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The influence of green knowledge management and management commitment on ESG performance mediated by aggressive low carbon innovation

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ABSTRACT

This study investigates the influence of Green Knowledge Management (GKM), Green Market Orientation (GMO), and Management Commitment (MC) on Environmental, Social, and Governance (ESG) performance, emphasizing the mediating role of Aggressive Low Carbon Innovation (ALCI). A quantitative approach was employed, using structured questionnaires collected from 210 top and middle managers across 30 energy companies. Data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). GKM significantly affects ALCI (β = 0.483) and ESG performance (β = 0.202), with a notable indirect effect via ALCI (β = 0.151). GMO directly impacts ALCI (β = 0.279) and ESG (β = 0.312), and indirectly through ALCI (β = 0.087). MC significantly influences ALCI (β = 0.219) and ESG (β = 0.168), with an indirect effect via ALCI (β = 0.068). ALCI positively affects ESG performance (β = 0.312), confirming its mediating role. GKM, GMO, and MC enhance ESG performance both directly and indirectly through ALCI. Organizations aiming to improve ESG outcomes should invest in green knowledge, market orientation, and leadership commitment to foster low-carbon innovation and drive sustainable performance.

Contribution/ Originality: Implementing aggressive low-carbon innovation as a new concept to mediate green knowledge management (GKM), green market orientation (GMO), and management commitment (MC) on environmental, social, and governance (ESG) performance.

1. INTRODUCTION

Over the past few decades, concerns about climate change and the need to move quickly toward a low-carbon economy have significantly increased the profile of sustainability across various sectors [1]. Governments, investors, and other stakeholders are increasing pressure on businesses to demonstrate sound social governance and environmental responsibility alongside their financial performance. An important measure of how well companies manage these responsibilities is their Environmental, Social, and Governance (ESG) performance [2]. In Indonesia's energy sector, where companies are responsible for a significant amount of the nation's carbon emissions, this issue is particularly urgent. According to the Ministry of Environment and Forestry [3], Pertamina Group, Indonesia's largest state-owned energy company, is a significant contributor to the approximately 34% share of greenhouse gas emissions in the energy sector. The company's efforts to adhere to international agreements such as the Paris Agreement and Indonesia's Net Zero Emission (NZE) 2060 target, pledged at COP26, are being closely monitored.

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However, recent reports from the Ministry of Energy and Mineral Resources (ESDM) and audits by the Supreme Audit Agency (BPK) have revealed inconsistencies in ESG disclosures, gaps in carbon management plans, and a lack of integration of green innovation practices among its subsidiaries [4].

Most previous research has focused on external factors such as investor influence, regulatory pressure, or corporate reputation, despite the growing body of literature on ESG drivers. Few studies have examined internal organizational capabilities, specifically how Management Commitment (MC) and Green Knowledge Management (GKM) support aggressive low-carbon innovation (ALCI) and improve ESG performance. This study empirically investigates how GKM and MC influence ESG performance through the mediating role of ALCI within the Pertamina Group, thereby addressing this knowledge gap. By emphasizing internal enablers of sustainable transformation, the study offers new insights to the ESG literature. Additionally, it provides strategic guidance for businesses in carbon-intensive industries.

One of Indonesia's largest energy companies, Pertamina, is crucial for supplying the nation's energy needs as well as meeting global sustainability standards. It is challenging to align the company's operations with environmental sustainability goals because it operates in an industry that has historically been associated with high carbon emissions. As Indonesia works to fulfill its obligations under the Paris Agreement and the SDGs, there is increasing pressure on Pertamina to become a more environmentally conscious business [5]. This change will affect the company's ability to compete in the global market as well as its reputation and long-term survival. Implementing comprehensive sustainability strategies that integrate environmental, social, and governance (ESG) frameworks is therefore essential [6].

To promote sustainability, businesses should adopt strategic approaches such as Green Knowledge Management (GKM). By implementing low-carbon technologies and developing eco-friendly innovations, GKM involves managing, sharing, and applying knowledge related to environmental sustainability [7]. GKM is crucial for businesses aiming to innovate, boost operational efficiency, and reduce their environmental impact, according to historical data. GKM has a significant impact on a company's ESG performance by promoting the systematic collection, organization, and application of environmentally sustainable knowledge within corporate operations. GKM encourages practices that reduce ecological footprints and enhance resource efficiency by enabling businesses to integrate environmental considerations into operations and decision-making [8, 9]. GKM becomes a transformative tool that encourages both regulatory compliance and the development of creative solutions to issues presented by climate change when paired with aggressive low-carbon innovation (ALCI). Low-carbon innovations act as catalysts in this process by transforming the strategies and knowledge acquired from GKM into practical applications, such as waste reduction, process optimization, and the adoption of renewable energy [9]. This synergy improves ESG outcomes by ensuring that environmental sustainability initiatives are both significant and scalable. Furthermore, GKM fosters cross-functional collaboration and knowledge sharing among companies, developing a mindset that embraces change and thrives in a dynamic sustainability environment [10]. Aggressive low-carbon innovation helps firms transition from traditional operational models to sustainable business paradigms that prioritize the long-term health of people and the planet by mediating the relationship between GKM and ESG performance [11, 12]. Harnessing this dynamic is crucial for energy companies like Pertamina to meet global sustainability goals and maintain competitiveness in a market that is becoming more environmentally conscious [13].

Another crucial element that facilitates the effective application of sustainability strategies is management commitment [1, 14, 15]. Strategic decision-making that promotes long-term sustainability is made possible by strong managerial commitment, which also promotes the consistent application of sustainability policies. Based on Wahyuni et al. [13], Devoted management can enhance corporate ESG performance and hasten the adoption of eco-friendly practices. In line with the company's vision and operational procedures, committed leadership makes sure that sustainability goals are both aspirational and achievable [12, 16]. Management demonstrates its commitment to addressing climate issues and reducing the company's carbon footprint by prioritizing aggressive low-carbon

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innovation, which significantly enhances ESG outcomes [17, 18]. Low-carbon innovation is the process by which management commitment is translated into observable outcomes. It facilitates the adoption of advanced technologies and approaches that reduce their negative effects on the environment, such as carbon capture systems, energy-efficient procedures, and the integration of renewable energy sources. By allocating resources, encouraging sustainable practices, and establishing specific goals for reducing emissions, committed management creates an environment conducive to innovation [19, 20]. This approach encourages organizational-wide engagement and ensures that sustainability initiatives are continuously monitored and refined. In sectors like energy, where sustainability pressures are significant, management's role in championing aggressive low-carbon innovation (ALCI) is essential for achieving measurable improvements in ESG performance. As a mediator, proactive low-carbon innovation does more than just align management's intentions with practical ESG achievements; it also positions the firm as a leader in sustainability, enhancing its reputation, stakeholder trust, and long-term competitiveness in a rapidly evolving global market [21].

Previous research has highlighted the importance of GKM, management commitment, and ALCI in supporting corporate sustainability. Jia et al. [16] demonstrated that GKM has a beneficial effect on sustainable performance and the development of environmentally friendly technologies in the building industry. Ahmad et al. [21] found that GKM enhances the firm's ability to innovate green processes, which in turn supports the firm's competitiveness. Ahmad et al. [21] determined that the backing of sustainability initiatives and the involvement of management are crucial to the success of green supply chain management. Ahmad et al. [21] discovered that managerial buy-in acts as a mediator for green innovation and company output, especially in reducing carbon emissions. ALCI allows companies to respond more quickly to external environmental pressures through aggressive strategies in low-carbon innovation. Similarly, Abbas and Khan found that green culture and innovation, supported by knowledge management practices, are crucial for achieving green performance [20]. Furthermore, Sahoo noted that green technology innovation and data-driven strategies can significantly improve environmental performance Sahoo et al. [9]. El-Kassar and Singh [10] noted that intensive green innovation has a direct impact on reducing a firm's carbon footprint, which improves global competitiveness. Although various studies have been conducted, most of them are still general in nature and lack highlighting the specific relationship between GKM, management commitment, and ALCI in improving ESG performance, especially in the energy sector such as Pertamina Group.

Environmental, social, and governance (ESG) performance assesses a corporation's effectiveness in managing these three interconnected factors. The environmental dimension encompasses the management of carbon emissions, the utilization of renewable energy, and the mitigation of the environmental impact of the company's operational activities. The social dimension covers employee welfare, community relations, and the company's social contributions. The governance dimension assesses transparency, accountability, and ethics in the management of the company. ESG performance is increasingly relevant with the rising global pressure to achieve sustainability targets, including Net Zero Emissions (NZE) by 2060, which has been launched by the Indonesian government.

An approach to knowledge management that focuses on sustainability in the environment is known as Green Knowledge Management (GKM). Among the many aspects of GKM are the processes of gathering, archiving, disseminating, and using information related to eco-friendly innovations and technologies. According to studies conducted at Pertamina, GKM is a key component in facilitating the growth of low-carbon businesses through planned and systematic knowledge management. GKM enables companies to integrate green technology solutions into operational processes, thereby improving efficiency and sustainability performance.

Management commitment reflects the level of support and involvement of top management in realizing the company's sustainability strategy. In the context of the Pertamina group, management commitment is demonstrated through the implementation of a dual growth strategy, namely strengthening existing businesses while developing low-carbon businesses. This commitment includes support for low-carbon technology initiatives, renewable energy development, and investment in carbon markets. The commitment of upper management is crucial for the

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organization's strategic policy implementation to be sustainable and for the allocation of resources to be sufficient [21].

Aggressive low-carbon innovation involves developing technologies and strategies aimed at significantly reducing carbon emissions. ALCI combines two main elements: green innovation capability and strategic aggressiveness. In Pertamina's context, ALCI is implemented through major investments in carbon capture technology (CCS/CCUS), carbon market development, and renewable energy adoption. Achieving a low-carbon economy may be accelerated, providing the firm with a competitive edge in the global market.

This research provides a novel contribution to the sustainability literature by examining the ALCI as a mediating approach: This research develops the concept of ALCI as a mediating mechanism linking GKM and management commitment with a firm's ESG performance. ALCI is positioned as a more aggressive innovation strategy in reducing carbon emissions, differing from the more conservative green innovation approach in previous studies. Most previous studies were conducted in the manufacturing and construction sectors [22]. By focusing on Pertamina Group, a company in the energy sector with significant carbon emissions, this study contributes to the limited literature in this area. It helps Indonesia achieve the net-zero emissions goal by 2060 by providing major energy companies with strategic insights to accelerate the transition to a low-carbon economy [22].

The implementation of ALCI is particularly important for a large energy company such as Pertamina Group. Pertamina, one of Indonesia's largest carbon emitters, is under significant pressure to meet international obligations, including the Paris Agreement, and to achieve Net Zero Emission (NZE) targets by 2060 [23]. Through the use of GKM and strong managerial commitment, Pertamina can implement aggressive low-carbon innovations and improve its environmental, social, and governance (ESG) performance. This study aims to understand how management commitment and green knowledge management impact an organization's ESG performance through aggressive low-carbon innovation. It is expected that the results of this study will significantly enhance the body of knowledge on sustainability management and provide energy companies with strategic guidance.

Despite the growing body of literature on ESG drivers, most previous studies have remained limited in several critical ways. First, much of the existing research tends to emphasize external factors such as regulatory pressures, stakeholder demands, or reputational concerns while paying insufficient attention to internal organizational capabilities. Second, studies that do explore internal factors often focus broadly on green innovation or environmental strategies without clearly unpacking the specific mechanisms that translate knowledge and commitment into ESG outcomes. In particular, the roles of Green Knowledge Management (GKM) and Management Commitment (MC) as internal enablers have been underexplored, especially in their interaction with more aggressive forms of innovation aimed at rapid decarbonization. Furthermore, existing research has largely centered on manufacturing or construction sectors, leaving a notable gap in the energy sector especially within state-owned enterprises operating in carbon-intensive contexts like Indonesia. This study addresses these limitations by investigating the mediating role of Aggressive Low-Carbon Innovation (ALCI) in the relationship between GKM, MC, and ESG performance in Pertamina Group. In addition to contributing to the theoretical discussion of sustainable innovation, this study's focus on an energy company with strategic relevance to Indonesia's Net Zero Emission (NZE) 2060 commitment offers sector-specific insights with useful implications for high-emission industries. Given the urgency of climate action, the study provides a more contextually grounded and nuanced understanding of how internal capabilities drive sustainable transformation, which is both timely and necessary.

Novelty of the Research: This study provides empirical evidence on the mediating role of Aggressive Low Carbon Innovation (ALCI) in linking Green Knowledge Management (GKM) and Management Commitment (MC) to ESG performance, particularly within the high-carbon energy sector. While previous research has explored green innovation broadly, few have specifically examined how aggressive innovation strategies function within carbon-intensive industries like the Pertamina Group. By analyzing these relationships in the context of a large state-owned

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energy enterprise, this study extends the empirical literature and offers sector-specific insights that can inform both academic discourse and practical sustainability strategies.

Table 1. Research operational variables.

No.	Operational definition of variables	Indicator	Source
1	Green knowledge management (GKM): The management of systematic processes used by an organization to acquire, share, and transfer environmentally related knowledge and innovation.	1. Green knowledge creation 2. Green knowledge application 3. Green knowledge sharing 4. Green knowledge storage 5. Access to green practices information 6. Formalized green knowledge documentation	Wang, et al. [14]; and Hameed, et al. [24]
2	Management commitment (MC): The level of involvement, support, and leadership from management toward implementing environmental sustainability and innovation.	1. Environmental values and ethics 2. Resource allocation 3. Communication of vision and mission 4. Encouragement and evaluation of green innovation initiatives	Papadas, et al. [25]; Hens, et al. [26]; Zailani, et al. [27] and Daily and Huang [28]
3	Aggressive low-carbon innovation (ALCI): Innovation that emphasizes rapid and significant development of low-carbon technologies and practices to reduce environmental impact.	1. Innovation capability 2. Resource allocation 3. Sustainability commitment 4. Green investment 5. Technological advancement	Li, et al. [29] and Zhang, et al. [30]
4	ESG performance: Performance measures that reflect a company's total social, environmental, and governance impact and initiatives.	1. Environmental performance 2. Social performance 3. Governance performance	Clark, et al. [31]

Table 1 presents the operational definitions, indicators, and sources of the variables used in this study. Green Knowledge Management (GKM) is defined as the systematic process of acquiring, sharing, and applying environmental knowledge within organizations, with six key indicators including knowledge creation, application, sharing, storage, access to green practices, and formal documentation. Management Commitment (MC) refers to the leadership's engagement and support in fostering environmental initiatives, measured through indicators such as environmental values, resource allocation, communication of vision, and support for innovation. Aggressive Low Carbon Innovation (ALCI) is described as proactive efforts to develop and implement low-carbon technologies, captured through indicators like technology adoption, investment in green R&D, and leadership support. Finally, ESG Performance reflects the organization's environmental, social, and governance impacts, measured through sustainability disclosures, social contributions, and alignment with ESG indices. The sources listed in Table 1 provide theoretical and empirical support for the operationalization of each variable

2. RESEARCH METHOD

2.1. Research Design

This study employs a quantitative correlational research design to examine the relationships among Green Knowledge Management (GKM), Management Commitment (MC), Aggressive Low Carbon Innovation (ALCI), and

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ESG performance. This design enables analysis of both direct and indirect effects, specifically assessing ALCI's mediating role in the relationship between GKM and ESG performance, as well as between MC and ESG performance. This approach is appropriate for hypothesis testing in complex models involving latent constructs.

2.2. Population and Sample

The population comprises enterprises in Indonesia's energy sector that actively adopt sustainability policies and report on ESG performance. The study examines holdings and subsidiaries within Pertamina Group, which are essential to Indonesia's energy transition strategy.

A purposive sample method was employed using the subsequent inclusion criteria.

1. Companies have executed ESG/sustainability initiatives for a minimum of three years.
2. Companies publicly reveal their ESG performance or exhibit proactive low-carbon innovation activities.
3. Participants are upper- or middle-level managers directly engaged in sustainability, innovation, or knowledge management activities.

A total of 30 companies were selected based on these criteria. Three to five managers were chosen from each organization, resulting in a total of 210 respondents. This multi-informant approach enhances the reliability and validity of organizational-level data.

2.3. Data Collection Tool

Data were collected using a digitally administered structured questionnaire, developed by adapting validated measurement items from prior studies and contextualized for Indonesia's energy industry. Each item used a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). The questionnaire comprised the following constructs:

- Green Knowledge Management (7 items): Measures organizational practices related to green knowledge acquisition, sharing, and application.
- Management Commitment (6 items): Captures strategic support, leadership involvement, and top-level commitment to sustainability.
- Aggressive Low-Carbon Innovation (8 items): Assesses the speed, intensity, and investment in carbon-reducing technologies.
- ESG Performance (9 items): Covers environmental impact (e.g., emission reduction), social responsibility programs, and governance transparency.

Prior to full deployment, the instrument underwent content validation and a pilot test involving 20 respondents. The reliability of all constructs was confirmed with Cronbach's alpha values exceeding 0.70.

2.4. Analysis Method

There were two primary steps to the data analysis process:

1. Descriptive Statistics

Descriptive analysis was used to profile the respondents (e.g., company size, implementation period of sustainability initiatives) and to describe response patterns across variables using frequencies and percentages.

2. Structural Equation Modeling with PLS

SEM-PLS was employed using SmartPLS software due to its robustness in handling small to medium sample sizes, non-normal data, and complex models with mediating variables. The analysis included:

1. Measurement Model (Outer Model) Evaluation:

a. Convergent Validity: Evaluated by factor loadings (target > 0.70) and Average Variance Extracted (AVE > 0.50).

b. a. Discriminant validity: assessed by the Fornell-Larcker criterion.

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c. Reliability: Confirmed using Cronbach's Alpha, Composite Reliability (CR > 0.70), and Average Variance Extracted (AVE).

2. Structural Model (Inner Model) Evaluation:

a. Path Coefficients and T-values: Evaluated to determine the robustness and significance of the proposed associations.

b. Coefficient of Determination (R^2): Denotes the percentage of variance elucidated by the independent variables.

c. Mediation Analysis: To test whether ALCI mediates the effects of GKM and MC on ESG performance.

All hypotheses were tested at a 5% significance level, adhering to the recommended procedures for SEM-PLS analysis in social and management sciences.

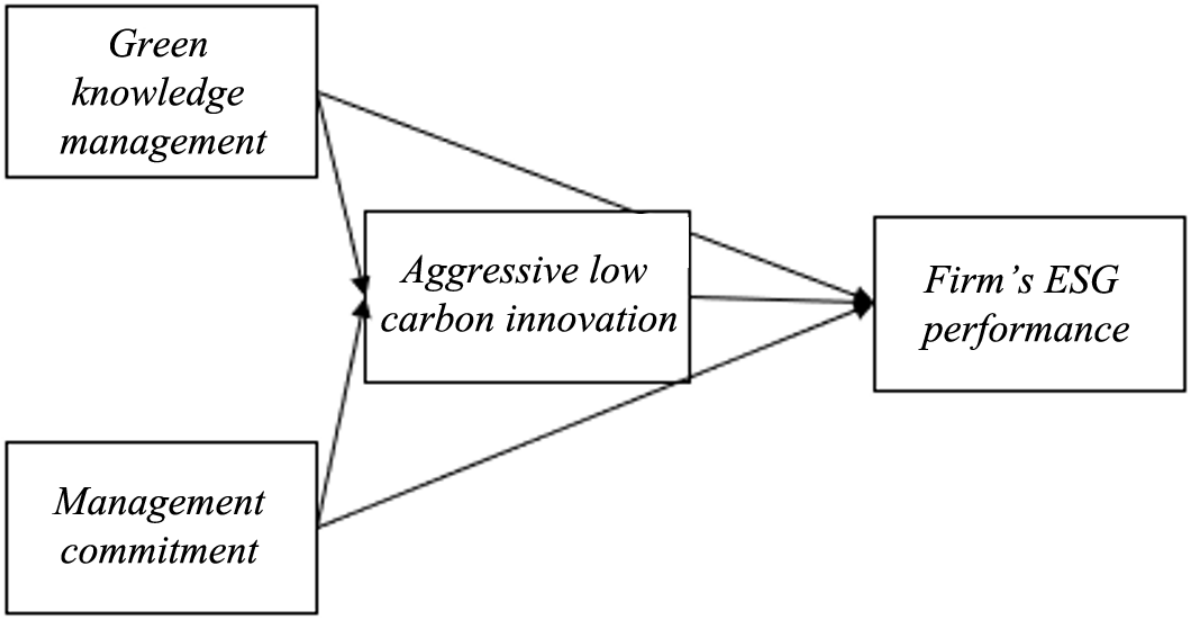

Figure 1. Conceptual framework.

Figure 1 illustrates the conceptual framework of this study, which examines the relationships between Green Knowledge Management (GKM), Management Commitment (MC), Aggressive Low Carbon Innovation (ALCI), and a firm's ESG performance. GKM and MC are proposed as antecedents that directly and indirectly influence ESG performance. Both variables are hypothesized to exert a direct effect on ESG performance and an indirect effect through the mediating role of ALCI. ALCI is positioned as a central mechanism that channels the influence of GKM and MC into improved ESG outcomes. This model reflects the integration of strategic environmental knowledge, leadership support, and innovation efforts in driving sustainable organizational performance.

3. THEORY AND CONCEPTUAL FRAMEWORK

Green Knowledge Management (GKM) is one of the most crucial instruments for enhancing an organization's Environmental, Social, and Governance (ESG) performance. Abbas and Khan [32] found, for instance, that integrating green knowledge into organizational processes significantly enhances environmental responsibility and stakeholder engagement, two crucial ESG components. Similarly, El-Kassar and Singh [10] demonstrated that knowledge management abilities are essential for promoting green innovation, which in turn results in enhanced adherence to environmental laws and more robust governance structures. Systematic knowledge sharing and the development of green competencies have a positive impact on firms' efforts to reduce emissions and manage sustainability risks [8]. Furthermore, Wahyuni et al. [13] illustrated how GKM fosters a culture of environmental responsibility and continuous learning [20, 21, 33, 34].

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According to all of these studies, businesses that implement Green Knowledge Management strategies have a higher chance of enhancing their ESG performance by integrating sustainability into their internal knowledge bases and decision-making processes. Consequently, one could contend that.

H_1: Green Knowledge Management has a positive and significant effect on Environmental, Social, and Governance (ESG) performance.

Management commitment is necessary for the effective execution of sustainability plans and the accomplishment of ESG performance targets. Support from upper management has a significant impact on how environmental and social objectives are incorporated into business plans, which enhances ESG results [35]. Similarly, Singh and El-Kassar [36] found that the presence of committed leadership is positively connected with the development of sustainability-oriented policies that promote long-term environmental and social responsibility. Fatima et al. [37] found that when management demonstrates a strong commitment through resource allocation and policy implementation, strong corporate governance mechanisms are fostered. Similarly, Siregar et al. [38] pointed out that leadership participation and ongoing support are necessary for institutionalizing ESG metrics and ensuring stakeholder compliance [12, 39, 40].

These findings suggest that integrating ESG principles across the organization and guaranteeing strategic alignment toward sustainability require a high level of management commitment. As a result, the following theory is possible.

H_2: Management commitment has a positive and significant effect on environmental, social, and governance (ESG) performance.

Green Knowledge Management (GKM) significantly influences assertive low-carbon innovation by establishing a systematic framework for the collection and use of sustainability-focused knowledge. GKM can be used by organizations to reduce emissions, improve resource efficiency, and adopt renewable technologies. By fostering an innovative and environmentally conscious culture, GKM equips teams with the knowledge and tools they need to pursue bold, low-carbon strategies. This mutually beneficial partnership ensures that the knowledge acquired from GKM is not merely theoretical but is transformed into noteworthy innovations that help the business become a sustainability leader [41]. As a result, the following theory is possible:

H_3: "Green Knowledge Management (GKM) has a significant positive effect on aggressive low-carbon innovation".

It has been shown that management commitment has a major impact on an organization's aggressive low-carbon innovation. A study by Jones et al. [42] found that management's commitment to sustainability directly boosts funding for low-carbon innovation and fosters an environment that promotes interdepartmental collaboration to meet emission reduction targets. In addition to offering strategic guidance, management's steadfast dedication to ESG objectives creates a corporate culture that motivates employees to come up with innovative ways to reduce the company's environmental impact [43]. Additionally, Hsieh et al. [44] highlighted that when management is dedicated to establishing ambitious carbon targets, organizations are forced to adopt low-carbon technologies and environmentally friendly practices more aggressively [45, 46].

The results indicate that managerial commitment is necessary for organizations that wish to pursue and adopt more aggressive low-carbon technologies. The hypothesis can therefore be expressed as follows:

H_4: Management commitment has a positive and significant impact on aggressive low-carbon innovation.

The relationship between aggressive low-carbon innovation and improved ESG performance has been highlighted in a number of studies. Low-carbon innovation is essential for promoting environmental sustainability, claim [47] and Broadstock et al. [48]. Businesses can improve environmental performance by drastically reducing energy consumption, waste, and greenhouse gas emissions through the use of modern technologies and innovative approaches. By strengthening adherence to legal requirements and promoting transparency, these innovations not only help the environment but also enhance governance frameworks.

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Furthermore, by satisfying stakeholder expectations for corporate responsibility, aggressive innovation has a positive impact on the social dimension of ESG. By demonstrating that businesses are actively pursuing sustainable solutions, it promotes community trust and ultimately improves their social outcomes. Low-carbon innovation is positioned as a crucial driver of ESG performance due to the alignment of environmental, social, and governance objectives [47, 48].

Considering the data from earlier studies, we postulate that:

Hypothesis 5 (H_5): Aggressive low-carbon innovation positively affects a firm's ESG performance by enabling environmental improvements, fostering social trust, and supporting effective governance through innovation-driven solutions.

Studies have consistently demonstrated that Green Knowledge Management (GKM), which provides organizations with the information and tools necessary for sustainable practices, is essential for enhancing a firm's ESG performance. By encouraging the collection, organization, and sharing of knowledge centered on sustainability, GKM assists businesses in finding creative ways to reduce their environmental impact and improve corporate governance. However, the knowledge acquired through GKM is transformed into workable, sustainable solutions by aggressive low-carbon innovation, which serves as a bridge. Research indicates that companies with a strong GKM framework are more likely to implement energy-efficient procedures, renewable energy sources, and low-carbon technologies, all of which contribute to quantifiable gains in environmental sustainability [49]. Additionally, companies that combine aggressive innovation and GKM not only lower emissions but also improve governance by enhancing transparency and conforming to legal requirements. As the community views these initiatives as ethical business practices, social outcomes also improve.

Based on the data from earlier research, we suggest that:

Hypothesis 6 (H_6): Aggressive low-carbon innovation mediates the relationship between Green Knowledge Management (GKM) and ESG performance, transforming sustainability knowledge into tangible outcomes across the environmental, social, and governance dimensions.

Studies indicate that managerial commitment is essential for advancing a company's sustainability objectives. When management is profoundly dedicated to ESG objectives, they provide strategic direction, assign requisite resources, and formulate policies that promote the implementation of sustainable practices. This commitment sets the tone for organizational culture and ensures that sustainability is embedded at every level of the organization [12, 50]. Furthermore, aggressive low-carbon innovation serves as a mechanism that operationalizes management's commitment. Studies highlight that committed leadership motivates and empowers teams to pursue innovative solutions that focus on reducing carbon emissions and advancing environmental sustainability [12, 50]. Through this innovation, management's vision for sustainability is translated into concrete actions, including the development and implementation of low-carbon technologies and processes. These innovations contribute directly to environmental improvements, enhanced governance, and greater stakeholder engagement, aligning with broader ESG objectives.

Building on these findings, we hypothesize that:

Hypothesis 7 (H_7): Aggressive low-carbon innovation mediates the relationship between management commitment and ESG performance, translating leadership's sustainability commitment into tangible improvements in environmental, social, and governance outcomes.

4. RESULTS

4.1. Outer Model

4.1.1. Convergent Validity

In this analysis, the extent to which the indicators in the reflective model are significantly related to the latent construct being measured is assessed. In this case, the factor loadings of the indicators must be sufficiently high (greater than 0.7).

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Table 2. Outer loading.

Indicator	*ALCI*	FEP	*GKM*	*GMO*	MC
ALCI1	0.845				
ALCI10	0.796				
ALCI11	0.903				
ALCI12	0.912				
ALCI13	0.875				
ALCI14	0.851				
ALCI15	0.862				
ALCI2	0.809				
ALCI3	0.802				
ALCI4	0.907				
ALCI5	0.910				
ALCI6	0.725				
ALCI7	0.818				
ALCI8	0.879				
ALCI9	0.887				
FEP1		0.842			
FEP2		0.777			
FEP3		0.759			
FEP4		0.781			
FEP5		0.742			
FEP6		0.848			
FEP7		0.906			
FEP8		0.861			
FEP9		0.877			
GKM1			0.771		
GKM10			0.851		
GKM11			0.884		
GKM12			0.876		
GKM13			0.909		
GKM14			0.841		
GKM15			0.881		
GKM2			0.732		
GKM3			0.802		
GKM4			0.728		
GKM5			0.814		
GKM6			0.842		
GKM7			0.839		
GKM8			0.875		
GKM9			0.770		
GMO1				0.764	
GMO10				0.852	
GMO11				0.873	
GMO12				0.901	
GMO13				0.748	
GMO14				0.818	
GMO15				0.833	
GMO2				0.840	
GMO3				0.869	
GMO4				0.867	
GMO5				0.801	
GMO6				0.750	
GMO7				0.741	
GMO8				0.882	
GMO9				0.791	
MC1					0.861
MC10					0.895
MC11					0.906
MC12					0.916
MC13					0.891
MC14					0.856

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Indicator	*ALCI*	FEP	*GKM*	*GMO*	MC
MC15					0.885
MC2					0.868
MC3					0.894
MC4					0.881
MC5					0.820
MC6					0.880
MC7					0.864
MC8					0.874
MC9					0.882

Table 2 presents the outer loading values of the indicators used to measure the latent constructs in this study: Aggressive Low Carbon Innovation (ALCI), Firm's ESG Performance (FEP), Green Knowledge Management (GKM), Green Market Orientation (GMO), and Management Commitment (MC) are the constructs evaluated. All indicator loadings exceed the minimum threshold of 0.70, indicating strong reliability and convergent validity for each construct. The ALCI construct is measured by 15 indicators, with loading values ranging from 0.725 to 0.912, demonstrating a high level of internal consistency. The FEP construct includes 9 indicators with loadings between 0.742 and 0.906. Similarly, the GKM, GMO, and MC constructs each consist of 15 indicators with strong factor loadings, all above 0.728. These results confirm that each indicator reliably reflects its respective latent variable, supporting the measurement model's adequacy for further structural analysis.

The values of these loadings range from 0.725 to 0.916, indicating that these constructs are strongly represented by their indicators. The highest values were observed in "Management Commitment" (MC11) and "Management Commitment" (MC12), suggesting that these constructs have significant explanatory power. All of the indicators' relatively high values demonstrate the measurement model's robustness, which supports the validity of the relationships evaluated in this study. Furthermore, all items are considered legitimate since the indicators' factor loadings are high (above 0.7), satisfying the criteria for indicator reliability. This ensures that the indicators accurately reflect the concepts they represent. The assessment of discriminant validity, which confirmed that each construct was distinct from the others, further supported the accuracy of the relationships measured in this study.

Table 3. Reliability.

Variable	Cronbach's alpha	rho_A	Composite reliability
Aggressive low carbon innovation	0.973	0.974	0.976
Firm's ESG performance	0.940	0.944	0.950
Green knowledge management	0.967	0.970	0.971
Green market orientation	0.966	0.967	0.969
Management commitment	0.979	0.979	0.981

Table 3 presents the reliability assessment of the latent variables through Cronbach's alpha, rho_A, and composite reliability values. All constructs exhibit high internal consistency, with Cronbach's alpha values ranging from 0.940 to 0.979, exceeding the commonly accepted threshold of 0.70. The rho_A values also fall within a similar high range (0.944 to 0.979), confirming the stability of the measurements. Composite reliability values, which are considered more accurate for reflective constructs, range from 0.950 to 0.981, further supporting the reliability of the measurement model. Among the constructs, Management Commitment demonstrates the highest reliability scores across all three indicators. These results collectively confirm that all measurement items consistently represent their respective constructs, ensuring robust internal reliability for further analysis.

4.1.2. Reliability

The results of the reliability analysis demonstrate that each variable in the model meets the predetermined dependability standards. The Aggressive Low Carbon Innovation (ALCI) construct's composite reliability (rho_a) of

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0.974 and Cronbach's alpha of 0.973 both surpass the necessary thresholds, demonstrating its exceptional reliability. The company's ESG Performance (FEP) model is also highly trustworthy. The construct's composite reliability (rho_a) of 0.944 and Cronbach's alpha of 0.940, both of which are above the required norms, validate its reliability within the measurement model. Green Knowledge Management (GKM) is highly reliable, as evidenced by its composite reliability (rho_a) of 0.970 and Cronbach's alpha of 0.967. These values meet the thresholds, confirming the robustness of the GKM construct within the model.

4.1.3. Commitment to Management (MC)

This subsection discusses the direct effects of management commitment and other variables on aggressive low-carbon innovation and ESG performance. Management commitment is considered a key driver in supporting environmental strategies and innovation initiatives within organizations. Table 4 presents the results of the direct path coefficients obtained through PLS-SEM analysis, which evaluate the magnitude and significance of each hypothesized relationship among the constructs.

Table 4. Direct effect.

Hypothesis	Original sample (O)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
Aggressive low carbon innovation -> Firm's ESG performance	0.312	0.068	4.566	0.000
Green knowledge management -> *Aggressive low-carbon innovation*	0.483	0.074	6.518	0.000
Green knowledge management -> Firm's ESG performance	0.202	0.076	2.643	0.008
Green market orientation -> *Aggressive low-carbon innovation*	0.279	0.079	3.521	0.000
Green market orientation -> Firm's ESG performance	0.312	0.082	3.820	0.000
Management commitment -> *Aggressive low-carbon innovation*	0.219	0.068	3.236	0.001
Management commitment -> Firm's ESG performance	0.168	0.083	2.018	0.044

Table 4 presents the results of the direct effect analysis using the Partial Least Squares Structural Equation Modeling (PLS-SEM) approach. The findings show that Management Commitment (MC) has a significant positive effect on Aggressive Low Carbon Innovation (ALCI) ($\beta = 0.219$, $p = 0.001$) and also directly influences the firm's ESG performance ($\beta = 0.168$, $p = 0.044$). Additionally, Green Knowledge Management (GKM) significantly affects ALCI ($\beta = 0.483$, $p < 0.001$) and the firm's ESG performance ($\beta = 0.202$, $p = 0.008$). Green Market Orientation (GMO) also demonstrates a significant direct impact on both ALCI ($\beta = 0.279$, $p < 0.001$) and ESG performance ($\beta = 0.312$, $p < 0.001$). Notably, ALCI itself exerts a strong direct effect on ESG performance ($\beta = 0.312$, $p < 0.001$), validating its role as a strategic mediator. These results confirm that management commitment, along with knowledge and market orientation, plays a critical role in fostering innovation and improving ESG outcomes.

4.2. Inner Model

4.2.1. Direct Effect

ALCI → FEP: Aggressive Low Carbon Innovation (ALCI) and Firm's ESG Performance (FEP) have a strong positive correlation, as evidenced by the path coefficient of 0.312, t-statistic of 4.566, and p-value of 0.000. The hypothesis is supported by the fact that the p-value is less than 0.05, suggesting that ALCI has a significant impact on FEP.

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GKM → ALCI: Green Knowledge Management (GKM) and ALCI have a strong positive correlation, as shown by the path coefficient of 0.483, t-statistic of 6.518, and p-value of 0.000. This hypothesis is supported by the p-value, which is less than 0.05 and shows that GKM has a significant impact on ALCI.

GKM → FEP: A significant positive correlation between GKM and FEP is indicated by the path coefficient of 0.202, t-statistic of 2.643, and p-value of 0.008, respectively. The hypothesis is supported by a p-value of less than 0.05, which shows that GKM has a direct and substantial effect on a company's ESG performance.

GMO → ALCI: The path coefficient of 0.279, the t-statistic of 3.521, and the p-value of 0.000 indicate a strong positive correlation between Green Market Orientation (GMO) and ALCI. The hypothesis is supported, as the p-value is below 0.05.

GMO → FEP: The path coefficient of 0.312, accompanied by a t-statistic of 3.820 and a p-value of 0.000, suggests a substantial positive correlation between GMO and FEP. This theory is also validated.

MC → ALCI: The path coefficient of 0.219, t-statistic of 3.236, and p-value of 0.001 indicate a strong positive correlation between Management Commitment (MC) and ALCI. A p-value below 0.05 substantiates the hypothesis, signifying that MC exerts a significant influence on ALCI.

MC → FEP: A path coefficient of 0.168, accompanied by a t-statistic of 2.018 and a p-value of 0.044, indicates a significant positive correlation between MC and FEP. The p-value, being slightly below 0.05, supports the hypothesis that MC directly influences ESG performance.

Table 5. Indirect effect.

Hypothesis	Original sample (O)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
Green knowledge management -> Aggressive low carbon innovation -> Firm's ESG performance	0.151	0.034	4.381	0.000
Green market orientation -> Aggressive low carbon innovation -> Firm's ESG performance	0.087	0.032	2.690	0.007
Management commitment -> *Aggressive low carbon innovation* -> Firm's ESG performance	0.068	0,039	2.476	0.014

Table 5 presents the results of the indirect effect analysis using the bootstrapping method in PLS-SEM. The findings indicate that ALCI significantly mediates the influence of GKM on ESG performance ($\beta = 0.151$, $p < 0.001$), GMO on ESG performance ($\beta = 0.087$, $p = 0.007$), and MC on ESG performance ($\beta = 0.068$, $p = 0.014$). These results support the hypothesis that ALCI plays a pivotal role in transmitting the positive effects of green strategic capabilities and leadership commitment into enhanced ESG outcomes.

4.2.2. Indirect Effect

GKM → ALCI → FEP: The path coefficient is 0.151, accompanied by a t-statistic of 4.381 and a p-value of 0.000, signifying a substantial indirect effect of Green Knowledge Management (GKM) on Firm's ESG Performance (FEP) via Aggressive Low Carbon Innovation (ALCI). Given that the p-value is below 0.05, the hypothesis is supported, indicating that GKM exerts a favorable indirect effect on FEP through ALCI.

GMO → ALCI → FEP: The path coefficient is 0.087, the t-statistic is 2.690, and the p-value is 0.007, indicating a significant indirect influence of Green Market Orientation (GMO) on FEP via ALCI. The p-value, being below 0.05, supports the hypothesis, suggesting that GMO indirectly enhances ESG performance through the improvement of ALCI.

MC → ALCI → FEP: The path coefficient is 0.068, accompanied by a t-statistic of 2.476 and a p-value of 0.014, indicating a significant indirect influence of Management Commitment (MC) on FEP through ALCI. The p-value being below 0.05 supports this hypothesis, confirming that MC indirectly enhances ESG performance through the adoption of assertive low-carbon innovation.

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5. DISCUSSION

5.1. Direct Effect

The relationship between Green Knowledge Management (GKM) and Aggressive Low Carbon Innovation (ALCI), as well as between Management Commitment (MC) and a firm's ESG Performance (FEP), showed mixed results. The effect of ALCI on FEP is significantly positive; this finding aligns with previous research by Xie et al. [51], which emphasizes that companies adopting aggressive green innovation strategies tend to excel in environmental, social, and governance aspects. Additionally, research by Huang [52] indicates that a company's market standing and competitive ability can be enhanced through innovation aimed at reducing carbon emissions. Therefore, companies committed to low-carbon innovation are more effective in achieving their sustainability goals and improving overall ESG performance.

GKM has a significant positive effect on ALCI, and likewise exerts a significant direct impact on FEP. These findings indicate that effective environmental knowledge management contributes meaningfully to enhancing the company's ESG performance. Previous research by Widyanti et al. [8] underlined the significance of green knowledge storage as a system for facilitating sustainable innovation. Moreover, Gauthier and Zhang [53] discovered that green knowledge management is a key component of corporate strategy renewal, which encompasses more aggressive innovation.

The relationship between MC and ALCI shows a significant effect. These results are in line with research by El-Kassar and Singh [10], who came to the conclusion that buy-in from upper management is critical to fostering environmentally conscious innovation and improving business outcomes. Support from senior management is a critical determinant in the success of sustainability projects. Rubel et al. [54] furthermore, it was emphasized that Green Human Resource Management (GHRM) techniques might enhance environmental consciousness within firms, therefore fostering green innovation. The direct correlation between GHRM and FEP lacks substantial significance. This discovery aligns with the studies conducted by Yudawisastra et al. [11]. The findings showed that knowledge and expertise in green management significantly enhance the implementation of green management practices and contribute directly and significantly to the organization's sustainability performance. In addition, Al-Hakim and Hassan [55] also revealed that effective knowledge management can contribute to organizational innovation and performance, but the outcomes are significantly contingent upon the specific context and circumstances of an organization.

GKM and MC have the potential to improve ESG innovation and performance; their success is highly dependent on organizational context and management support. To understand the elements that mediate these relationships and identify strategies to enhance the effectiveness of GKM and MC in achieving sustainability goals, the effects of MC on ALCI and FEP show interesting results in this study's context. Widyanti et al. [8] emphasized that management commitment within the company is crucial for driving the implementation of aggressive innovation strategies. Committed management emphasizes achieving environmental objectives and plays a statistically significant role in ensuring the sustainability of company operations through supportive green policies. Consistent with prior research, our findings underscore the significant influence of top-level commitment on the success of green innovation initiatives within organizations [53].

However, while a significant relationship was observed between MC and ALCI, the direct relationship between MC and FEP also demonstrated statistical significance. Ahmad et al. [21] revealed that although committed management can introduce policies that support ESG, their influence on ESG performance can be limited in the absence of collective action from other stakeholders. A company's ESG performance is also heavily impacted by external variables, including market forces and government laws. Ahmad et al. [21] also point out that good ESG performance can contribute to increased firm value, but this depends largely on how firms integrate ESG strategies into their managerial practices.

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The results of this study are consistent with the existing literature, which indicates a significant influence of MC on sustainable innovation. However, the direct effect on ESG performance is always directly observable. This underscores the importance of managing sustainability initiatives comprehensively, considering both the organization's internal commitment and external variables, including current regulations. Further research to understand the relationships among these factors could help businesses achieve their sustainability objectives more effectively.

5.1.1. Comparison with Prior Studies and Explanation of Unexpected Results

The study's conclusion that Green Knowledge Management (GKM) has a significant and highly influential impact on both Aggressive Low Carbon Innovation (ALCI) and ESG Performance (FEP) aligns with prior research emphasizing GKM's primary contribution to green technological innovation and sustainability outcomes through mediating variables such as Green Intellectual Capital (GIC). This underscores how effectively internalizing and leveraging green knowledge drives strong advancements in innovation and delivers measurable improvements in ESG performance [14]. This indicates that Green Knowledge Management (GKM) exerts a significant and immediate influence on ESG performance through critical intermediary mechanisms. The connection between GKM and green innovation is strongly reinforced by the presence of a solid green corporate culture, which significantly enhances environmental outcomes. The presence of supportive cultural elements in this study further strengthens the direct and indirect contributions of GKM to ESG performance [15].

Furthermore, the findings validate a statistically significant and strongly impactful direct relationship between Management Commitment (MC) and ESG performance, consistent with earlier studies. A high level of commitment from top management plays a decisive role in strengthening the positive effect of ESG initiatives on overall business performance, especially when such commitment is embedded within comprehensive and strategically integrated sustainability planning. The presence of a direct effect in the current context may be attributed to supportive external influences such as favorable market dynamics, enabling regulatory frameworks, and a strong internalization of sustainability policies. Additionally, the active involvement of key stakeholders such as frontline employees and external partners enhances the effectiveness of top management's role, especially when accompanied by collaborative and unified organizational efforts [56].

These results underscore the complex and context-sensitive dynamics among GKM, MC, ALCI, and ESG outcomes. While GKM and MC are recognized as pivotal enablers of low-carbon innovation, their influence on ESG performance tends to be indirect but powerful, often channeled through mediating elements such as organizational culture, stakeholder participation, and institutional frameworks. Future research should explore these mediating and moderating pathways in greater depth to better identify the conditions under which GKM and MC can significantly and effectively enhance ESG performance.

5.2. Indirect Effect

Considering the oblique relationship between GKM (Green Knowledge Management), the findings indicate that GKM has a significant impact on the firm's aggressive low-carbon innovation (ALCI) and ESG performance (FEP). This research suggests that green knowledge management can promote low-carbon innovation, thereby enhancing the company's ESG performance. According to research by Gauthier and Zhang [53], green knowledge management can foster strategic innovation in business, particularly in adopting low-carbon technologies that support corporate sustainability. These findings align with that research. Furthermore, although green knowledge management always directly affects ESG performance, research by Yudawisastra et al. [11] indicates that it influences the organization's adoption of environmentally sustainable innovations.

The indirect relationship between FEP, ALCI, and Management Commitment (MC) also reveals noteworthy results. This suggests that a management firm's ESG performance is positively impacted by its dedication to

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promoting low-carbon innovation. This result is in line with research by El-Kassar and Singh [10] showing that management's contribution to green innovation is crucial to improving businesses' sustainability. Additionally, Rubel et al. [54] found that management-supported GHRM (Green Human Resource Management) practices can increase organizational environmental awareness, which in turn encourages green innovation that impacts the ESG performance of the company.

The study's findings support the idea that green knowledge management and management commitment can work together to improve ESG performance and promote low-carbon innovation in the business sector. However, the effectiveness of this relationship will depend on how quickly companies adopt green innovation and the support of external factors such as market forces and government regulations. Therefore, companies aiming to enhance ESG performance should consider stakeholder collaboration and broader innovation strategies, in addition to internal knowledge management and management commitment.

Comparison with Prior Studies and Explanation of Unexpected Results

The significant and strongly influential indirect effect of Green Knowledge Management (GKM) on a firm's ESG Performance (FEP) through Aggressive Low Carbon Innovation (ALCI) reinforces the findings of previous studies, which demonstrate that green knowledge, when properly internalized and strategically applied, can greatly enhance a firm's innovation capabilities and environmental responsiveness [57]. This result emphasizes that GKM plays a crucial enabling role in advancing sustainability through innovation. However, the presence of a strong relationship between Green Knowledge Management (GKM) and a firm's ESG performance (FEP) suggests that possessing green knowledge, when actively transformed into innovative and practical solutions, consistently delivers tangible sustainability outcomes. This finding supports the theory of dynamic capabilities, which asserts that knowledge, when mobilized through proactive innovation processes, leads to significant and measurable improvements in ESG performance [58].

Leadership engagement in sustainability demonstrates a statistically significant effect, particularly when aligned with innovation-driven initiatives and cross-functional integration. This synergy plays a critical role in driving successful and impactful sustainability outcomes. The indirect impact of management commitment (MC) on FEP through ALCI lends more credence to this. It is interesting to note that, contrary to some studies that found direct effects of MC on ESG outcomes [29], the current study demonstrates that management's influence is more effective when it is channeled through a commitment to green innovation rather than standalone policies. This could be due to contextual differences such as industry pressures, organizational readiness, or the level of maturity of ESG implementation in companies.

These indirect effects highlight the importance of process-based pathways in achieving sustainability. They contend that, in order to effectively impact ESG performance, internal organizational capabilities such as GKM and MC must work in concert and be connected to concrete innovation outputs. Instead of depending on discrete leadership or policy implementation efforts, companies seeking to improve their ESG outcomes should develop integrated strategies that incorporate managerial vision, structured knowledge systems, and innovation investments.

6. CONCLUSIONS

Through aggressive low-carbon innovation (ALCI), this study quantitatively demonstrates that green knowledge management (GKM) has a significant and strongly influential effect on a firm's ESG performance. management commitment (MC) also shows a significant and powerful influence on both ALCI and ESG outcomes. The mediating role of ALCI is pivotal—firms that consistently promote low-carbon innovation are highly effective in transforming their internal green knowledge and leadership commitment into enhanced ESG performance. These findings affirm that internal capabilities such as GKM and MC play a critical and decisive role in driving sustainability, especially when aligned with innovation-oriented strategies and implemented systematically across the organization.

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6.1. Practical Implications

For village officials and policymakers, these findings emphasize the importance of establishing regulatory and institutional support for green innovation. Policies that incentivize knowledge sharing, management engagement in sustainability, and investments in low-carbon technologies can improve ESG outcomes at both local and national levels. Organizations, especially in the energy sector, should invest in structured green knowledge systems and actively involve leadership in promoting sustainability-aligned innovations. Furthermore, collaborative efforts with community stakeholders can enhance ESG impacts and foster shared environmental responsibility.

6.2. Limitations and Future Research

The study is limited by its geographic focus on Indonesia's energy sector and a relatively narrow sample size, which may limit the generalizability of results to other sectors or regions. Additionally, it primarily focuses on internal organizational drivers without extensively examining external moderating variables such as government policy, market competition, or cultural context. Future research should consider longitudinal approaches to explore the long-term effects of green innovation on ESG performance and expand the scope to include diverse industries and international comparisons. Investigating the role of cross-sector collaboration and stakeholder engagement would also enrich the understanding of how GKM and MC contribute to sustainable development.

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