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Research article

Exploring firm and country's specific factors affecting carbon emission reduction performance: Study on selected ASEAN countries

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ABSTRACT

The research aims to analyze the determinants that impact a company's capability to mitigate carbon emissions in various ASEAN countries, specifically Indonesia, Malaysia, Thailand, the Philippines, and Singapore. The investigation delves into company-specific factors, including corporate social responsibility (CSR) strategy, green innovation, corporate governance, and product responsibility, as well as country-specific factors such as voice and accountability, regulatory quality, government effectiveness, and the rule of law. The results reveal that all examined company-specific factors exhibit a positive and significant influence on a company's capability to reduce carbon emissions. Nonetheless, the influence of country-specific factors on emission reduction performance remains indefinite. While regulatory quality and government effectiveness are significantly associated with a company's emission reduction performance, the same relationship does not apply to voice and accountability and the rule of law.

1. Introduction

The concept of Sustainable Development has garnered significant global attention following the establishment of the 2030 deadline for the Sustainable Development Goals (SDGs) by the United Nations. Substantial and ongoing collaborative efforts are being directed toward addressing the urgent global challenges of climate change, carbon dioxide removal, and the widespread uptake of renewable energy sources [1]. Therefore, the imperative to reduce carbon emissions has become increasingly recognized as a pivotal element in the pursuit of environmental sustainability on a global scale [2]. This recognition highlights the need for a collaborative approach that encompasses both corporate actions and public governance policies. Firm-specific factors such as green innovation, corporate social responsibility (CSR) strategies, corporate governance, and product responsibility play a crucial role in mitigating carbon footprints [3–5]. At the same time, country-specific factors through robust public governance mechanisms characterized by voice and accountability, regulatory quality, government effectiveness, and the rule of law are essential to creating a conducive environment for these corporate actions to yield substantial environmental sustainability impacts [6]. These government factors not only aid in regulating and monitoring environmental practices but also facilitate the adoption of eco-friendly strategies among corporations. The interplay between these firm-specific and country-specific factors is fundamental in achieving the goals of reducing carbon emissions and promoting environmental sustainability.

The Association of Southeast Asian Nations (ASEAN) is an important region in the global economy that faces both environmental

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challenges and opportunities [7,8]. The ASEAN market is gaining prominence and is a crucial context for studying factors affecting the effectiveness of carbon emission reduction performance due to substantial industrialization growth in this region. As an emerging market, it is essential to understand how both firm-specific factors, such as green innovation, CSR strategy, corporate governance, and product responsibility, and country-specific factors, such as public governance frameworks like voice and accountability, regulatory quality, government effectiveness and the rule of law, contribute to environmental sustainability efforts. By understanding the role of these factors, we can develop a more comprehensive and effective approach to addressing environmental sustainability from the firm perspective and a country perspective tailored to the specific needs of the ASEAN context.

The primary objective of this study is to provide a comprehensive analysis of the factors that determine carbon emission reduction performance among listed firms in the ASEAN capital market context. The study investigates the interplay between firm-specific factors, namely green innovation, CSR strategy, corporate governance product responsibility, and country-specific factors, such as voice and accountability, regulatory quality, government effectiveness, and the rule of law. The research questions and objectives are designed to delve deeper into the multifaceted influences that drive effective carbon emission strategies, highlighting the complex interactions between corporate actions and national governance frameworks. The study aims to provide nuanced insights into the various determinants of carbon emission reduction performance in a critical emerging market context, making significant contributions to the fields of environmental economics, corporate sustainability, and public governance. This research is expected to provide a better understanding of the underlying mechanisms that enable firms to reduce carbon emissions and contribute to sustainable development, especially in the ASEAN region.

The existing body of literature on environmental policies typically provides a broad overview of their impact on a nation's carbon footprint. However, such research often fails to take into account the intricate workings of individual firms in reducing carbon emissions [9,10]. On the firm's level, scholars have studied carbon emission reduction determinants from various perspectives. For instance, Meraj et al. [11] highlighted the significant role of renewable energy integration in the grid and its impact on reducing carbon emissions. Similarly, Hosan Lipu et al. [12] discussed the role of energy storage systems and their impact on reducing carbon emissions, particularly in the context of Malaysia's 2050 carbon emission reduction targets. Furthermore, studies have shown that green innovation and CSR strategies are critical in driving corporate environmental performance [13,14]. In addition to firm-specific factors, the effectiveness of national policies and governance structures, such as regulatory quality and government effectiveness, has also been found to moderate the relationship between environmental outcomes and financial outcomes significantly [15]. It is essential to gain a granular understanding of the factors that determine carbon emission reduction at a firm level. This kind of knowledge could help us identify the specific actions that companies can take to reduce their carbon footprint and contribute to a more sustainable future. It is particularly vital given the increasing pressure on corporations to contribute to national and regional climate change mitigation goals.

Although many studies, such as those by Zheng and Jin [16], Raihan and Tuspekova [17], and Raihan et al. [18], have examined environmental sustainability and carbon emission reduction, there is still a lack of research that combines firm and country-specific factors, especially in the ASEAN market. While some studies have focused on green innovation, corporate social responsibility (CSR), and environmental risk management at the firm level, others have looked at public governance factors, such as voice and accountability, regulatory quality, government effectiveness, and the rule of law at the national level. However, there is a need for more in-depth research that combines these dimensions to examine their overall impact on carbon emission reduction performance. While existing research has individually explored these dimensions either at the firm or the national level, this study proposes a novel intersectional analysis that aims to provide a holistic understanding of the multifaceted influences (firm and country-specific factors) on carbon emission reduction performance. The study promises to offer deeper insights into the firm-specific conditions and public governance that effectively support environmental sustainability efforts in the ASEAN context, thereby contributing a unique perspective to the discourse on firm environmental management and national policy-making.

The study presents a comprehensive contribution to both theoretical and practical understanding of environmental sustainability as follows:

- Analyzes the impact of green innovation, CSR strategy, corporate governance, and product responsibility on carbon emission reduction
- Evaluates the role of voice and accountability, regulatory quality, government effectiveness, and the rule of law in influencing corporate carbon emission reduction efforts.
- Combines firm-specific and country-specific factors to provide a holistic understanding of their impact on carbon emission reduction performance.
- Investigates the unique environmental sustainability challenges and opportunities within the ASEAN market, an important emerging economy.
- Offers practical insights and strategies for policymakers and corporations to enhance environmental performance and achieve sustainable development goals.

Despite the increasing emphasis on carbon emission reduction, existing literature often treats firm-specific and country-specific factors in isolation [19,20]. While some studies focus on the role of green innovation and CSR strategies at the corporate level [9–11], others examine the impact of national policies and governance on environmental outcomes [12–14]. However, there is a lack of comprehensive research that integrates these dimensions to understand their combined effect on carbon emission reduction performance. This gap is particularly evident in the context of the ASEAN region, where diverse economic and regulatory environments present unique challenges and opportunities for carbon mitigation [21].

The significance of this study lies in its holistic approach to examining carbon emission reduction performance. By integrating firm-

specific factors such as green innovation, CSR strategy, corporate governance, and product responsibility with country-specific factors like voice and accountability, regulatory quality, government effectiveness, and the rule of law, this research provides a nuanced understanding of the multifaceted influences on carbon emission strategies. The novelty of this study is underscored by its intersectional analysis, which bridges the gap between corporate actions and national governance frameworks, offering a comprehensive perspective that is often missing in existing literature.

In the ASEAN context, there is a notable policy void regarding the alignment of corporate and national efforts towards carbon emission reduction. While countries like Malaysia have set ambitious targets for 2050 [8], limited research exists on how corporate practices can be effectively integrated with national policies to achieve these goals. This study addresses this void by providing empirical evidence on the interplay between firm-specific actions and country-specific governance, thereby offering actionable insights for policymakers and corporate leaders.

The study fills a notable gap in the existing literature that often considers these dimensions in isolation. This approach not only advances theoretical frameworks within environmental economics and corporate sustainability but also provides a rich empirical basis for understanding carbon emission reduction in the ASEAN region. The study's empirical evidence offers novel insights into the complex interplay between corporate actions and national governance frameworks. Such insights are valuable for policymakers, regulatory bodies, and corporations seeking to enhance environmental performance in emerging markets. The study underscores the significance of supportive public governance and strategic corporate initiatives in achieving sustainable development goals, providing a practical roadmap for aligning business practices with environmental objectives. The study's contributions extend beyond academic enrichment, offering tangible strategies and policy recommendations to promote effective carbon emission reduction strategies in the ASEAN context and thus supporting global sustainable development efforts.

2. Background

The Association of Southeast Asian Nations (ASEAN) is a regional organization comprising ten member states: Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam. Together, these countries have shown a growing commitment to tackling climate change and reducing carbon emissions. This commitment is driven by their recognition of the significant environmental challenges stemming from rapid economic development, industrial growth, and urban expansion across the region [22].

ASEAN countries have collectively and individually committed to international agreements, such as the Paris Agreement, aiming to limit the rise of global temperature and mitigate the impact of climate change [23]. The ASEAN Socio-Cultural Community (ASCC) Blueprint 2025 outlines the region's strategic approach to environmental sustainability, emphasizing the importance of integrating sustainable practices into national policies and regional cooperation frameworks [24]. Each member state has submitted Nationally Determined Contributions (NDCs), which outline their specific targets and strategies for reducing greenhouse gas emissions [22].

The economic landscape of ASEAN is diverse, with varying levels of development and industrialization. Countries like Indonesia, Malaysia, Thailand, and Vietnam have significant manufacturing and agricultural sectors, which are major sources of carbon emissions [25]. These economies are also rich in natural resources, including fossil fuels, which further complicate their carbon reduction efforts. Conversely, countries like Singapore have focused on high-value services and technology, leading to different emission profiles and reduction strategies [26].

Institutional frameworks in ASEAN countries play a crucial role in shaping carbon emission reduction strategies. Environmental ministries and agencies are typically tasked with developing and implementing climate policies. For instance, Indonesia's Ministry of Environment and Forestry, Malaysia's Ministry of Energy, Science, Technology, Environment and Climate Change (MESTECC), and Thailand's Ministry of Natural Resources and Environment are key players in their respective national contexts. These institutions work on various fronts, including regulatory measures, economic incentives, and public awareness campaigns, to promote emission reductions.

ASEAN countries face several challenges in their carbon emission reduction efforts. These include balancing economic growth with environmental sustainability, addressing energy security concerns, and managing the social impacts of transitioning to low-carbon economies [27]. However, there are also significant opportunities, such as the potential for regional cooperation in renewable energy development, technology transfer, and capacity building. Initiatives like the ASEAN Plan of Action for Energy Cooperation (APAEC) aim to enhance energy efficiency and increase the share of renewable energy in the regional energy mix [28].

The institutional background of ASEAN countries reflects a complex interplay of economic, environmental, and policy factors influencing carbon emission reduction performance. While there is a strong regional commitment to addressing climate change, the specific approaches and challenges vary across member states. Understanding these nuances is crucial for exploring the factors that affect carbon emission reduction performance at both firm and country levels within the ASEAN context.

3. Theoretical framework

3.1. Stakeholder theory

Stakeholder Theory is a concept developed mainly by Freeman [29], which asserts that an organization comprises multiple stakeholders with differing interests and claims. These stakeholders may include shareholders, employees, customers, suppliers, communities, and governments. The theory suggests that the success of an organization depends on how well it can manage and balance these competing interests effectively [30]. Stakeholder Theory provides a nuanced perspective to examine the relationship

between companies and their stakeholders in regard to corporate environmental responsibility and sustainability. The theory highlights the importance of addressing stakeholder concerns to reduce carbon emissions and improve environmental performance [31,32]. Stakeholder Theory provides a framework for understanding the complex, interrelated nature of corporate responsibility and the environment.

The proposed conceptual model in this study is a comprehensive framework that merges Stakeholder Theory with firm-specific and country-specific determinants of carbon emission reduction performance. The model outlines the different pathways through which these variables affect carbon emission reduction, highlighting the significant role of stakeholder engagement and expectations in shaping corporate environmental strategies and performance. This model provides a useful guide for companies that seek to reduce their carbon emissions in a manner that is consistent with the expectations of their stakeholders and the broader society while also taking into account the regulatory and legal frameworks in which they operate.

Stakeholder Theory is a suitable approach for examining the factors that determine the performance of carbon emission reduction. This theory recognizes the multifaceted relationships between a company and its stakeholders and acknowledges the complexity of balancing their diverse interests. It provides a framework for understanding how these interests influence corporate strategies and outcomes, including environmental sustainability efforts. Furthermore, Stakeholder Theory's emphasis on ethical and responsible business practices aligns with the growing importance of sustainability and environmental stewardship. Therefore, it serves as an appropriate theoretical foundation for research in this area.

3.2. Institutional theory

According to Institutional Theory, organizations are not autonomous entities that operate independently. Instead, they are highly influenced by their external environment, which includes the regulatory, cognitive, and normative pillars [33,34]. These institutional forces shape the behavior of organizations, as they are compelled to conform to societal expectations to gain legitimacy, access resources, and ensure their survival [35]. Companies that adopt environmentally sustainable practices are more likely to be viewed as legitimate and trustworthy by stakeholders [36,37]. Institutional Theory is particularly relevant to the analysis of corporate environmental responsibility because it highlights the importance of external institutional forces in shaping firms' strategies toward reducing carbon emissions [38,39].

Using an Institutional Theory-based conceptual model, the study takes into account both firm-specific and country-specific factors that affect carbon emission reduction performance. It highlights the interplay between institutional pressures and corporate practices to demonstrate how green innovation, CSR strategy, corporate governance, and product responsibility are influenced by external norms, regulations, and cognitive frameworks. The model provides insights into how institutional forces shape corporate strategies and practices for carbon emission reduction, emphasizing the role of legitimacy and conformity to external expectations in driving environmental performance. By considering the various pathways through which institutional influences impact corporate behavior, the model provides a more complete understanding of the complex dynamics that underlie environmental performance.

Institutional Theory is considered as a suitable framework for exploring the factors that affect carbon emission reduction performance. This theory emphasizes the importance of institutional pressures and the need for legitimacy, which provides a reliable way to understand how external norms and regulations influence a company's environmental strategies [40,41]. This perspective is particularly relevant in areas where regulatory enforcement and cultural norms vary, affecting a company's approach to environmental sustainability. Institutional Theory's focus on the broader socioeconomic and regulatory context provides valuable insights into how companies can navigate complex institutional landscapes to improve their carbon emission reduction efforts [39,42].

4. Hypothesis development and key determinants of carbon emission reduction

4.1. Green innovation and carbon emission reduction

Worldwide, all countries are facing the crisis of climate change. They are addressing this issue by focusing on implementing green energy innovation initiatives and promoting a sustainable future through environmental sustainability [43]. Green innovation is a concept that involves the development and application of environmentally friendly products, processes, and practices [44]. It encompasses a wide range of activities, including the efficient use of energy, the use of renewable energy technologies like solar and wind power, the effective management of waste, and the design of eco-friendly products [45,46]. Green innovation is crucial in the context of global climate change and the urgent need for sustainable development practices [47,48]. Green innovation can lead to cost savings, increased efficiency, and improved quality of life for all [49–51]. Three significant factors that play key roles in reducing carbon emissions are clean energy, technological innovation, and political-institutional quality [52]. Studies suggest that there is a long-term cointegration relationship between green technology innovation and carbon dioxide reduction [38,53]. It implies that adopting green technology may not deliver immediate financial and environmental benefits. It requires an upfront investment, and the payback period is often long.

Through the lens of stakeholder theory, the favorable association between green innovation and the reduction of carbon emissions is elucidated by underscoring the imperative for organizations to acknowledge the varied interests and requirements of their stakeholders. Stakeholders, comprising customers, employees, suppliers, investors, and the broader community, are increasingly placing emphasis on sustainability and environmental stewardship. By embracing green innovations, organizations can effectively address these stakeholder concerns, augment their corporate social responsibility, and cultivate stronger ties with pivotal segments. This alignment with stakeholder expectations not only fosters goodwill and trust but also compels organizations to integrate

environmentally sound technologies and practices, ultimately culminating in substantial reductions in carbon emissions and fostering a more sustainable future.

Numerous empirical studies have demonstrated a positive link between green innovation and carbon emission reduction. For instance, Li, Yu [53] and Cong, Zhu [54] found that firms investing in environmentally friendly innovations experienced a significant decrease in their carbon footprint. Similarly, Horbach (2008) reported that the adoption of green technologies led to substantial energy savings and emission reductions in the manufacturing sector [55,56]. Wang, Khan [44] delineates green innovation as comprising both product and process innovations that contribute to environmental sustainability. The results of the study by Tariq, Sun [57] also demonstrated that green technology development, green energy consumption, energy efficiency, and imports all have a significant negative correlation with GHG emissions. The role of policy in fostering an environment conducive to green innovation has also been a focal point of research. The study by Chang, Liu [58] on environmental policy design and technological innovation concludes that policies targeting specific technologies and sectors are more effective in promoting green innovation and, consequently, in reducing carbon emissions.

Hypothesis 1. Green innovation is positively associated with carbon emission reduction performance.

4.2. Corporate social responsibility strategy and carbon emission reduction

The corporate social responsibility (CSR) strategy is an essential element of corporate governance that encompasses a broad spectrum of policies and activities aimed at ensuring that corporations act responsibly toward society, the economy, and the environment [59]. This strategy involves initiatives such as community development programs, environmental protection measures, and ethical business practices that are designed to minimize negative impacts while promoting positive contributions to the wider world [60,61]. CSR strategy is a reflection corporation's commitment to sustainability, ethical conduct, and social responsibility. It can enhance a company's reputation and strengthen its relationships with stakeholders [62,63]. CSR strategy is closely associated with company regulatory compliance and proactive engagement in sustainable practices [64,65]. This approach encourages the adoption of cleaner and more efficient technologies, waste reduction, and resource optimization, all of which are essential in reducing carbon emissions.

In accordance with stakeholder theory, the correlation between a corporate social responsibility (CSR) strategy and the attenuation of carbon emissions can be elucidated by underscoring the significance of addressing the diverse interests and requisites of an organization's stakeholders. Notably, stakeholders, encompassing clientele, personnel, investors, suppliers, and the wider community, anticipate firms to exhibit environmental conscientiousness. By incorporating carbon emission reduction within their CSR strategy, companies can effectively tackle these environmental apprehensions, thereby fostering reliance and allegiance among stakeholders. This alignment with stakeholder expectations not only enhances the firm's standing and credibility but also propels the assimilation of sustainable initiatives and technologies, ultimately culminating in noteworthy reductions in carbon emissions and the advancement of enduring environmental sustainability.

Empirical studies and theoretical frameworks support the proposition that a robust CSR Strategy is instrumental in enhancing a company's environmental performance. A study by Zhou, Zhu [66] delves into the impact of CSR on carbon emission reduction within supply chains. The study concludes that enhancing consumer green preferences and trust can improve the carbon emission reduction rate among manufacturing enterprises. The findings suggest that market capacity and green innovation costs significantly influence the optimal carbon emission reduction rate, providing insights for governments and enterprises in low-carbon subsidies and supply chain management. Wu and Li [67] investigate how different CSR undertaking modes influence technological innovation and carbon emission reduction decisions in a supply chain. Focusing on a low-carbon supply chain consisting of a producer and a retailer, it examines the impact of CSR on technological innovation and carbon-emission-reduction intensity using the Stackelberg game. The study finds that increased CSR awareness among member firms leads to improved carbon-emission-reduction intensity, technological innovation level, and product sales volume.

Hypothesis 2. CSR strategy is positively associated with carbon emission reduction performance.

4.3. Corporate governance and carbon emission reduction

Corporate governance encompasses the systems and processes a company employs to ensure accountability, fairness, and transparency in its dealings with stakeholders. This includes a commitment to adhering to the best practices in governance, which affect various aspects like board diversity, executive compensation, shareholder rights, and sustainability practices. The interconnection between corporate governance and carbon emission reduction has been examined through various theoretical lenses and methodologies across different geographical and sector-specific contexts. A prevalent theme is the application of stakeholder theory, which suggests that considering the broader interests of all stakeholders rather than solely shareholders leads to more ethical and successful outcomes. This theory is particularly relevant to environmental sustainability, positing that companies with strong governance structures are likely to prioritize reducing carbon emissions as it aligns with the long-term interests of stakeholders, including customers, communities, and regulators.

Through the application of stakeholder theory, it becomes evident that corporate governance plays a crucial role in positively influencing the reduction of carbon emissions. This dynamic stems from corporate governance's capacity to effectively address the varied interests and requirements of an organization's stakeholders. By upholding robust corporate governance practices, an organization ensures that the concerns of stakeholders, such as shareholders, employees, customers, suppliers, and the community, are

intricately woven into the fabric of the company's strategic and operational decision-making processes. By prioritizing both environmental sustainability and carbon emission reduction within their governance framework, firms can meet stakeholder expectations for ethically responsible corporate conduct. This alignment not only bolsters the firm's standing and trust among stakeholders but also propels the adoption of sustainable practices and technologies, resulting in substantial reductions in carbon emissions and fostering enduring environmental sustainability.

Empirical literature broadly supports the notion that robust corporate governance can lead to significant improvements in carbon emission reduction performance. High-quality corporate governance is associated with more transparent and comprehensive carbon emission disclosures, which are critical for stakeholders assessing a firm's environmental impact [68]. Another study focuses on how Environmental, social, and Governance (ESG) performance impacts corporate behaviors related to carbon reduction. It was found that high ESG performance facilitates carbon reduction goals through various mechanisms, such as alleviating financing constraints, enhancing innovation efficiency, and enabling more effective risk management [69]. Corporate boards play a pivotal role in enhancing a firm's carbon performance by instituting effective governance practices. The effectiveness of such governance is often amplified by the board's resource provision capabilities and its understanding of environmental issues, thereby directly influencing the firm's carbon emission reduction performance [70].

Hypothesis 3. Corporate governance is positively associated with carbon emission reduction performance.

4.4. Product responsibility and carbon emission reduction

Product responsibility is a critical aspect of sustainable business practices. It reflects a company's commitment to producing high-quality goods and services while ensuring the safety and well-being of its customers. This responsibility also extends to protecting the privacy and integrity of customer data. Moreover, companies have a duty to minimize the environmental impact of their products throughout their lifecycle, from production to disposal. This includes reducing carbon emissions associated with the production process. The literature suggests that fulfilling this responsibility can act as a catalyst for innovation, inspiring companies to develop more efficient manufacturing processes, integrate renewable energy sources, and minimize waste. In addition to complying with regulatory requirements, these innovations enhance the company's reputation and earn the trust of stakeholders. This is essential for the long-term success and sustainability of the business, making product responsibility a crucial element of any sustainable business strategy.

Utilizing stakeholder theory, the positive correlation between product responsibility and the reduction of carbon emissions performance can be elucidated by highlighting how the consideration of the diverse interests and demands of stakeholders influences corporate conduct. Stakeholders, such as customers, employees, investors, regulators, and the broader community, increasingly anticipate companies to manufacture environmentally responsible products. By incorporating product responsibility into their business strategies, firms can ensure that their products are designed, manufactured, and distributed with a focus on minimizing environmental impact. This proactive approach not only aligns with stakeholder expectations for sustainability but also propels the adoption of innovative, eco-friendly practices and technologies. Consequently, these endeavors result in a substantial reduction in carbon emissions, augmenting both the firm's environmental performance and its reputation among stakeholders.

Extensive research suggests a positive relationship between product responsibility and carbon emission reduction performance, supported by both empirical evidence and theoretical foundations. According to the stakeholder theory, companies that prioritize the needs of their stakeholders, including environmental concerns, are more likely to adopt sustainable practices that reduce carbon emissions. Studies have shown that organizations with higher levels of transparency in their production processes and greater involvement in sustainability practices tend to perform better in reducing emissions [71,72]. In retail and supply chain contexts, incorporating product responsibility into corporate strategies, like selecting product mixes with favorable cross-price elasticity, significantly lowers waste and carbon emissions [73]. Adopting carbon footprinting and responsibility allocation within supply chains encourages firms to improve their emission efficiencies and achieve optimal social value under emission regulations [74]. Strategies that involve carbon emission reduction and product collection in closed-loop supply chains, particularly under cap-and-trade regulation, effectively lower emissions and improve environmental and economic performance [75].

Hypothesis 4. Product responsibility is positively associated with carbon emission reduction performance.

4.5. Voice and accountability and carbon emission reduction

The term " voice and accountability" in public governance refers to the degree of citizen participation in government selection, freedom of expression, and association formation within a country [76,77]. This vital aspect of public governance plays a crucial role in shaping how environmental issues are addressed and discussed within a society. In accordance with the institutional theory, societies that rank high in voice and accountability tend to subject companies to greater public and stakeholder scrutiny regarding their environmental impact [78–80]. This increased scrutiny is a result of a population that is more informed and engaged in environmental issues. Companies operating in such societies are more likely to prioritize efforts to reduce carbon emissions as a way of responding to public concerns and demands. This prioritization is due to the increased pressure and expectations placed upon them by a more active and engaged public.

Through the lens of Institutional Theory, the affirmative correlation between voice and accountability and a company's reduction in carbon emissions can be explicated by underscoring the influence of external pressures and norms on organizational conduct. Institutional theory postulates that companies function within a framework of formal and informal regulations, norms, and

anticipations instituted by society, regulators, and industry standards. By integrating mechanisms for voice and accountability, such as transparent reporting, stakeholder engagement, and robust governance structures, companies can harmonize their operations with these external expectations for environmental stewardship. This synchronization not only enhances the company's legitimacy and reputation but also fosters the adoption of sustainable practices and technologies. Consequently, companies with robust voice and accountability mechanisms are better positioned to curtail their carbon emissions, thereby contributing to overarching environmental sustainability and compliance with institutional imperatives.

The theoretical underpinning of this relationship is grounded in the principles of public governance and corporate environmental responsibility. A country with a strong voice and accountability mechanisms can create a regulatory environment that encourages or mandates firms to adopt greener practices. Voice and accountability measure the extent to which citizens can participate in governance and protect their freedoms, which has meaningful implications for environmental governance. The theoretical perspectives that connect voice and accountability to environmental performance posit that democratic institutions facilitate the flow of information between citizens and policymakers, which leads to more responsive and responsible management of environmental resources [81]. The accountability mechanisms in democracies, including free press and civic activism, enable environmental issues to gain prominence in public discourse and policy agendas [82].

Hypothesis 5. Voice and accountability are positively associated with the firm's carbon emission reduction performance.

4.6. Regulatory quality and carbon emission reduction

Regulatory quality in the context of public governance refers to the government's ability to establish and enforce policies that facilitate the growth of the private sector [76,77]. An effective regulatory framework is characterized by regulations that are well-designed, clear, coherent, and transparent [83]. This framework should also be flexible enough to adapt to new environmental challenges, such as emissions standards, waste management protocols, and conservation efforts. Strong regulations have the potential to control pollution, protect natural resources, and encourage innovative sustainability practices [84]. They can also influence the behavior of economic actors and encourage the public to partake in environmental stewardship [85]. In addition to promoting environmental protection, regulatory quality can also spur the adoption of environmental technologies and encourage corporate responsibility for environmental issues. By establishing clear guidelines and incentives, regulatory frameworks can help to stimulate innovation and encourage companies to develop and implement green technologies to reduce environmental harm.

Utilizing Institutional Theory, the positive correlation between regulatory quality and a firm's carbon emission reduction performance can be explained by emphasizing the influence of high-quality regulatory frameworks on organizational conduct. Institutional theory posits that firms are impacted by the formal rules, regulations, and norms within their operational milieu. High regulatory quality ensures unambiguous, consistent, and enforceable environmental standards that firms are obligated to adhere to. By establishing a well-defined regulatory framework, firms are compelled to embrace sustainable practices and technologies to meet these regulations. This not only ensures compliance with environmental norms but also stimulates innovation and efficiency in the reduction of carbon emissions. Consequently, firms operating under high-quality regulatory regimes are more likely to attain substantial enhancements in their carbon emission reduction performance, aligning their endeavors with societal and institutional anticipations for environmental accountability.

Governments globally are continually enacting regulations and policies to address climate change and encourage sustainable development [86]. High regulatory quality entails setting rigorous environmental standards and regulations that companies must abide by. This drives firms to implement more innovative carbon emission reduction strategies, resulting in a cleaner and healthier environment for all. By prioritizing regulatory quality, the government can ensure that businesses operate in a socially responsible and sustainable manner, promoting economic growth while safeguarding natural resources [87]. Properly designed environmental regulations can spur innovation, reduce waste, and improve resource efficiency, leading to a reduction in carbon emissions [88,89]. Regulatory quality also promotes the uptake of environmental technologies. It encourages corporate environmental responsibility [90]. Chang, Liu [58] investigated the impact of green technology innovation on CO2 emissions reduction, emphasizing the role of local environmental regulations. They found that environmental regulations positively moderate the impact of green knowledge innovation on CO2 emissions reduction. Zhou, Guan [52] examined the impact of China's emission trading scheme (ETS) on industry-level green innovation, revealing insights into how different industries, especially those in the upstream segment of the supply chain, which are typically high-emission industries, are influenced by and respond to environmental regulations.

Hypothesis 6. Regulatory quality is positively associated with the firm's carbon emission reduction performance.

4.7. Rule of law and carbon emission reduction

The rule of law is a fundamental principle of public governance that holds that a nation should be governed by laws rather than by the arbitrary decisions of individual government officials [76,77]. At the national level, this principle plays a crucial role in shaping environmental outcomes. The rule of law is evaluated based on the level of trust in and adherence to societal rules, which includes the quality of contract enforcement, property rights, and the judiciary [76,91]. In the context of environmental governance, the rule of law ensures that environmental policies are consistently applied and enforced [92]. It also ensures that legal frameworks support sustainable practices, such as those that promote the protection and conservation of natural resources [93–95]. A well-functioning rule of law fosters better environmental outcomes by consistently applying and enforcing environmental laws and policies. Strong legal frameworks are theorized to underpin the creation and enforcement of environmental regulations [96–98]. Additionally, they protect

property rights and facilitate the resolution of environmental disputes. The rule of law strengthens transparency and accountability by providing legal avenues for civil society [99], including environmental organizations, to challenge environmentally harmful practices [100].

In light of institutional theory, the favorable relationship between the rule of law and a company's reduction of carbon emissions can be elucidated by underscoring the influence of a stable and predictable legal framework on organizational behavior. Institutional theory posits that companies are shaped by the established rules, norms, and expectations within their institutional context. A robust rule of law ensures the consistent enforcement of environmental regulations, transparency in legal processes, and holds companies accountable for their actions. This legal clarity and enforcement prompt companies to adopt sustainable practices and technologies to comply with environmental standards. Operating within a robust legal framework, companies are incentivized to decrease their carbon emissions to sidestep legal penalties and bolster their credibility and reputation. Accordingly, a strong rule of law fosters an environment where companies are more likely to implement effective carbon emission reduction strategies in accordance with societal and institutional expectations for environmental stewardship.

The rule of law pertains to the level of trust and compliance that individuals and organizations have towards the legal system and the social norms that govern society [101,102]. It encompasses various factors such as the efficiency of enforcing contracts, safeguarding of property rights, the dependability of law enforcement agencies and the judiciary, and the prevalence of crime and violence in a given society [103]. A strong and consistent rule of law creates a secure and predictable environment for businesses, which is essential for long-term investments in eco-friendly technologies and sustainable business practices [104]. In essence, the rule of law plays a critical role in creating a stable and conducive environment for businesses to thrive and contribute to the socio-economic development of a country [105]. Comprehensive legal frameworks can guide industries toward lower carbon emissions, showcasing the effectiveness of legal measures in the sustainability domain [106].

Hypothesis 7. Rule of law is positively associated with the firm's carbon emission reduction performance.

4.8. Government effectiveness and carbon emission reduction

The measure of government effectiveness is an essential gauge of governance quality, as it showcases the quality of public services, the level of independence of the civil service from political pressure, the efficiency of policy formulation and implementation, and the government's dedication to its policies [76,77]. In the context of environmental policy, government effectiveness is a measure of the state's ability to execute policies and regulations aimed at reducing carbon emissions and managing the transition to a sustainable, low-carbon economy. This involves not only the development of policies but also their effective implementation, monitoring, and enforcement. Institutional theory posits that effective institutions are indispensable for the successful implementation of environmental laws and policies. This means that governments need to establish strong institutions, such as regulatory bodies and enforcement agencies, to ensure that environmental policies are implemented effectively. Effective government also fosters a predictable and transparent environment that enables long-term planning and investment in green technologies. This is essential for businesses and investors to have the confidence to invest in sustainable technologies and practices, which are critical to achieving a sustainable and low-carbon economy.

Through the lens of institutional theory, the positive correlation between government effectiveness and a firm's capacity to reduce carbon emissions can be elucidated by emphasizing the manner in which proficient governance shapes organizational conduct through the consistent implementation of explicit policies. Institutional theory posits that corporations function within a framework of formal regulations and norms established by their institutional environment. Government effectiveness, characterized by efficient public services, robust regulatory quality, and effective enforcement mechanisms, fosters a predictable and supportive climate for corporations to operate sustainably. When governments effectively execute environmental policies and regulations, corporations are incentivized and frequently mandated to embrace eco-friendly practices and technologies to adhere to these standards. This alignment with regulatory expectations not only enhances a corporation's legitimacy and competitive edge but also propels substantial reductions in carbon emissions. Consequently, in environments where governments prevail with effectiveness, corporations are more likely to attain superior performance in curbing carbon emissions, thereby reflecting the institutional dedication to environmental sustainability.

Studies underscore the role of robust institutions in fostering environments where policies can be effectively implemented. Research on the impact of the Chinese carbon emission trading pilot demonstrates that companies subjected to this environmental regulation exhibit enhanced environmental performance compared to their unregulated counterparts [107]. The study indicates that regulated companies tend to improve their environmental performance, suggesting a positive association between stringent government policies and corporate carbon emission reduction efforts. Another investigation into China's carbon emission trading policy reveals that such market-based environmental regulations can indeed bolster enterprise ESG performance significantly. The study highlights that this type of policy encourages firms to invest more in research and development and to advance their internal governance structures, leading to improved ESG performance. The effects are particularly pronounced in firms that are more digitally transformed, receive higher government subsidies, and operate in low-carbon sectors. Empirical evidence also suggests that effective governance mechanisms are associated with better compliance with environmental regulations, greater transparency in the execution of environmental policies, and more substantial public sector investment in sustainable technologies. These outcomes are typically attributed to the ability of effective governments to enforce laws, mobilize resources, and engage stakeholders in meaningful ways.

Hypothesis 8. Government effectiveness is positively associated with the firm's carbon emission reduction performance

5. Research design and methodology

5.1. Research design

The research design employs a quantitative research approach, which relies on empirical data to explore the connections between the different independent variables and the dependent variable. The main variable that this study focuses on is carbon emission reduction performance. This is a measure of how effectively companies manage and reduce their carbon emissions. The independent variables are divided into two categories: factors specific to the company and factors specific to the country. Specific factors that apply to companies include green innovation, CSR strategy, corporate governance, and product responsibility. In order to understand how countries differ from one another, it's important to examine four key countries' factors: voice and accountability, regulatory quality, government effectiveness, and rule of law. By examining these four countries' specific factors, we can gain a better understanding of how countries differ in terms of government, business, and societal norms. Graphically, interconnected variables involved in this study are presented in Fig. 1.

5.2. Sample and data collection

The research study has selected firms from five prominent ASEAN countries, namely Indonesia, Singapore, Malaysia, Thailand, and the Philippines. These countries are chosen based on their inclusion of ESG (Environmental, Social, and Governance) scoring in the Refinitiv Eikon Database, with a specific emphasis on their carbon emission reduction practices. This selection criterion ensures that the study focuses on firms with well-documented and measurable ESG practices. By concentrating on firms with ESG scores, the study's sample is aligned with those companies that have more structured and transparent sustainability practices, thus providing more reliable data for analysis. The study's selection methodology ensures that the data analyzed is from firms with established and verifiable ESG practices, providing a more robust and comprehensive analysis of the impact of ESG practices on carbon emission reduction.

The current study is based on a comprehensive and diverse set of observed variables. All the variables are based on secondary data obtained from reliable and well-known sources, such as recognized databases and publications of reputable international organizations. The Refinitiv Eikon Database is the primary source of data for several crucial variables, including carbon emission reduction performance, green innovation, CSR strategy, corporate governance, and product responsibility. Finally, publications by the World Bank are the source of country governance indicators such as voice and accountability, regulatory quality, rule of law, and government effectiveness. This study analyses data from a cross-sectional sample of 563 companies based in five ASEAN countries during the year 2022.

5.3. Variable definition and measurement

The study explores two classifications of independent variables, namely firm-specific and country-specific factors, that are predicted to affect carbon emission performance (dependent variable). Firm-specific factors consist of green innovation, CSR strategy, corporate governance, and product responsibility. Meanwhile, voice and accountability, regulatory quality, rule of law, and government effectiveness are country-specific factors. Table 1 presents a comprehensive description of the understanding of each variable and its measurement.

5.4. Model and statistical analysis

The study proposes that carbon emission reduction performance (CERP) is a function of green innovation (GI), CSR strategy (CSR), corporate governance (CG), product responsibility (PR), voice and accountability (VACA), regulatory quality (REQUAL), rule of law (RULAW) and government effectiveness (GOVEC). The model analysis for this study is constructed as follows:

$$CERP = \alpha + \beta_1 GI + \beta_2\ CSR + \beta_3 CG_i + \beta_4 PR + \beta_5 VACA + \beta_6 REQUAL + \beta_7 RULAW + \beta_8 GOVEC + error.$$

The research study employs a statistical technique called Partial Least Squares Structural Equation Modeling (PLS-SEM) to investigate the proposed relationships between variables. PLS-SEM is a well-suited approach for exploring complex models that

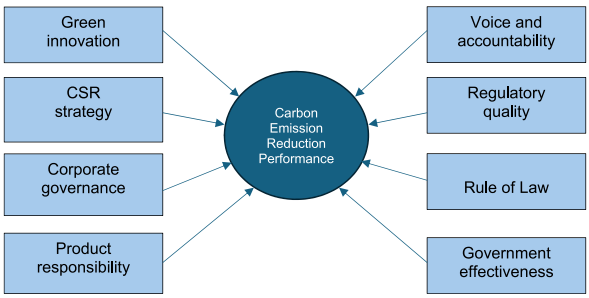

Fig. 1. Research framework.

Table 1
Operationalization variables.

Variable	Definition	Measurement
Carbon emission reduction performance (Dependent)	Firm's commitment and effectiveness towards reducing environmental emission in the production and operational processes.	Emission score of ESG Metric (Refinitiv Eikon Database)
Green innovation (independent)	Firm's capacity to reduce the environmental costs and burdens for its customers, and thereby creating new market opportunities through new environmental technologies and processes or eco-designed products.	Environmental Innovation score of ESG Metric (Refinitiv Eikon Database)
CSR strategy	Firm's practices to integrates economic (financial), social and environmental dimensions into its day-to-day decision-making processes.	CSR strategy score of ESG Metric (Refinitiv Eikon Database)
Corporate governance	Firm's commitment and effectiveness towards following best practice corporate governance principles.	Management score of ESG Metric (Refinitiv Eikon Database)
Product responsibility	Firm's capacity to produce quality goods and services, integrating the customer's health and safety, integrity and data privacy.	Product responsibility score of ESG metric (Refinitiv Eikon Database)
Voice and accountability	The extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media	Worldwide Governance Indicator (WGI) by World Bank
Regulatory quality	The ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development	Worldwide Governance Indicator (WGI) by World Bank
Rule of law	Extent to which agents have confidence in and abide by the rules of society. These rules include the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence	Worldwide Governance Indicator (WGI) by World Bank
Government effectiveness	The quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies	Worldwide Governance Indicator (WGI) by World Bank

involve multiple predictor variables and is ideal for exploratory research. PLS-SEM is primarily a variance-based approach used for modeling complex relationships between observed and latent variables, especially in exploratory research settings or when the primary goal is prediction. It is often employed in business, management, and social sciences research where the theoretical knowledge may not be sufficiently mature to specify a priori theories or when dealing with complex models and relatively small sample sizes. This technique allows for the assessment of both the measurement and structural models, making it a useful tool for this study. The structural model is a statistical tool that is used to evaluate the relationships between different variables. To measure the strength and direction of the effects of these factors, path coefficients are estimated. These coefficients give an indication of how much each factor contributes to the overall performance of carbon emission reduction. In addition, the statistical analysis also includes size effect analysis to evaluate the predicate of coefficient strength (Strong, moderate, weak, or no effect).

Table 2
Descriptive statistics of emission reduction and firm-specific factors.

	Country	N	Mean	Median	SD	Minimum	Maximum
Emissions Reduction Performance	Indonesia	68	51.3	47.1	24.0	0.0	99.6
	Malaysia	258	39.6	37.8	28.6	0.0	97.4
	Philippines	34	54.1	53.1	23.1	13.2	96.1
	Singapore	73	56.1	59.8	23.2	2.6	99.4
	Thailand	130	53.3	54.5	25.3	6.0	99.1
CSR Strategy	Indonesia	68	52.6	52.1	27.9	0.6	99.4
	Malaysia	258	54.8	57.7	28.5	0.0	99.4
	Philippines	34	49.6	48.7	29.4	1.3	98.6
	Singapore	73	51.5	32.6	26.2	2.7	99.5
	Thailand	130	53.7	46.3	27.5	2.6	98.3
Green Innovation	Indonesia	68	23.3	0.0	29	0.0	94.4
	Malaysia	258	16.5	0.0	27.1	0.0	95.2
	Philippines	34	29.6	26.8	27.9	0.0	86.0
	Singapore	73	34.3	24.7	30.6	0.0	95.2
	Thailand	130	26.2	19.3	28.8	0.0	88.1
Corporate Governance	Indonesia	68	51.2	50.6	28.9	0.6	99.4
	Malaysia	258	51.8	50.0	29.4	0.1	99.6
	Philippines	34	49.4	48.7	29.8	1.3	98.7
	Singapore	73	52.7	53.8	28.2	0.6	98.3
	Thailand	130	51.6	53.9	29.3	1.4	99.7
Product Responsibility	Indonesia	68	60.9	65.3	30.5	0.0	99.7
	Malaysia	258	47.6	46.2	27.8	0.0	99.6
	Philippines	34	60.2	65.6	24.2	21.3	96.8
	Singapore	73	60.2	61.6	26.9	9.3	99.3
	Thailand	130	62.0	67.1	26.9	0.0	99.7

6. Results

6.1. Descriptive statistics

Table 2 presents a summary of the descriptive statistics of emission reduction performance and firm-specific factors, namely CSR strategy, green innovation, corporate governance, and product responsibility. The analysis of emissions reduction performance and CSR strategies in Indonesia, Malaysia, the Philippines, Singapore, and Thailand reveals that each country has different levels of effectiveness. Indonesia and the Philippines show moderate to high effectiveness in emissions reduction, with Indonesia focusing particularly on product responsibility and corporate governance, while the Philippines excels in product responsibility. Malaysia, on the other hand, has lower effectiveness in emissions reduction but is more engaged in broader CSR activities. Singapore leads in both emissions reduction and green innovation. In contrast, Thailand has a balanced approach to emissions reduction but lags in green innovation. This regional overview suggests that environmental and CSR strategies are implemented differently, potentially influenced by cultural, regulatory, and economic factors specific to each country.

This study aims to gain a comprehensive understanding of the environmental initiatives and carbon emission reduction performance of different countries. To accomplish this goal, the study analyses the public governance landscapes of each nation. It assesses four pillars of public governance, which are voice and accountability, regulatory quality, government effectiveness, and the rule of law, to measure public governance health and its impact on environmental policies. To help readers understand better, Fig. 2 illustrates the four pillars of public governance of five sample countries from ASEAN.

The five countries of Indonesia, Malaysia, the Philippines, Singapore, and Thailand have distinct public governance profiles. Among these countries, Indonesia and Thailand show moderate in terms of government and regulatory quality, but they face concerns with the rule of law, which may potentially affect the enforcement of environmental legislation. In contrast, Malaysia demonstrates a strong governance system with high scores in regulatory quality, rule of law, and government effectiveness, indicating that it has a conducive environment for implementing carbon emission standards. On the other hand, the Philippines has limitations in public governance that may hinder effective environmental management, marked by lower scores in the rule of law and regulatory quality. Finally, Singapore stands out with remarkably high scores across all public governance indicators, ensuring effective implementation and adherence to environmental regulations and setting a high standard in public governance excellence related to environmental issues.

6.2. PLS-SEM analysis of aggregate data

The output from a Partial Least Squares Structural Equation Modeling (PLS-SEM) analysis provides insight into the relationships between firm-specific and country-specific factors and carbon emission reduction performance (CERP) in selected ASEAN countries. The following analysis of the results is based on the data provided (Table 3) using aggregate observations of 5 ASEAN countries (Indonesia, Malaysia, the Philippines, Singapore, and Thailand).

The impact of various factors explored in this study on a firm's ability to reduce carbon emissions is not uniform, with some factors having a more significant effect than others. However, a few key factors have been identified as playing a crucial role in the reduction of carbon emission performance. The CSR Strategy, in particular, has been found to have a strong and reliable relationship with carbon emission reduction performance (CERP), as evidenced by a high path coefficient of 0.426 and a highly significant t-statistic of 12.980. Additionally, Green Innovation and Product Responsibility, with path coefficients of 0.117 and 0.214, respectively, have both been found to have a positive impact on carbon emission reduction performance (CERP), with statistically significant p-values well below the 0.05 threshold. Although Corporate Governance has a relatively modest impact (path coefficient of 0.097) compared to other firm-specific factors, it still has a statistically significant effect on carbon emission reduction performance (CERP).

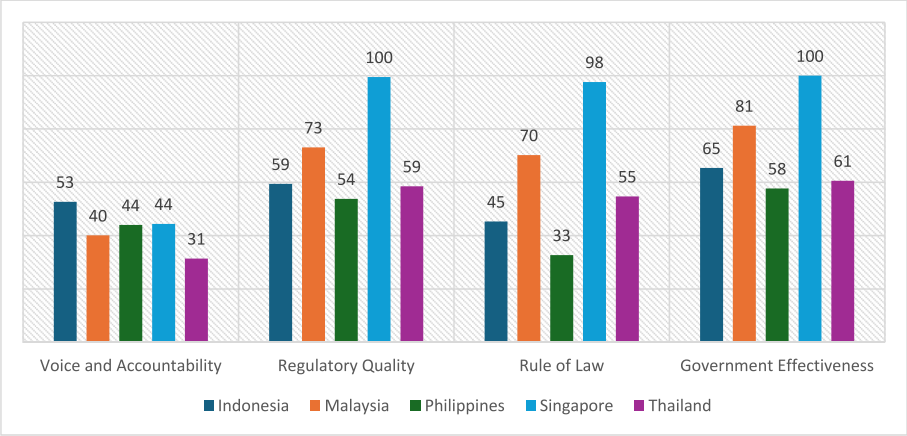

Fig. 2. Public Governance of five ASEAN countries.

Table 3
Summary of PLS-SEM output.

	Path Coefficient	Standard deviation	T statistics	P values	Confident Interval	
					2.5 %	97.5 %
CSR Strategy - > CERP	0.426	0.033	12.980	0.000	0.361	0.491
Green Innovation - > CERP	0.117	0.034	3.450	0.001	0.051	0.183
Corporate Governance - > CERP	0.097	0.035	2.810	0.005	0.029	0.165
Product Responsibility - > CERP	0.214	0.034	6.309	0.000	0.150	0.279
Regulatory Quality - > CERP	1.037	0.191	5.436	0.000	0.658	1.404
Rule of Law - > CERP	−0.065	0.280	0.232	0.817	−0.610	0.496
Voice and Accountability - > CERP	0.079	0.107	0.745	0.457	−0.130	0.293
Government Effectiveness - > CERP	−1.032	0.335	3.082	0.002	−1.721	−0.375
Total Observations	563					
R Square	0.427					

The research findings on the influence of country-specific factors on carbon emission reduction performance (CERP) are mixed. The study shows that Regulatory Quality has a significant positive impact on carbon emission reduction performance (CERP), with a high path coefficient of 1.037 and robust association. This indicates that countries with better regulatory systems tend to have higher levels of carbon emission reduction performance (CERP). On the other hand, Government Effectiveness has a notably negative influence on carbon emission reduction performance (CERP), with a path coefficient of −1.032 and a significant p-value. This means that countries with effective governments tend to have lower levels of carbon emission reduction performance (CERP). However, the impact of Voice and Accountability and Rule of Law on CERP is inconclusive. The study shows that their respective path coefficients of 0.079 and −0.065 do not denote statistical significance at conventional levels (p-values are 0.457 and 0.817, respectively). This suggests that more research is needed to determine the relationship between these factors and carbon emission reduction performance (CERP). Graphically, the output of the PLS-SEM analysis is shown in Fig. 3.

The reduction of carbon emissions in the ASEAN region is influenced by various factors, including firm-specific ones such as CSR strategy and Product Responsibility. These factors play a significant role in driving carbon emission reduction performance (CERP). Moreover, country-specific factors like Regulatory Quality and Government Effectiveness also have a crucial impact on promoting or

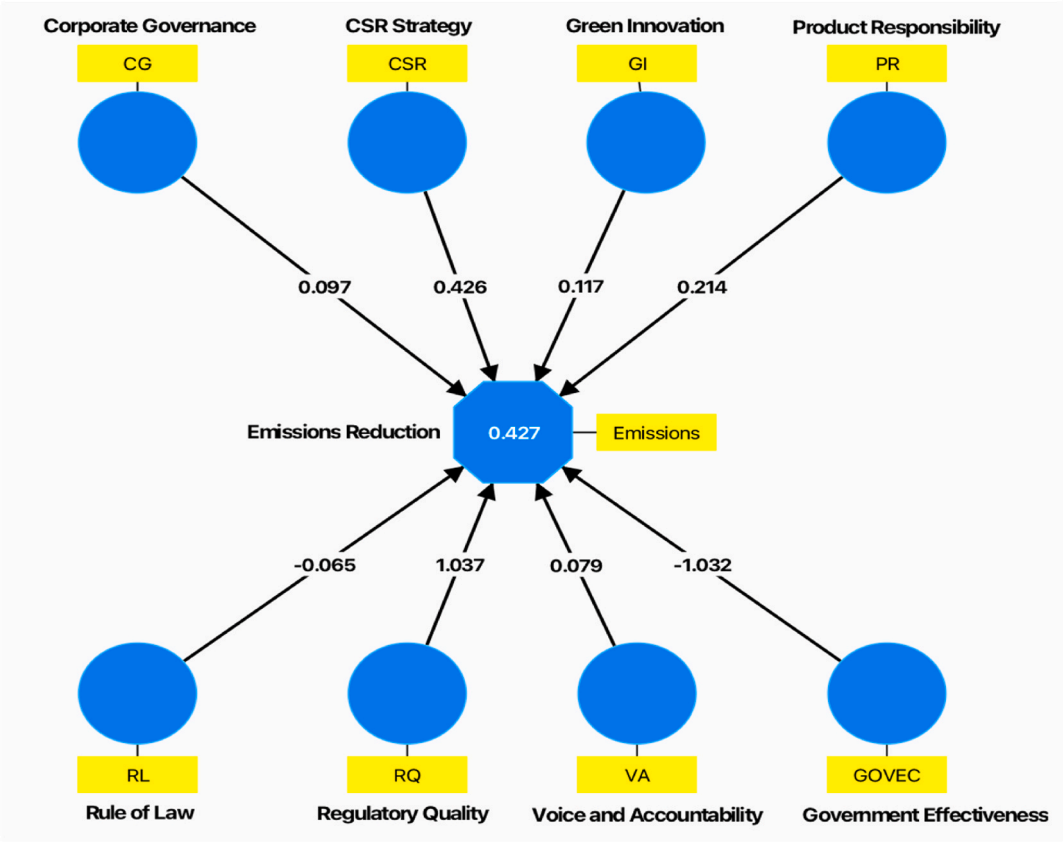

Fig. 3. SEM-PLS Graphical output.

hindering carbon emission reduction performance (CERP). Regulatory Quality is essential in promoting carbon emission reduction performance (CERP), while Government Effectiveness has an inverse relationship with carbon emission reduction performance (CERP), implying the need for potential policy interventions in this area. Interestingly, Voice and Accountability and Rule of Law do not have a clear-cut influence on carbon emission reduction performance (CERP), suggesting the need for further investigation into these areas. The model used to understand these factors explains 42.7 % of the variance in carbon emission reduction performance (CERP), signifying moderate explanatory power.

6.3. PLS-SEM analysis of the individual country

The provided data in Table 4 represents a country-wise breakdown of a PLS-SEM analysis examining firm specific factors influencing carbon emission reduction performance (CERP) in ASEAN countries. The analysis includes variables such as CSR Strategy, Green Innovation, Corporate Governance, and Product Responsibility. The model's goodness of fit is indicated by the R-square value, and the sample size for each country is represented by N.

Table 4 of the research report reveals valuable insights into the relationship between carbon emission reduction performance (CERP) and various firm-specific factors across five ASEAN countries, namely Indonesia, Malaysia, Philippines, Thailand, and Singapore. The study found that the impact of CSR Strategy varied significantly across the countries, with the exception of the Philippines, where no significant relationship was found. Similarly, the influence of Green Innovation was not consistent across the countries. Moreover, Corporate Governance and Product Responsibility displayed varying levels of influence, with Corporate Governance being particularly significant in the Philippines. The study suggests that these variations could be explained by country-specific factors such as economic, cultural, regulatory, or industrial factors. Additionally, the differences in sample sizes and R-square values highlight the need for a tailored approach to designing environmental policies and strategies that take into account the unique characteristics of each country. Overall, the research findings underscore the importance of understanding the country-specific factors that influence carbon emission reduction performance (CERP) and adopting a customized approach to environmental policies and strategies.

6.4. Effect size analysis

Effect size analysis is a statistical concept that measures the strength of the relationship between two variables beyond the simple determination of significance provided by p-values. Unlike significance tests that determine if an effect exists, effect size measures the magnitude of the effect. It is especially useful when comparing the practical impact of different variables. Table 5 summarizes the effect size firm and country-specific factors affecting carbon emission reduction performance (CERP) of five selected ASEAN countries.

The effect size of firm-specific factors was found to have a varied impact. It was observed that the CSR strategy had a moderate effect size (F Square = 0.26), falling within the threshold range of 0.15–0.35. This suggests that CSR strategy is a relatively influential factor in affecting carbon emission reduction performance (CERP). On the other hand, Green Innovation, Corporate Governance, and Product Responsibility each showed a weak effect size (F Square = 0.02, 0.02, and 0.07, respectively), all falling within the threshold range of 0.02–0.15. This indicates that although these factors are present, they contribute minimally to the variance in carbon emission

Table 4
The output of PLS-SEM on the Firm's specific factors.

Malaysia (R square = 0.477, N = 258)	Coefficient	Standard deviation	T statistics	P values
CSR Strategy - > CERP	0.550	0.042	13.001	0.000
Green Innovation - > CERP	0.122	0.048	2.535	0.011
Corporate Governance - > CERP	0.068	0.051	1.328	0.184
Product Responsibility - > CERP	0.176	0.047	3.72	0.000
Indonesia (R square = 0.358, N = 68)				
CSR Strategy - > CERP	0.239	0.094	2.544	0.011
Green Innovation - > CERP	0.102	0.109	0.938	0.348
Corporate Governance - > CERP	0.159	0.111	1.432	0.152
Product Responsibility - > CERP	0.348	0.113	3.09	0.002
Thailand (R square = 0.408, N = 130)				
CSR Strategy - > CERP	0.477	0.075	6.349	0.000
Green Innovation - > CERP	0.091	0.071	1.277	0.202
Corporate Governance - > CERP	0.041	0.079	0.521	0.602
Product Responsibility - > CERP	0.254	0.072	3.554	0.000
Philippines (R square = 0.399, N = 34)				
CSR Strategy - > CERP	−0.109	0.216	0.508	0.612
Green Innovation - > CERP	0.082	0.144	0.569	0.569
Corporate Governance - > CERP	0.648	0.174	3.714	0.000
Product Responsibility - > CERP	0.172	0.127	1.356	0.175
Singapore (R square = 0.194, N = 73)				
CSR Strategy - > CERP	0.201	0.131	1.529	0.126
Green Innovation - > CERP	0.160	0.119	1.343	0.179
Corporate Governance - > CERP	0.203	0.095	2.135	0.033
Product Responsibility - > CERP	0.202	0.112	1.809	0.070

Table 5
Summary of effect size analysis.

	F Square	Cohen F Square Range	Effect Size
CSR Strategy - > CERP	0.26	0.15–0.35	Moderate
Green Innovation - > CERP	0.02	0.02–0.15	Weak
Corporate Governance - > CERP	0.02	0.02–0.15	Weak
Product Responsibility - > CERP	0.07	0.02–0.15	Weak
Regulatory Quality - > CERP	0.06	0.02–0.15	Weak
Rule of Law - > CERP	0.00	<0.02	No Effect
Voice and Accountability - > CERP	0.00	<0.02	No Effect
Government Effectiveness - > CERP	0.02	0.02–0.15	Weak

reduction performance (CERP) among the firms within these ASEAN countries.

Regarding country-specific factors, the results convey a predominantly weak impact on carbon emission reduction performance (CERP). Regulatory Quality, with an F Square of 0.06, and Government Effectiveness, with an F Square of 0.02, both exhibit weak effect sizes, encapsulated within the threshold range of 0.02–0.15. These findings suggest a marginal influence on the firms' carbon emission reduction performance (CERP). Notably, the Rule of Law and Voice and Accountability factors have an F Square of 0.00, which is below the threshold of 0.02, indicating no effect on carbon emission reduction performance (CERP). This underlines that within the context of the ASEAN countries studied, these country-specific factors do not significantly contribute to the firms' abilities to reduce carbon emissions.

7. Discussion

The relationship between Corporate Social Responsibility (CSR) Strategy and Carbon Emission Reduction Performance (CERP) is a strong and reliable one. This is due to the evolving nature of CSR, which has increasingly integrated environmental sustainability as a core component. The finding in this study is in line with previous studies such as conducted by Dhanda and Malik [108], Issa [109], Tang, Cao [110] and Meng, Zang [111]. Firms that adopt effective carbon management strategies within their CSR policies are more likely to disclose information about their emissions and engage in carbon reduction initiatives, leading to enhanced financial performance [108]. Empirical analysis showed that carbon reduction initiatives are positively associated with financial performance in firms, especially after the Paris Agreement, suggesting a strong relationship between CSR strategies focused on emission reduction and corporate performance [109]. Studies indicate that CSR can significantly enhance corporate carbon performance, with internal and external factors like corporate governance and internationalization affecting the strength of this relationship [111]. Research on companies in China found that efforts in carbon emission reduction enhance both corporate operational and financial performance, affirming the beneficial role of CSR in promoting environmental and fiscal health [110]. The adoption of CSR strategies that focus on reducing carbon footprints, improving energy efficiency, and promoting sustainable resource usage not only enhances a firm's reputation but also drives operational efficiencies that reduce costs and improve compliance with global environmental standards [110]. This linkage suggests that companies that proactively engage in comprehensive CSR activities are likely to see substantial improvements in their environmental outcomes. This supports the notion that environmental responsibility is a strategic asset rather than a compliance obligation and can bring significant benefits to a company's reputation and bottom line [112,113].

Findings in this study indicate that Green Innovation is a vital aspect of a company's environmental strategy, and it has a significant but modest impact on Carbon Emission Reduction Performance (CERP). Research has demonstrated that green innovation has a positive impact on CERP, though the magnitude of this impact can vary. For instance, in China, green innovations significantly improve Carbon Emission Reduction Performance (CERP), with certain types of innovations like green technology having a notable impact in specific regions and sectors [114]. Similarly, studies have shown that green technology innovations significantly reduce CO2 emissions, especially in economically developed areas or those with high environmental management inputs [115]. While green innovations generally support carbon emission reduction, the extent of their impact can be modest and highly dependent on other factors such as regional economic conditions, the level of industrialization, and existing environmental policies. For example, green innovations in low-income regions or sectors with less strict environmental regulations may have a lesser impact compared to high-income areas or heavily regulated sectors [116]. The effectiveness of green innovations can also be sector-specific. For instance, in the construction sector, green innovations have shown a substantial positive effect on reducing carbon emissions influenced by environmental regulation intensity [117].

Product Responsibility is a critical aspect of a firm's environmental sustainability efforts. It involves managing a company's products throughout their lifecycle, from design to disposal, with the aim of reducing their environmental impact. A significant path coefficient in this study suggests that firms that prioritize sustainable product design, use eco-friendly materials, and implement recycling or upcycling processes can significantly improve their Carbon Emission Reduction Performance (CERP). The findings in this study support previous studies, such as those by Bi and Liu [118], He and Yu [119], and Cicconi [120]. Employing eco-design principles during the product life cycle helps to reduce products' negative environmental impacts and promotes recycling and material reusability, which, in turn, supports lower carbon emissions [118]. Innovative eco-design approaches, like using weighted edge-coloured graphs for product low-carbon design, significantly reduce carbon footprint across the product's lifecycle [119]. Collaborative and interactive eco-design frameworks that engage multiple stakeholders (designers, manufacturers, suppliers) in evaluating secondary raw materials and sustainable processes also contribute to reducing carbon emissions [120]. Companies that

invest in sustainable practices can achieve a competitive advantage by enhancing their environmental performance while meeting the needs of their customers. The concept of the circular economy is at the core of this approach, emphasizing the importance of resource efficiency and waste reduction as key drivers of environmental sustainability. By adopting a circular economy approach, firms can create a more sustainable future by minimizing their environmental footprint and conserving natural resources.

Corporate Governance plays an essential role in enforcing environmental policies and practices within firms. Although the impact of Carbon Emission Reduction Performance (CERP) is relatively modest, its significance cannot be ignored. Effective governance mechanisms, such as the role of boards in overseeing environmental strategies, integration of sustainability into risk management processes, and transparent reporting practices on environmental performance, are fundamental to ensuring environmental responsibility. Governance acts as a facilitator for embedding sustainability in the strategic decision-making process, making it an integral part of the company's culture and values. The studies by Elsayih, Datt [121] and Wahyuni, Ulum [122] highlight the importance of Corporate Governance in promoting environmental responsibility. The presence of an environmental committee and higher board independence are associated with enhanced Carbon Emissions Reduction Performance (CERP) in firms [121]. Good corporate governance, particularly aspects such as the board of directors and audit committee, significantly affect the disclosure of carbon emissions [122].

The strong positive impact of Regulatory Quality on Carbon Emissions Reduction Performance (CERP) underscores the critical role of having coherent and effective regulatory frameworks in environmental management. The study suggests that high-quality regulations not only set clear standards and goals for reducing emissions but also create incentives for innovation and compliance through mechanisms such as taxes, subsidies, and credits. In other words, governments that develop and enforce stringent environmental regulations can significantly drive improvements in national Carbon Emissions Reduction Performance (CERP). This highlights the importance of policy clarity and enforcement in environmental governance, as they can influence the behavior of businesses and individuals toward a more sustainable future [123]. These findings are in line with previous studies such as by Neves, Marques [20], Khanna, Deltas [124], Anton, Deltas [125]. Regulatory quality contributes to reducing CO2 emissions, demonstrating the effectiveness of such regulations in environmental management [20]. Regulatory pressures, including anticipated regulations, promote the adoption of pollution prevention technologies, which can lead to significant reductions in emissions [124]. The effect of environmental self-regulation is also evident, where higher quality environmental management systems lead to lower toxic emissions and improved overall environmental performance [125].

The studies highlight the significance of the effectiveness of the government in achieving environmental objectives and improving the Carbon Emissions Reduction Performance (CERP). It suggests that bureaucratic inefficiency and corruption can have a detrimental effect on environmental outcomes, indicating that ineffective government structures can cause poor implementation of environmental policies, delays in enforcing regulations, and a lack of support for sustainable practices. Therefore, the study emphasizes the need to enhance governmental transparency, accountability, and efficiency to support environmental objectives and improve CERP. By doing so, it is possible to ensure that environmental policies are implemented effectively, regulations are enforced efficiently, and sustainable practices are supported, leading to positive environmental outcomes. The findings in this study are inline with previous studies such as by Chen and Lin [126], Yang, Liao [127], and Sun, Gao [128]. A study highlighted that government-implemented carbon emissions trading schemes effectively improve carbon and energy performance, emphasizing the critical role of government in pursuing carbon neutrality goals [126]. Research on China's local governments found that competition among them for setting ambitious emission reduction goals, though it might slightly hinder economic growth in the short term, significantly improves environmental performance [127]. A differential game model demonstrated that government-enterprise cooperation in emission reduction under carbon trading policies could significantly enhance enterprise efficiency in reducing emissions, suggesting an effective synergy between governmental and corporate efforts [128].

The study's results indicate that the impact of Voice, accountability, and Rule of Law on environmental performance is not clear-cut. While these governance factors are generally expected to promote transparency and adherence to environmental regulations, the non-significant path coefficients suggest that other variables, such as cultural, economic, or political contexts, may have a mediating influence. Fredriksson and Mani [129] explored the dual effects of the rule of law on environmental policy. They argue that while an increase in the rule of law can make policy implementation more stringent, it also potentially increases industry efforts to influence policies through corruption, highlighting the contextual influence of corruption on environmental outcomes. Kramarz and Park [130] discuss the paradox where increased accountability mechanisms have not necessarily translated into better environmental outcomes. They suggest that biases in how environmental goals are set and what is monitored may dilute the effectiveness of accountability mechanisms. Chen [92] discusses the interplay between economic growth, the rule of law, and environmental policy stringency, showing how political and economic contexts can significantly alter the effectiveness of the rule of law in environmental governance. This indicates that the relationship between governance factors and environmental performance is complex and requires further examination. The findings highlight the need to investigate the role of democratic processes and legal structures in environmental policies and practices across different national settings. By doing so, we can better understand how governance factors interact with other contextual factors to influence environmental performance.

8. Policy implications

The reduction of carbon emissions is influenced in different ways by factors specific to each country. Therefore, it is crucial to thoroughly examine how effectively policies are being put into action and enforced. Even the most thoughtfully crafted environmental regulations can fall short if they are not properly carried out. Successful policy implementation hinges on the coordination of various government agencies, the provision of adequate resources, and the establishment of clear guidelines for enforcement. Without these

components, policies may exist only in theory, failing to achieve their intended impact in practice.

Ensuring consistent enforcement of environmental regulations is crucial for effectively reducing harmful emissions into the atmosphere. This encompasses regular monitoring, thorough inspections, and the implementation of penalties for non-compliance. Inadequate enforcement can result in a lack of accountability and compromise the efforts of dedicated companies striving to minimize their carbon footprint. Strengthening enforcement mechanisms guarantees that all companies adhere to the same rigorous standards and actively contribute to achieving national emission reduction targets.

To maximize the impact of efforts to reduce emissions, it is crucial for policymakers in ASEAN countries to prioritize the establishment and enforcement of robust implementation mechanisms. It is imperative for policymakers to develop comprehensive environmental regulations that specifically address the challenges posed by carbon emissions. These regulations should be grounded in scientific evidence and informed by best practices derived from experiences in other regions. By providing clear and detailed guidelines, policymakers can effectively aid companies in comprehending their obligations and taking the necessary steps to curtail emissions.

It is essential to prioritize the strengthening of the operational and administrative capacities of regulatory bodies responsible for upholding environmental regulations. This involves implementing tailored training programs to equip personnel with the necessary expertise in environmental law, compliance monitoring, and enforcement procedures. Additionally, providing sufficient resources, such as modern technologies and equipment, is critical to bolstering their ability to effectively monitor and regulate environmental activities. Ongoing support and mentoring for regulatory agencies, including regular performance evaluations and skill development opportunities, are necessary to ensure sustained efficiency and effectiveness in implementing environmental policies.

The study highlights the importance of both company-specific and country-specific factors in driving carbon emission reduction performance. While internal corporate practices play a significant role, the broader regulatory and governance context cannot be overlooked. A focused effort on improving policy implementation and enforcement will be crucial in ensuring that environmental regulations result in measurable emission reductions. As ASEAN countries continue to tackle climate change challenges, understanding and enhancing these determinants will be key to their success. Effective strategies must take into account the complex interaction between corporate initiatives and the regulatory environment to promote a sustainable future.

9. Limitations

The study on carbon emission reduction performance across ASEAN countries is a significant research effort that aims to provide insights into the performance of different countries in reducing carbon emissions. The study, while valuable, is limited by a number of factors that may influence the generalizability and accuracy of its results. One of the most notable limitations is the variability in effect sizes of factors such as CSR Strategy, Green Innovation, Corporate Governance, and Product Responsibility. This variability can be attributed to the different cultural, regulatory, and economic conditions across the region, which can affect the applicability of the findings to other regions. Additionally, differences in sample sizes and R-square values between countries can impact the statistical power of the study, potentially skewing the results and undermining their reliability. Overall, the study provides useful insights into the factors that influence carbon emission reduction performance, but it is important to take into account its limitations when interpreting the results.

When conducting research on topics such as corporate social responsibility, innovation, and corporate governance, it is crucial to be aware of certain limitations in how these variables are measured. Standard measures may not be able to capture the full range of nuances across different contexts, which means that more comprehensive and contextually relevant measures are required. Moreover, when it comes to public governance factors like the Rule of Law and Voice and Accountability, it is essential to consider whether these dimensions are being measured accurately. If they are not, it may be hard to comprehend their real impact on corporate environmental performance. Finally, when conducting studies that rely on cross-sectional data, it is essential to acknowledge the limitations of this approach. Without longitudinal data, it may be difficult to draw causal inferences between various variables and outcomes. Overall, it is important to be mindful of these limitations and to use the most appropriate methods when conducting research in this area.

To enhance the rigor of the methodology, various diagnostic tests should be incorporated. These include multicollinearity tests to ensure the independence of predictors, outlier and leverage diagnostics to identify and address influential data points, model fit diagnostics such as the standardized root mean square residual (SRMR) to evaluate how well the model fits the data, and predictive relevance diagnostics like the Stone-Geisser Q^2 test to assess the model's predictive power. Acknowledging these omissions, the research methodology lacks comprehensive diagnostic testing, which may impact the robustness and reliability of the findings. Future research should incorporate these tests to strengthen the methodological framework and ensure more reliable and valid results.

10. Future research directions

Despite some limitations, there are practical suggestions that can significantly enhance the quality of future research and the implementation of policies. It is crucial for policymakers to take into account the unique and diverse characteristics of each ASEAN country and tailor environmental regulations and corporate social responsibility initiatives accordingly. To achieve this, it is recommended to develop localized policy-making and enforcement mechanisms that can be effectively implemented in each country. In addition, establishing collaborative frameworks can greatly facilitate the sharing of best practices and technologies among countries that are facing similar environmental challenges. This can enable the region to develop more effective strategies for reducing carbon emissions, leading to a cleaner and more sustainable environment. By working together and sharing knowledge, ASEAN countries can make a significant contribution to global efforts to combat climate change.

In order to gain a deeper understanding of carbon emission reduction performance, it is crucial to conduct longitudinal studies that track the effects of specific factors over time. By doing so, we can identify causal relationships and gain a comprehensive understanding of how carbon emission reduction performance is affected by different variables. Moreover, it is important to develop and validate measurement tools that accurately reflect key constructs across different cultural contexts to ensure the accuracy of future studies. Furthermore, we need to explore the aspects of policy implementation and enforcement that most effectively enhance carbon emission reduction performance. This could lead to targeted interventions that address barriers to effective environmental governance. By addressing these issues, we can provide clearer guidance for enhancing carbon emission reduction strategies not only in ASEAN but globally. By conducting these studies, we can gain a better understanding of how to effectively reduce carbon emissions and create a more sustainable future for our planet.

11. Conclusion

The findings of this study provide a detailed insight into the complex and multifaceted dynamics involved in reducing carbon emissions within the ASEAN region. The study highlights the crucial roles played by firm-specific factors such as CSR strategy and Green Innovation, thereby stressing the need for companies to integrate environmental considerations into their core strategies. Moreover, the study reveals that regulatory quality at the country level has a significant impact on the success of carbon emissions reduction efforts, underscoring the importance of robust regulatory frameworks in creating an environment conducive to achieving high levels of Carbon Emission Reduction Performance. On the other hand, the negative impact of Government Effectiveness on Carbon Emission Reduction Performance raises critical questions about the role of government operations in supporting or obstructing environmental initiatives. Overall, this study provides a comprehensive analysis of the various factors that influence environmental performance in the region, which could help policymakers and stakeholders develop targeted interventions and policies aimed at enhancing Carbon Emission Reduction Performance.

The research conducted across various countries in the ASEAN region suggests that the effect of CSR strategy, green innovation, corporate governance, and product responsibility on Carbon Emission Reduction Performance is influenced by different factors in each country. This indicates that a customized approach to environmental policy and corporate strategy is essential to ensure optimal results. The study highlights that one-size-fits-all policies have limitations, given the diverse economic, cultural, and regulatory landscapes in the region. Furthermore, the differences in sample sizes and R-square values across studies emphasize the need to adapt models of environmental performance to reflect the specific contexts and conditions of each country. In conclusion, this research emphasizes the importance of adopting a tailored approach for effective environmental policy and corporate strategy in the ASEAN region.

The analysis puts forth that policymakers and business leaders in ASEAN countries need to take a close look at the variations in local conditions, ecosystems, and economies while developing and implementing their strategies for reducing carbon emissions. The policies designed for carbon emission reduction should be well-suited to the unique needs of each region and must be aligned with global environmental goals. These tailored policies have the potential to be more effective in enhancing Carbon Emission Reduction Performance regionally. Additionally, collaborative efforts among ASEAN countries could facilitate the exchange of knowledge, best practices, and technologies that are tailored to specific local contexts, thus fostering a more cohesive regional approach to environmental sustainability. Such a concerted effort can help accelerate the progress toward achieving the goals of the Paris Agreement and other international accords.

The research has discovered that the implementation of carbon emission reduction practices is influenced by the specific strategies adopted by companies and the regulatory frameworks of a country. However, these factors alone may not be sufficient to drive significant change. Therefore, it is imperative to adopt an integrated approach that combines initiatives at the firm level and robust, enforceable, and incentivized policies at the country level. The variations in the effectiveness of different factors across various countries highlight the importance of designing context-specific strategies that take into account the unique economic, cultural, and regulatory contexts of each country. Furthermore, the study recommends researchers investigate why certain factors are less effective and identify supplementary strategies that can be employed to enhance their impact on carbon emission reduction performance.

Data availability

Data is available upon request.

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CRediT authorship contribution statement

Sofik Handoyo: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation. **Ivan Yudianto:** Writing – review & editing, Writing – original draft, Visualization, Validation, Formal analysis, Data curation, Conceptualization. **Muhammad Dahlan:** Writing – review & editing, Writing – original draft, Visualization, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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