Monitoring of green market Needs 2. Green product development 3. Increasing Environmental Value for Customers 4. Understanding Customer Demand for Environmental Protection 5. Sharing Competitors' Environmental Operations	15	Du & Wang (2022)
X3	Management Commitment	1. Resource Allocation 2. Active involvement 3. Communication of Vision and Goals 4. Monitoring and Evaluation of Organizational Performance 5. Active Participation in Decision-Making 6. Promotion of a Culture of Accountability and Responsibility	15	Fatima & Elbanna (2023), Shirley, Awoi, Lowalan., Eric, Mutiiria., Evangeline, Gichunge. (2023).
Z	Aggressive Low Carbon Innovation	1. Rapid Environmentally-Friendly Product and Process Innovation 2. Aggressive Resource Allocation for Green Innovation 3. Implementation of Aggressive Low Carbon Strategies 4. Investment in Low Carbon Technologies	15	Xuejiao, Xu., Moyan, Cheng., Kun, Zhang. (2023).

No	Variable	Indicator	Item (n)	Source
		5. Proactive Adoption of Low Carbon Solutions		
Y	Firm's ESG Performance	1. Environmental Performance 2. Social Performance 3. Governance Performance	15	Drobetz et al., (2024)

METHODOLOGY

Research design

This study adopts a quantitative approach with a correlation research design to explore the relationships between the variables and test the proposed hypotheses. A quantitative approach is appropriate for examining causal relationships and providing objective, measurable data to evaluate the influence of various factors. The correlation design focuses on identifying the strength and direction of relationships between independent, dependent, and mediating variables in the study. Structural Equation Modeling (SEM) using Partial Least Squares (PLS) was employed as the primary analytical method, supported by SmartPLS software. SEM-PLS was chosen for its ability to handle complex models involving multiple constructs and indicators, as well as its flexibility in analyzing both direct and indirect effects. This analytical approach is particularly advantageous for studies with non-normal data distributions or relatively small sample sizes.

The cross-sectional data collection design ensures that data is gathered from respondents at a single point in time, capturing a snapshot of the variables under investigation. This approach facilitates the evaluation of relationships among variables without the need for longitudinal tracking. SEM-PLS is especially suited for exploratory research contexts and provides robust results even when traditional assumptions of normality and large sample sizes are not met. By integrating SEM-PLS with a structured questionnaire and purposive sampling, this study provides a comprehensive framework for understanding how independent variables such as Knowledge Management, Green Market Orientation and Management Commitment influence Aggressive Low Carbon Innovation and Firm's ESG Performance. This methodological approach ensures both rigor and flexibility, allowing for detailed analysis of complex relationships within the dataset.

Population and sample

The population for this study includes companies in Indonesia's energy sector, particularly those actively implementing sustainability strategies and ESG (Environmental, Social, and Governance) reporting. The sample consists of 210 top management respondents from Pertamina group. These individuals were selected through purposive sampling based on the following criteria:

1. Companies in the energy sector that have implemented sustainability initiatives for at least three years.
2. Companies that actively publish ESG reports or participate in low-carbon innovation programs.
3. Respondents occupying managerial or leadership roles related to green knowledge management, sustainability, or innovation.

This sample size is considered adequate for SEM-PLS analysis, ensuring robust results even with small sample sizes. Purposive sampling ensures that the selected respondents are relevant to the research objectives, improving the validity and reliability of the study's findings.

Data analysis

The data analysis was conducted in two stages: descriptive analysis and SEM-PLS analysis.

1. **Descriptive analysis**

   Descriptive statistics were used to summarize the characteristics of the sample, including company type, size, and the length of time sustainability practices had been implemented. Response distributions for each variable were analyzed and presented in percentages to provide an overview of the data.

2. SEM-PLS analysis

The SEM-PLS analysis was conducted in two stages: evaluation of the measurement model (outer model) and evaluation of the structural model (inner model).

Outer model evaluation

1) **Convergent validity:** Measured by assessing the outer loading values of indicators, with a threshold of >0.70.
2) **Discriminant validity:** Evaluated using the Fornell-Larcker criterion to ensure that constructs are distinct.
3) **Reliability:** Tested using Composite Reliability (CR > 0.70), Average Variance Extracted (AVE > 0.50), and Cronbach's Alpha (α > 0.70).

Inner model evaluation

1) **Path coefficients and t-values:** Tested to assess the significance of relationships between variables.
2) **R^2 (Coefficient of determination):** Indicates the proportion of variance in the dependent variable explained by the independent variables.
3) **Mediation analysis:** Assesses the mediating role of Aggressive Low Carbon Innovation in the relationship between Green Knowledge Management, Green Market Orientation, Management Commitment, and Firm's ESG Performance.

All analyses were conducted at a 5% significance level. SEM-PLS was chosen due to its robustness in handling non-normal data distributions, smaller sample sizes, and complex models

RESULTS

Respondent characteristics

This table presents the distribution of responses regarding the characteristics of respondents based on position, gender, age, function/company, education and length of service.

Table 2: Respondent characteristics

Characteristic Variable	Frequency (n)	Percentage (%)
Position		
Manager	70	33.30%
Ast Manager	60	28.60%
VP	50	23.80%
SVP	3	1.40%
BOD	27	12.90%
Gender		
Male	172	81.90%
Female	38	18.10%
Age		
26 – 30 Years	1	0.50%
31 – 35 Years	17	8.10%
36 – 40 Years	53	25.20%
41 – 45 Years	60	28.60%
46 – 50 Years	47	22.40%
> 50 Years	32	15.20%
Origin of Function/Company		
Pertamina Holding	88	41.90%
Pertamina Foundation Grup	1	0.48%
Portofolio – Patrajasa dan AP	5	2.38%
Portofolio - Pelita Air Service	4	1.90%
Portofolio – Pertamina IHC	4	1.90%
Portofolio - PTC	2	0.95%
Subholding C&T	19	9.05%
Subholding Gas	24	11.43%

Characteristic Variable	Frequency (n)	Percentage (%)
Subholding IML	10	4.76%
Subholding PNRE	12	5.71%
Subholding Refinery	12	5.71%
Subholding Upstream	29	13.81%
Educational Level		
Bachelor's Degree	57	27.10%
Master's Degree	139	66.20%
Doctoral's Degree	14	6.70%
Length of Time Worked		
0 – 5 Years	4	1.90%
6 – 10 Years	9	4.30%
11 – 15 Years	82	39.00%
16 – 20 Years	41	19.50%
21 – 25 Years	48	22.90%
26 – 30 Years	15	7.10%
> 30 Years	11	5.20%

Based on the respondent characteristic tabulation, the majority of respondents in this study are male (81.9%), with positions primarily held by managers (33.3%) and assistant managers (28.6%). Most respondents are aged between 36 and 45 years, particularly within the 41–45-year age range, which accounts for 28.6% of the total respondents. Regarding educational background, the majority of respondents hold a Master's degree (66.2%), while those with a Bachelor's and Doctoral degree constitute 27.1% and 6.7%, respectively. Most respondents are affiliated with Pertamina Holding (41.9%), followed by various subholdings, each representing smaller proportions. In terms of work experience, the majority of respondents have between 11 and 15 years of professional experience (39.0%), while those with fewer than 5 years or more than 30 years of experience represent only 1.9% and 5.2%, respectively. These findings suggest that the respondents in this study tend to have substantial professional experience, occupy managerial positions, and possess higher educational qualifications.

Outer model

Outer loading

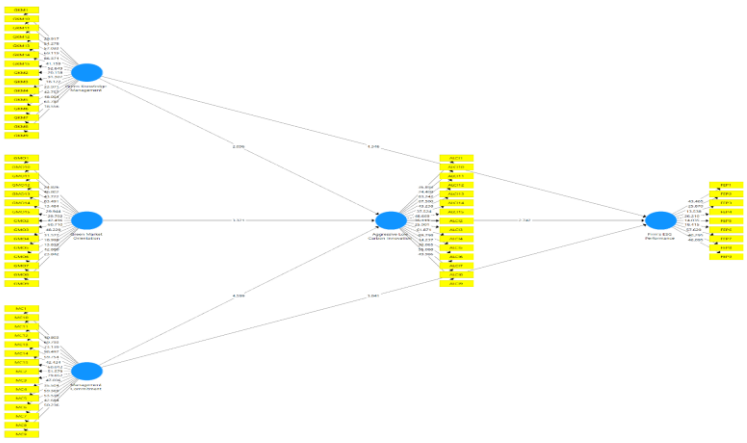

Figure 3: Outer model

The results in figure 3 indicate that most indicators exhibit satisfactory outer loading values (>0.7), confirming strong convergent validity for each construct. For Aggressive Low Carbon Innovation (ALCI), the highest-loading indicators, ALCI11 (0.903) and ALCI12 (0.912), highlight the significant contribution of resource allocation and low-carbon strategy implementation. Similarly, Firm's ESG Performance (FEP) demonstrates strong validity, with FEP9 (0.877) emphasizing corporate compliance with ESG regulations. Key indicators in Green Knowledge Management (GKM13: 0.909) and Green Market Orientation (GMO12: 0.901) further reinforce the critical role of green knowledge and market orientation in the model. While some indicators, such as ALCI6 (0.725) and GMO7 (0.741), exhibit relatively lower values, they remain within acceptable thresholds for exploratory research, albeit with weaker contributions to their respective constructs. Meanwhile, Management

Commitment (MC12: 0.916) stands out as a crucial determinant in corporate sustainability efforts. Overall, these findings validate the model's indicators and strengthen confidence in the quality of the measurement instruments used in this study.

Heterotrait-monotrait ratio (HTMT) analysis

The Heterotrait-Monotrait Ratio of Correlations (HTMT) is a statistical method used to assess discriminant validity in Structural Equation Modeling-Partial Least Squares (SEM-PLS). It evaluates whether a construct exhibits stronger relationships with its own indicators compared to indicators from other constructs. An ideal HTMT value should be below 0.85, although values up to 0.90 may still be acceptable in certain contexts. The following table presents the HTMT results for the analyzed model.

Table 3: HTMT results for the SEM-PLS model

	Aggressive Low Carbon Innovation	Firm's ESG Performance	Green Knowledge Management	Green Market Orientation	Management Commitment
Aggressive Low Carbon Innovation	—				
Firm's ESG Performance	0.804	—			
Green Knowledge Management	0.803	0.824	—		
Green Market Orientation	0.899	0.887	0.800	—	
Management Commitment	0.801	0.802	0.820	0.810	—

The HTMT results indicate that most values are below the 0.85 threshold, supporting good discriminant validity among constructs. For instance, the HTMT values between Aggressive Low Carbon Innovation and Firm's ESG Performance (0.804) and Aggressive Low Carbon Innovation and Green Knowledge Management (0.803) fall within the acceptable range. However, the HTMT value between Aggressive Low Carbon Innovation and Green Market Orientation (0.899) approaches the upper limit, although it remains within an acceptable range for discriminant validity. Other values, such as Firm's ESG Performance and Green Knowledge Management (0.824) and Management Commitment and Green Market Orientation (0.810), further reinforce the model's discriminant validity. Overall, the findings confirm that each construct maintains a stronger relationship with its own indicators than with those of other constructs, ensuring the robustness of the model for further analysis.

Reliability and correlations variables

Table 4: Reliability and correlations variables

Variable	Cronbach's Alpha	rho_A	Composite Reliability	AVE
Aggressive Low Carbon Innovation (Z)	0.973	0.974	0.976	0.728
Firm's ESG Performance (Y)	0.940	0.944	0.950	0.678
Green Knowledge Management (X1)	0.967	0.970	0.971	0.688
Green Market Orientation (X2)	0.966	0.967	0.969	0.678
Management Commitment (X3)	0.979	0.979	0.981	0.771

The table presents the evaluation of the measurement model for the variables in the study. It includes key reliability and validity metrics such as Cronbach's Alpha, rho_A, Composite Reliability, and

Average Variance Extracted (AVE). All variables exhibit excellent reliability, with Cronbach's Alpha and rho_A values well above the recommended threshold of 0.7. The Composite Reliability values are also high, ranging from 0.950 to 0.981, indicating strong internal consistency. The AVE values for all constructs are above the threshold of 0.5, with the highest being 0.771 for Management Commitment, which suggests adequate convergent validity. These results indicate that the measurement model is robust and reliable for further analysis of the relationships between constructs.

R-square (R^2): coefficient of determination analysis

The R-Square (R^2) analysis is employed to assess the predictive power of the structural model in SEM-PLS. This coefficient determines the extent to which the dependent constructs are explained by the independent constructs in the model. A higher R^2 value indicates a greater proportion of variance in the dependent variable accounted for by the model. The table below presents the R^2 and Adjusted R^2 values for Aggressive Low Carbon Innovation and Firm's ESG Performance.

Table 5: R-square and adjusted R-square results

Construct	R Square	R Square Adjusted	Interpretation
Aggressive Low Carbon Innovation	0.833	0.830	Strong
Firm's ESG Performance	0.818	0.816	Strong

The results indicate that Aggressive Low Carbon Innovation has an R^2 value of 0.833, meaning that 83.3% of its variability is explained by independent constructs within the model. This strong predictive power suggests that Green Knowledge Management and Management Commitment significantly contribute to the firm's pursuit of low-carbon innovation. Similarly, Firm's ESG Performance demonstrates an R^2 value of 0.818, indicating that 81.8% of its variability is accounted for by Green Market Orientation and Aggressive Low Carbon Innovation. This further confirms the model's robustness in explaining causal relationships between the constructs. Overall, these findings support the structural validity of the model, affirming that the independent variables exert a significant influence on the dependent constructs.

Effect size (f^2) analysis

The Effect Size (f^2) analysis is used to assess the magnitude of influence that an independent construct has on a dependent construct in the SEM-PLS model. The f^2 value determines the relative importance of each independent variable in explaining the variance of the dependent variable. The table below presents the f^2 results for Aggressive Low Carbon Innovation and Firm's ESG Performance.

Table 6: Effect size (f^2) in the SEM-PLS model

Construct	Aggressive Low Carbon Innovation	Firm's ESG Performance
Aggressive Low Carbon Innovation	—	0.252
Green Knowledge Management	0.160	0.228
Green Market Orientation	0.179	—
Management Commitment	0.180	0.189

The results indicate that Aggressive Low Carbon Innovation has an f^2 value of 0.252 in explaining Firm's ESG Performance, classifying it as a moderate effect, which suggests that low-carbon innovation significantly contributes to ESG performance improvement. Additionally, Green Knowledge Management also exhibits a moderate effect (f^2 = 0.228) on Firm's ESG Performance, emphasizing the critical role of green knowledge in enhancing sustainability performance. For Aggressive Low Carbon Innovation, Management Commitment (f^2 = 0.180) and Green Market Orientation (f^2 = 0.179) both have moderate influences, highlighting their importance in driving low-carbon innovation within firms. Green Knowledge Management (f^2 = 0.160) also demonstrates a notable effect on low-carbon innovation, reinforcing its significance in supporting sustainable technological advancements. Overall, these findings confirm that all independent constructs significantly influence the dependent constructs, with varying effect sizes, further strengthening the predictive validity of the research model.

Hypothesis testing

Table 7: Direct effect

Direct effect	Original sample (O)	T statistics (|O/STDEV|)	P values
Aggressive Low Carbon Innovation -> Firm's ESG Performance	0.272	2.742	0.008
Green Knowledge Management -> Aggressive Low Carbon Innovation	0.240	2.096	0.037
Green Knowledge Management -> Firm's ESG Performance	0.509	4.346	0.000
Green Market Orientation -> Aggressive Low Carbon Innovation	0.304	3.321	0.001
Green Market Orientation -> Firm's ESG Performance	0.342	3.721	0.000
Management Commitment -> Aggressive Low Carbon Innovation	0.403	4.599	0.000
Management Commitment -> Firm's ESG Performance	0.352	3.841	0.000

Table 6 illustrates the results of the analysis of direct relationships between variables that influence the company's ESG performance. The results show that Aggressive Low Carbon Innovation → Firm's ESG Performance (0.272, p = 0.008) has a significant positive effect on the company's ESG performance, indicating that aggressive low-carbon innovation contributes to improving ESG performance. Green Knowledge Management → Aggressive Low Carbon Innovation (0.240, p = 0.037), Green Market Orientation → Aggressive Low Carbon Innovation (0.304, p = 0.001) and Green Market Orientation → Firm's ESG Performance (0.342, p = 0.001) also show significant positive effects, emphasizing the important role of green knowledge management and green market orientation in driving aggressive low-carbon innovation. Furthermore, Green Knowledge Management → Firm's ESG Performance (0.509, p = 0.000) and Management Commitment → Firm's ESG Performance (0.352, p = 0.000) show highly significant relationships with the company's ESG performance, indicating that green knowledge management and managerial commitment have a substantial impact on ESG performance. Finally, Management Commitment → Aggressive Low Carbon Innovation (0.403, p = 0.000) shows that managerial commitment plays a crucial role in driving aggressive low-carbon innovation. All the relationships tested in this table show highly significant p-values, supporting the importance of these factors in enhancing the company's ESG performance.

Table 8: Indirect effect

Indirect Effect	Original Sample (O)	T statistics (|O/STDEV|)	P values
Green Knowledge Management -> Aggressive Low Carbon Innovation -> Firm's ESG Performance	0.174	3.602	0.000
Green Market Orientation -> Aggressive Low Carbon Innovation -> Firm's ESG Performance	0.220	3.704	0.000
Management Commitment -> Aggressive Low Carbon Innovation -> Firm's ESG Performance	0.291	3.749	0.000

The table above presents the indirect effects, T-statistics, and p-values for the relationships between various factors influencing a company's ESG performance through aggressive low-carbon innovation. All of the tested indirect effects show significant positive influence, with p-values below 0.05, indicating strong and statistically significant relationships. The indirect effects of Green Knowledge Management → Aggressive Low Carbon Innovation → Firm's ESG Performance (0.174, p = 0.000), Green Market Orientation → Aggressive Low Carbon Innovation → Firm's ESG Performance (0.220, p = 0.000), and Management Commitment → Aggressive Low Carbon Innovation → Firm's ESG Performance (0.291, p = 0.000) highlight that green knowledge management, green market orientation, and management commitment play crucial roles in enhancing a company's ESG performance through aggressive low-carbon innovation. This underscores the importance of these factors in driving low-carbon innovation, which in turn positively contributes to the company's ESG performance.

DISCUSSION

The direct effects of organizational factors on firm's ESG performance

The research shows that low-carbon innovation significantly improves a company's ESG performance (path coefficient = 0.272, T-statistics = 2.742, p = 0.008). This innovation enables the adoption of environmentally friendly technologies that reduce carbon footprints and increase efficiency, which strengthens the company's positive image and competitiveness (Rehman et al., 2024). Low-carbon innovation also supports environmental sustainability, social relationships with communities, and governance transparency (Guang-lin & Tao, 2023; Tabah et al., 2023).

Based on the research findings, Green Knowledge Management positively contributes to low-carbon innovation (path coefficient = 0.240, T-statistics = 2.096, p = 0.037). By integrating sustainability-related knowledge, companies can develop data-driven green technologies and best practices (Rehman et al., 2024). GKM accelerates the development of low-carbon innovations, improves responses to environmental regulations, and encourages inter-departmental collaboration (Maryam, 2023; Mingqiang, 2024).

The research also indicates that Green Knowledge Management enhances the company's ESG performance (path coefficient = 0.509, T-statistics = 4.346, p = 0.000). GKM helps integrate sustainability practices into the company's operations, improving regulatory compliance, and strengthening governance and social relationships in ESG (Guang-lin & Tao, 2023; Maryam, 2023). Companies with strong GKM tend to have a stronger ESG reputation and better competitiveness (Mingqiang, 2024).

Based on the research findings, Green Market Orientation drives low-carbon innovation by understanding market demand for environmentally friendly products (path coefficient = 0.304, T-statistics = 3.321, p = 0.001). Companies focused on the green market can create products that align with sustainability values and improve operational efficiency (Guang-lin & Tao, 2023; Mingqiang, 2024). This also strengthens the company's competitive position by leveraging global sustainability trends (Maryam, 2023).

The research shows that Management Commitment plays a key role in driving low-carbon innovation (path coefficient = 0.403, T-statistics = 4.599, p = 0.000). Support from top management ensures adequate resource allocation and the sustainability of green policy implementation (Safaa Abid Ali Abdulameer & Inari Mohammed, 2024). Committed leadership fosters an innovation culture and external collaboration to accelerate the development of green technologies (Mingqiang, 2024; Maryam, 2023).

Based on the research findings, Management Commitment to sustainability enhances the company's ESG performance (path coefficient = 0.352, T-statistics = 3.841, p = 0.000). ESG-oriented management supports emission reductions, energy efficiency, positive social policies, and improves transparency in ESG reporting (Safaa Abid Ali Abdulameer & Inari Mohammed, 2024; Guang-lin & Tao, 2023). Companies with leadership committed to sustainability tend to have higher ESG ratings and attract more long-term investments (Maryam, 2023; Mingqiang, 2024).

The indirect effects of organizational factors on firm's ESG performance

The research shows that Green Knowledge Management positively impacts Firm's ESG Performance through Aggressive Low Carbon Innovation, with a path coefficient of 0.174 (T-statistics = 3.602, p = 0.000), highlighting its significant role. Companies with strong green knowledge management systems are more likely to develop low-carbon innovations that enhance their ESG performance. According to Guang-lin and Tao (2023), integrating green knowledge into business processes accelerates the adoption of low-carbon technologies, contributing to sustainability. Green knowledge management helps companies identify innovation opportunities, facilitating the development of energy-efficient technologies and low-carbon solutions (Mingqiang, 2024). These innovations significantly improve environmental performance and reduce carbon footprints, as noted by Maryam, et al. (2023). Additionally, green innovation strengthens the social and governance aspects of ESG by improving transparency and stakeholder engagement (Safaa Abid Ali Abdulameer & Inari Mohammed, 2024). Overall, the research underscores the importance of green knowledge management in boosting ESG performance through low-carbon innovation, emphasizing the need for

companies to focus on supporting and accelerating low-carbon innovations.

The research shows that Green Market Orientation significantly influences Firm's ESG Performance through Aggressive Low Carbon Innovation, with a path coefficient of 0.220 (T-statistics = 3.704, p = 0.000). This indicates that green market orientation not only drives low-carbon innovation but also enhances ESG performance. By understanding market demand for eco-friendly products, companies can develop sustainable solutions that support long-term sustainability. According to Guang-lin and Tao (2023), adopting a green market strategy enables companies to develop low-carbon technologies that boost overall ESG performance. Green market orientation helps companies respond to consumer preferences for sustainability, improving competitiveness and environmental efficiency (Mingqiang, 2024). Furthermore, it strengthens the social aspect of ESG by fostering positive relationships with customers and stakeholders (Maryam, 2023). In governance, green market strategies promote transparency and accountability in ESG reporting (Safaa Abid Ali Abdulameer & Inari Mohammed, 2024). Overall, this research highlights that green market orientation enhances ESG performance through low-carbon innovation, emphasizing the need for sustainable investment to achieve both market competitiveness and sustainability goals.

The research reveals that Management Commitment significantly enhances Firm's ESG Performance through Aggressive Low Carbon Innovation, with an indirect effect having the highest path coefficient of 0.291 (T-statistics = 3.749, p = 0.000). Committed leadership provides strategic direction, resource allocation, and policies that support low-carbon innovation, strengthening ESG performance (Safaa Abid Ali Abdulameer & Inari Mohammed, 2024). Strong management support for green innovation directly impacts environmental aspects of ESG by reducing carbon emissions and improving energy efficiency (Guang-lin & Tao, 2023). Additionally, it enhances social dimensions by fostering positive policies for employees, communities, and customers, strengthening relationships with stakeholders (Mingqiang, 2024). In governance, management commitment increases transparency and accountability in ESG reporting (Maryam, 2023). Overall, without management support, low-carbon innovation cannot effectively drive ESG goals, emphasizing the need for leadership with a strong sustainability vision, investment in green technologies, and commitment to transparency and social responsibility.

INSIGHTS AND IMPLICATIONS

Theoretical Implications: This study enriches the sustainability literature by affirming that Aggressive Low Carbon Innovation enhances corporate ESG performance through mediators such as Green Knowledge Management, Green Market Orientation, and Management Commitment. These findings support the Natural Resource-Based View (NRBV) theory and stakeholder theory, showing that companies managing green knowledge and adopting green market orientation can improve their competitiveness and reputation in the global market while meeting stakeholder expectations in terms of sustainability.

Practical Implications: Companies need to develop sustainability strategies focused on low-carbon innovation with support from management commitment, green knowledge management, and green market orientation. The implementation of technology-based knowledge management systems, the development of environmentally friendly products, and the enhancement of ESG reporting transparency can strengthen ESG performance and competitiveness. Thus, companies can create long-term sustainable value, both financially and socially, in an era of business increasingly focused on ESG.

Limitations Of The Study

The limitations of this study include several aspects that need to be considered. First, this study only involved respondents from the sustainability-related teams at Pertamina group, which limits the generalization of the findings to this particular company and may not fully reflect practices in other industries. Second, the data collected is cross-sectional, which only provides a snapshot at a single point in time and cannot capture long-term changes or developments in the implementation of low-carbon innovation and ESG performance. Third, the use of a questionnaire as the data collection method may introduce response bias, as it relies on individuals' perceptions, which can be influenced by subjective factors. Additionally, the SEM PLS model used in data analysis relies on certain assumptions that may not fully capture the complexity of the relationships between variables in real-

world scenarios. Future research with a longitudinal approach and a more diverse sample would be valuable for providing a more comprehensive understanding.

CONCLUSION

The conclusion of this research shows that low-carbon innovation has a significant impact on improving a company's ESG performance, with green knowledge management, green market orientation, and management commitment as key factors supporting its implementation. Green innovation strengthens the environmental, social, and governance aspects of ESG, helping companies comply with sustainability regulations and gain long-term competitive advantages. Additionally, low-carbon innovation acts as a mediator in the relationship between green knowledge management and ESG, and companies with a green market orientation are better able to create sustainable products, enhance their corporate image, and strengthen stakeholder trust.

The recommendations from this study are that companies need to ensure strong leadership commitment in driving low-carbon innovation through clear sustainability policies and adequate budget allocation. Developing an effective knowledge management system, responding to green market trends, and integrating low-carbon innovation into sustainability strategies are key. Transparency in ESG reporting, cooperation with various parties, and incentives from the government are also crucial to accelerate the implementation of green innovation. Additionally, employee training and regular monitoring mechanisms will strengthen the sustainability culture and ensure that ESG strategies remain relevant.

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