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Green Intellectual Capital and Innovation: Keys to Sustainable Environmental Performance in Manufacturing

Mariska Ramadana[1], Yolanda Masnita[2], Husna Leila Yusran[3], Teddy Jurnali[4]

[1,2,3] Doctoral Program in Economic, Faculty of Econmics and Busines, Universitas Trisakti, Jakarta-Indonesia
[4] Faculty Business and Management, Universitas Internasional Batam, Batam-Indonesia

Abstract:
This research explores the critical influence of green intellectual capital (GIC), green dynamic capabilities (GDC), and green innovation on the environmental performance of manufacturing firms. In light of escalating global environmental challenges, companies are increasingly urged to implement sustainable practices to secure their competitive advantages. This study posits that GIC—comprising the intangible assets related to environmental knowledge and capabilities—alongside green innovation, which represents advancements in eco-friendly technologies, plays a vital role in improving environmental performance. Employing structural equation modeling (SEM) through AMOS, data were gathered from the Top Management Teams (TMT) of manufacturing companies in the Riau Islands, Indonesia. The analysis reveals that both GIC and GDC have a significant positive impact on environmental performance, suggesting that firms that prioritize environmental competencies and knowledge achieve enhanced sustainability metrics. Additionally, green innovation is shown to elevate both environmental performance and competitive advantage. These findings highlight the necessity for organizations and policymakers to foster intellectual capital development and innovative practices as integral components of sustainable business models, thereby addressing ecological challenges effectively.

Keywords: Green Intellectual Capital**,** Green Dynamic Capabilities**,** Green Innovation**,** Environmental Performance**,** Sustainability

1. Introduction

The world today faces increasingly complex and pressing environmental challenges. Indeed, since the industrial revolution, human activity has been the main driver of climate change. As a result, companies are widely expected to improve their environmental performance, which can also be seen as an important factor in maintaining corporate competitiveness (Asghar et al., 2020). However, effectively measuring and managing environmental performance remains a challenge, especially in fast-growing countries like Indonesia, where economic growth often comes at the expense of the environment. Although Indonesia is a signatory to the Paris Climate Agreement, the country still faces significant barriers to achieving its sustainability goals. Its reliance on coal-based power generation and ongoing deforestation are significant barriers to reducing its carbon footprint (Climate Change Performance Index, 2024).

The Environmental Performance Index (EPI) ranks 180 countries on the basis of 58 indicators in 11 categories, covering issues such as climate change, air pollution, waste management and biodiversity protection. Indonesia ranks 162 out of 180 countries, reflecting its poor environmental performance. Regionally, Indonesia ranks sixth worst in ASEAN with a score of 33.8 out of 100 (Block et al., 2024). These data indicate that Indonesia faces serious challenges in environmental issues and that greater efforts are needed to improve its performance and position.

In the discussion of environmental performance, environmental scholars have proposed the concept of green intellectual capital as an innovative concept to overcome ecological degradation and also as a competitive advantage for companies (Benevene et al., 2021; Jirakraisiri et al., 2021). Theoretically, the concept of green intellectual capital is derived from the broad concept of intellectual capital. Ranson and Stewart (1994) characterized intellectual capital as a store of information, data, knowledge, relationships, intellectual property, and brand reputation that collectively contribute to firm performance and value (Ali et al., 2021; Chatterjee et al., 2022). However, companies cannot rely solely on green intellectual capital to achieve significant improvements in environmental performance. In an effort to improve environmental

performance, companies must use their green intellectual capital as a basis for developing dynamic capabilities to adapt to changes and challenges in the existing environment.

By examining the interconnectedness of green intellectual capital, green dynamic capabilities, and green innovation, this research proposes a comprehensive framework that explains how these elements synergistically enhance environmental performance. This holistic approach has been insufficiently explored in existing literature, thereby filling a critical gap.

Green intellectual capital is defined as an intangible asset that includes the knowledge reserves of the firm and the ability to increase its value (Du & Wang, 2022; Masoulas, 1998). Green intellectual capital includes knowledge, processes, skills, and systems specifically designed to build and maintain influence with external stakeholders (Akhtar et al., 2024). Liu (2010) defines green intellectual capital as the combination of environmental information and the firm's ability to expand competitive advantage.

From an economic perspective, Helfat and Raubitschek (2000) and Dougherty (1992) consider dynamic capabilities as a corporate guideline that reflects management's ability to exploit opportunities to achieve optimal financial performance and build a competitive advantage. Along with the development of research on dynamic capabilities in the context of continuous innovation, (Chen & Chang, 2013) proposed the concept of "green development" in the theory of dynamic capabilities and introduced the concept of Green Dynamic Capabilities (GDC). Green dynamic capabilities are the internal capabilities of firms that enable them to respond quickly and effectively to stakeholder demands related to environmental issues (Teece, 2018).

Accordingly, green innovation also plays an important role in creating value for companies in the era of sustainability, where environmental issues are a top priority (Wang & Juo, 2021). This is because green innovation involves companies' efforts to update products, services, technologies, strategies, and management styles with the aim of promoting sustainable development (Li *et al*., 2018). Given its dual influence on financial and environmental performance and its role in achieving sustainable development, green innovation is considered important for further research (Li *et al*., 2017).

2. Literature Review and Hypothesis Development

The concept of "green economy" is now increasingly applied, transforming traditional practices and ways of using resources (Yadiati et al., 2019). An important aspect that needs to be highlighted in this context is the management of resources and knowledge through the application of the concepts of green intellectual capital and green dynamic capabilities. Green intellectual capital has become a key element that supports companies in aligning their objectives with sustainable development, especially in efforts to improve environmental performance and the company's competitive advantage (Yadiati et al., 2019).

Green dynamic capabilities give firms the flexibility to allocate resources to remain competitive in the face of environmental regulations and increase consumer awareness of sustainability (Wang & Juo, 2021). In addition, green dynamic capabilities help firms adopt green innovations that not only increase competitiveness but also reduce environmental degradation Green dynamic capabilities give firms the flexibility to allocate resources to remain competitive in the face of environmental regulations and increase consumer awareness of sustainability (Wang & Juo, 2021). In addition, green dynamic capabilities help firms adopt green innovations that not only increase competitiveness but also reduce environmental degradation (Abrudan *et al*., 2022).

In addition, companies can also strive for sustainability by reducing costs, saving energy, and protecting the environment. Green innovation plays a role in supporting these efforts and increasing financial benefits (Borsatto & Bazani, 2021). Green innovation involves the development and application of products, systems, and technologies designed to reduce environmental influence and support sustainability. The main focus of green innovation is to optimize resource use, reduce waste and emissions, and implement environmentally friendly alternatives that not only provide environmental benefits but also increase the competitive advantage of the organization (Song & Yu, 2018).

2.1 Green intellectual capital on environmental performance

Chuang and Huang (2018) emphasize that improving a company's environmental performance depends largely on its ability to develop knowledge and resources related to sustainability. Martínez-Falcó et al. (2024) also add that green intellectual capital plays a role in minimizing environmental costs by ensuring efficiency and sustainability in the use of resources. In addition, green intellectual capital fosters strong environmental awareness and knowledge among employees, which ultimately strengthens the organization's

collective responsibility toward the environment. In addition, green intellectual capital enables companies to meet and exceed existing environmental regulations, ensuring that higher standards are achieved (Asiaei et al., 2023; Tran et al., 2023).

Research by Wang and Juo (2021) and Mansoor et al. (2021) also shows that green intellectual capital has a positive and significant effect on a firm's environmental performance. Firms with high levels of green intellectual capital tend to have better environmental performance. We propose that a firm's green intellectual capital—encompassing knowledge and expertise related to environmental sustainability—positively influences its environmental performance. This means that companies that effectively harness and manage their environmental knowledge and capabilities are likely to achieve superior sustainability outcomes.

H1: The Influence of Green Intellectual Capital on Environmental Performance.

2.2 Green dynamic capabilities on environmental performance

Reyes-Santiago *et al*. (2019) found that dynamic capabilities have a significant positive effect on improving environmental performance. In line with this, Kertahadi and Dwiatmanto (2014) also found that dynamic capabilities have a positive effect on a firm's environmental performance. These results indicate that improving environmental performance depends on the company's ability to detect new environmental problems and opportunities (sensing), mobilize resources to address these opportunities (seizing), and renew and reorganize resources to face dynamic environmental challenges (reconfiguring) (Forés *et al*., 2023). Green dynamic capability plays a role in improving social and environmental performance and has great potential to address environmental issues such as global warming, depletion of natural resources, waste reduction, and environmental pollution (Rezende et al., 2019). It is posited that green dynamic capabilities, which provide firms with the agility to adapt and innovate in response to environmental changes, significantly enhance environmental performance. This suggests that firms equipped with the ability to redirect resources and efforts toward sustainable practices will exhibit improved environmental outcomes.

H2: The Role of Green Dynamic Capabilities in Enhancing Environmental Performance.

2.3 Green innovation on environmental performance

In their research, Zaid et al. (2024) found a significant positive effect of green innovation on environmental performance. These results are also supported by the findings of Rehman et al. (2021) that green innovation practices lead to improved environmental performance. In addition, Riaz et al. (2024) also shows the strong positive influence of green innovation in reducing the amount of pollutants and supporting environmental performance. Carrión-Flores and Innes (2010) add that companies that adopt green innovation tend to have better environmental performance and also have the potential to support economic growth through more sustainable business practices. Thus, green innovation is not only a response to stakeholder pressure, but also a proactive step to improve environmental performance and gain competitive advantage (Ullah et al., 2022). We hypothesize that investing in green innovation—characterized by the development and implementation of environmentally friendly technologies and practices—leads to a marked improvement in environmental performance. Thus, organizations engaged in green innovation are expected to achieve a competitive edge while simultaneously progressing toward sustainability goals.

H3: The Impact of Green Innovation on Environmental Performance.

3. Methodology

This study uses a quantitative approach, which is objective in nature and involves the collection and analysis of numerical data and the application of statistical techniques to test hypotheses (Hermawan & Yusran, 2017). This quantitative approach is enhanced by the survey method, which aims to collect information from respondents to describe, compare, or explain aspects of knowledge, attitudes, and behaviors (Bougie & Sekaran, 2019). In this study, a cross-sectional approach was also applied in the survey conducted (Hermawan & Yusran, 2017). Data collection was conducted through a questionnaire, which consisted of closed-ended questions to obtain more structured data. This questionnaire was designed to measure variables relevant to the research hypothesis. According to Fowler, (2014), the survey method can provide valuable insights into the views, attitudes, and behaviors of the respondents in a particular research context.

The population of this study are large and medium manufacturing companies spread throughout the Riau Islands, including Batam, Karimun, Bintan, Lingga Islands, Natuna and Anambas Islands. For sample selection, this study uses a non-probability sampling approach, which is a sampling technique without a

sampling framework that is more subjective in nature (Bougie & Sekaran, 2019). The specific method used in this study is purposive sampling, using the criteria of companies certified to ISO 14001 on environmental management systems. The unit of analysis in this study is the Top Management Team (TMT), which includes the CEO, board members, and/or company managers who are authorized to make strategic decisions related to sustainability and the environment.

The dependent variable in this study is environmental performance with 6 indicators, while the independent variables are green intellectual capital (7 indicators), green dynamic capabilities (5 indicators), and green innovation (6 indicators). These dimensions are measured using a Likert scale from 1 to 5 (1 = strongly disagree, 2 = disagree, 3 = somewhat agree, 4 = agree, and 5 = strongly disagree).

4. Results and Discussion

4.1 Statistics Descriptive

In this study, 280 questionnaires were distributed. Of these, 173 questionnaires were successfully returned, with a response rate of 62%. Descriptive data on companies and respondents can be seen in Table 1 below:

Table 1: Descriptive statistics of respondents

Criteria	Number of Respondents	Percentage
Company Age		
1-5 years	4	2%
More than 5 – 10 years	11	6%
More than 10 – 15 years	13	8%
More than 15 – 20 years	68	39%
Over 20 years	77	45%
Number of employees		
41-50 employees	22	13%
More than 50 employees	151	87%
Respondent gender		
Female	75	43%
Male	98	57%
Respondent Age		
20-30 years	58	34%
More than 30 – 40 years	24	14%
More than 40 – 50 years	73	42%
Over 50 years	18	10%
Respondent education level		
Diploma	3	2%
Bachelor (S1)	121	70%
Master (S2)	45	26%
Doctorate (S3)	4	2%
Position of respondents		
President Director (CEO)	9	5%
Member of the Board of Directors	17	10%
Manager	102	59%
Supervisor	45	26%
Respondent Tenure		
1 – 5 years	23	13%
More than 5 – 10 years	51	29%
More than 10 – 20 years	85	49%
Over 20 years	14	8%
Total	**173**	**100%**

Source(s): Authors own work (2025)

Based on Table 1, this study shows that the majority of the sampled manufacturing companies in Riau Islands have been in operation for more than 15 years (84%), reflecting the importance of business resilience and experience in business continuity. Most companies are classified as large, with more than 50 employees

(87%). The demographic profile of respondents shows that the majority of respondents are men (57%), with an almost equal number of women (43%), supporting the view that gender diversity improves business performance. In terms of age, 42% of respondents were between the ages of 41 and 50, and 34% were between the ages of 20 and 30, indicating that leadership positions are filled by productive and experienced individuals. There is also a high level of education, with 70% of respondents having a bachelor's degree and 26% having a master's degree. Work experience is also an important factor, with 49% of respondents having more than 10 years of experience, emphasizing that long experience contributes to the stability and performance of the company.

Table 2: Descriptive statistics Variable

Variable	Mean	Std. Deviation
Green Intellectual Capital	4.03	0.76
Green Dynamic Capabilities	3.67	0.86
Green Innovation	3.90	0.78
Environmental Performance	3.97	0.74

Source(s): Authors own work (2025)

Based on Table 2, this study shows that the average mean of green intellectual capital is 4.03 with a standard deviation of 0.76, which indicates that manufacturing companies in Riau Islands are well aware of their green intellectual capital. This reflects that companies have started to develop sustainability practices in human resource management, organizational structure, and external relations. The average mean value of green dynamic capabilities is 3.67, indicating that there is still room for optimization efforts to improve green dynamic capabilities and environmental performance. The average mean of green innovation mean is 3.90 with a standard deviation of 0.78, which indicates that companies have begun to adopt various green strategies and technologies to improve operational efficiency and reduce environmental impact. In addition, the average score for environmental performance is 3.97 with a standard deviation of 0.74, indicating that companies have made various efforts to reduce adverse environmental impacts through waste management, energy efficiency, and reducing the use of hazardous materials.

Table 3 below shows the results of the validity test using the standardized regression weight test and the Average Variance Extracted (AVE), which is based on the factor loading of each indicator on the measured latent variable with a limit of factor loading > 0.50 and AVE > 0.50.

Table 3: Validity Test Results

Variable	Indicator	Estimate	AVE	Validity
Green Intellectual Capital	GIC1	0.788	0.725	**Valid**
	GIC2	0.761		**Valid**
	GIC3	0.908		**Valid**
	GIC4	0.939		**Valid**
	GIC5	0.864		**Valid**
	GIC6	0.587		**Valid**
	GIC7	0.735		**Valid**
Green Dynamic Capabilities	GDC1	0.787	0.785	**Valid**
	GDC2	0.988		**Valid**
	GDC3	0.722		**Valid**
	GDC4	0.97		**Valid**
	GDC5	1.017		**Valid**
Green Innovation	GI1	0.972	0.792	**Valid**
	GI2	0.683		**Valid**
	GI3	0.861		**Valid**
	GI4	0.9		**Valid**

Variable	Indicator	Estimate	AVE	Validity
	GI5	0.806		**Valid**
	GI6	0.801		**Valid**
Environmental Performance	EP1	0.925	0.810	**Valid**
	EP2	0.865		**Valid**
	EP3	0.879		**Valid**
	EP4	0.858		**Valid**
	EP5	0.876		**Valid**
	EP6	0.824		**Valid**

Source(s): Authors own work (2025)

All indicators on Green Intellectual Capital have a factor loading value ≥ 0.50, with the highest value in GIC4 (0.939) and the lowest value in GIC6 (0.587). Green Innovation also shows good validity, with factor loadings ranging from 0.683 to 0.972. Green Dynamic Capabilities (GDC) shows a high factor loading value, with GDC5 reaching (1.017) and the lowest value at GDC1 (0.787), which still meets the validity criteria. All indicators on Environmental Performance variable also show valid factor loading values, with a range of values between 0.824 and 0.925, indicating that the indicators have a strong contribution to the construct being measured.

In addition, Table 4 below presents the results of the reliability test using Composite Reliability (CR) and Cronbach's Alpha, which function to assess the internal consistency and convergent validity of each latent variable. The minimum threshold used to ensure reliability is CR> 0.70, while a Cronbach's Alpha value of ≥ 0.70 indicates that the instrument has good reliability, and a value of ≥ 0.80 indicates a high level of internal consistency.

Table 4: Reliability Test Results

Variable	Composite Reliability (CR)	Cronbach's Alpha
Green Intellectual Capital	0.892	0.841
Green Dynamic Capabilities	0.911	0.844
Green Innovation	0.910	0.870
Environmental Performance	0.918	0.895

Source(s): Authors own work (2025)

A significance level of <0.05 is used to determine the significance of the influence between variables. The hypothesis is considered accepted if the p-value is <0.05 or the Critical Ratio (CR) value is >1.960. The results of the hypothesis testing are shown in Table 5 below:

Table 5: Hypothesis Test Results

Hypothesis		Estimate	C.R.	p-*value*	Conclusion
H1	The Influence of Green Intellectual Capital on Environmental Performance	0.465	3.033	***	**Supported**
H2	The Role of Green Dynamic Capabilities in Enhancing Environmental Performance.	0.312	3.480	***	**Supported**
H3	The Impact of Green Innovation on Environmental Performance	1.040	13.300	***	**Supported**

Source(s): Authors own work (2025)

Based on the data analysis performed, the discussion of the hypothesis is presented as follows:

H_1: Green Intellectual Capital has a positive effect on Environmental Performance

The hypothesis testing results indicate that Green Intellectual Capital (GIC) has a path coefficient of 0.465 with a p-value of 0.000. Since the p-value is below the conventional significance level of 0.05, the null hypothesis (H0) is rejected, and the alternative hypothesis (H1) is accepted. These results provide statistical

evidence that GIC has a positive and significant effect on environmental performance.

The acceptance of H1 confirms that the higher the level of GIC implementation, the greater the improvement in a company's environmental performance. This implies that companies that effectively manage and develop their GIC are better equipped to reduce adverse environmental impacts and enhance operational efficiency. These findings align with the RBV theory, which suggests that an organization's knowledge, capabilities, and intangible assets play a crucial role in improving performance outcomes, particularly in sustainability contexts.

According to Hoang and Truong (2024), improvements in environmental management not only contribute to lower waste disposal costs but also enhance the perceived value of eco-friendly products and strengthen the company's image. Similar findings have been reported by Asiaei et al. (2022) and Yusliza et al. (2019), who emphasize the role of environmental performance in achieving long-term competitive advantage.

Moreover, Chuang and Huang (2018) argue that improvements in environmental performance are largely determined by how effectively firms accumulate and utilize their GIC. This includes the implementation of energy-efficient technologies and fostering awareness of environmental protection throughout the organization. Supporting this perspective, Yadiati et al. (2019) highlight that GIC contributes significantly to firms' environmental performance and advocate for its integration as a core strategy for achieving sustainability goals.

The findings reinforce the RBV Theory by demonstrating the strategic role of GIC in enhancing sustainability outcomes. As noted by Martínez-Falcó et al. (2024), GIC facilitates more efficient resource utilization and enables companies to minimize environmental costs. Furthermore, Shah et al. (2021) and Buysse and Verbeke (2003)underscore the need for adequate resources and strategic planning to implement effective green practices and management. Therefore, this study positions GIC as a critical internal capability that supports environmental responsiveness and drives organizational sustainability.

The analysis concludes that hypothesis H1 is accepted, demonstrating that green intellectual capital positively contributes to environmental performance. These findings suggest practical implications for companies to invest in developing green intellectual capital as an essential component of sustainability strategies. Further research could explore additional aspects of green intellectual capital and their interaction with changing market dynamics.

H_2: Green Dynamic Capabilities has a positive effect on Environmental Performance

The hypothesis testing results indicate that Green Dynamic Capabilities (GDC) have a path coefficient of 0.312 with a p-value of 0.000. Since the p-value is lower than the established significance threshold of 0.05, the null hypothesis (H0) is rejected and the alternative hypothesis (H2) is accepted. This indicates that GDC have a positive and significant effect on environmental performance.

The acceptance of H2 confirms that an increase in green dynamic capabilities corresponds with an improvement in environmental performance. This finding is consistent with the study conducted by Reyes-Santiago et al. (2019), which demonstrated the significant role of GDC in enhancing environmental performance outcomes. Green dynamic capabilities enable firms to proactively respond to environmental challenges through three core processes: sensing opportunities and risks in the environment, seizing these opportunities by mobilizing relevant resources, and reconfiguring internal assets to adapt to dynamic environmental conditions (Forés et al., 2023).

Furthermore, the research of Yu et al. (2022) and Chen and Chang (2013) supports the notion that green dynamic capabilities play a key role in integrating and optimizing internal resources to achieve long-term sustainability goals. These capabilities foster organizational agility in implementing green strategies, ensuring alignment between environmental objectives and operational execution.

The results of this study reinforce the theoretical underpinnings of RBV theory, particularly in the context of green practices. As highlighted by Bresciani et al. (2023), the development of green dynamic capabilities supports core operational processes such as waste recycling, environmental management, and green product innovation. These processes collectively drive environmentally responsible behavior and support the broader integration of sustainability within the organization.

Moreover, Ma et al. (2022) emphasize that GDC encourage the active participation of employees in environmental initiatives, thereby fostering innovation and continuous improvement in green practices. Thus, green dynamic capabilities not only support environmental performance but also serve as a critical

enabler of organizational transformation toward sustainability.

In conclusion, the analysis confirms that green dynamic capabilities positively and significantly influence environmental performance. These findings underline the importance for firms to build and enhance their dynamic capabilities in a green context, enabling them to adapt to environmental changes, implement effective sustainability strategies, and maintain a competitive advantage. Future research could explore how different dimensions of GDC interact with other organizational capabilities in shaping comprehensive sustainability outcomes.

H_3: Green Innovation has a positive effect on Environmental Performance

The results indicate that Green Innovation (GI) has a path coefficient of 1.040 with a p-value of 0.000. Since the p-value is less than the predetermined significance level of 0.05, the null hypothesis (H0) is rejected and the alternative hypothesis (H3) is accepted. This confirms that green innovation has a positive and significant effect on environmental performance.

The acceptance of H3 demonstrates that higher levels of green innovation are associated with improvements in environmental performance. This is supported by prior research from Kumar et al. (2025) and Kuo et al. (2022), which consistently show that green innovation contributes significantly to environmental outcomes. Green innovation enables firms to adopt sustainable practices through the development of eco-friendly products, processes, and technologies that minimize resource consumption and environmental harm.

El-Kassar and Singh (2019) argue that the integration of green innovation strengthens a company's competitive advantage by enhancing sustainability performance while also improving operational efficiency. Similarly, Kumar et al. (2025) note that green innovation often results in tangible benefits such as reduced energy usage, lower emissions, improved waste management, and enhanced public image all of which contribute to long-term financial and environmental success.

This finding aligns with the RBV theory, which highlights innovation as a key driver of environmental performance improvements. As highlighted by Aftab et al. (2023), the application of environmentally friendly processes and technologies supports the reduction of energy consumption and waste generation, directly contributing to better ecological outcomes. Moreover, Shahbaz and Malik (2025) emphasize that awareness and commitment to incorporating green innovation into core operations are crucial for fostering a sustainable business model. This implies that firms investing in green innovation are more likely to achieve not only improved environmental performance but also a sustainable competitive position in the market.

In conclusion, the analysis confirms that green innovation significantly and positively affects environmental performance. These findings underscore the strategic importance of embedding green innovation into corporate operations as a pathway to achieving sustainability goals. Future research may explore specific types of green innovations and their differential impacts across industries or regions.

5. Conclusion

The results of this study indicate that green intellectual capital and green innovation have a direct impact on environmental performance. Based on the results of the data analysis test conducted, the following conclusions are obtained:

a. Green intellectual capital has a positive and significant effect on environmental performance. This result explains that the better the application of green intellectual capital, the better the environmental performance of the company (Hoang & Truong, 2024). Companies that consistently develop green intellectual capital tend to be better at reducing adverse environmental issues, improving operational efficiency, and strengthening business competitiveness and sustainability (Shah et al., 2021). Therefore, investing in green intellectual capital is an important strategy for companies to address environmental challenges and global competition.

b. Green dynamic capabilities have a positive and significant effect on environmental performance. This result shows that the higher the green dynamic capabilities in a company, the better the environmental performance achieved (Reyes-Santiago et al., 2019). Companies with good sensing, seizing, and reconfiguring capabilities can be more effective in adopting environmentally friendly practices, optimizing resources, and increasing business competitiveness and sustainability (Forés et al., 2023). Therefore, developing green dynamic capabilities is a strategic step for companies to take in order to meet the ever-changing environmental challenges.

c. Green innovation has a positive and significant effect on environmental performance. This result shows that the higher the level of green innovation in the firm, the better the environmental performance achieved (Kumar et al., 2025; Kuo et al., 2022). With the highest path coefficient value of 1.040, green innovation has the greatest influence on improving environmental performance. Companies that actively adopt green innovations, such as green technologies and energy efficiency, can reduce waste, emissions, and resource consumption, which ultimately improves business sustainability and competitiveness (Shahbaz & Malik, 2025).

This study has several limitations. First, it focuses exclusively on manufacturing firms in Riau, which may limit the generalizability of the findings to other industries or regions with different business dynamics. Sectors such as services or technology may have different sustainability and innovation strategies. Second, the use of questionnaires carries the risk of subjective bias, as respondents may provide socially desirable answers rather than reflecting actual business conditions. This could affect the validity of the results.

Future research should expand its scope beyond manufacturing to include industries such as services, technology, and other sectors that may implement different sustainability strategies. Broadening the scope of the study could also improve the generalizability of the findings. In addition, using a mixed-methods approach by combining quantitative surveys with qualitative methods such as in-depth interviews or case studies could mitigate questionnaire bias and provide deeper insights into how companies implement sustainability strategies. Future research could also explore variables such as digital green innovation, which has been shown to improve environmental performance by facilitating the integration of sustainability into operations and decision-making processes (Dong et al., 2023; Sarwar & Mustafa, 2023; Yin et al., 2022). In addition, incorporating variables such as economic and social performance could provide a holistic understanding of corporate sustainability by balancing economic, social, and environmental performance (Kuo et al., 2022).

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