Article Type: Research Paper

Management accounting practice in climate change era: Lesson learned from sensitive industries

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Abstract

Research aims: This study examines the implementation of carbon management accounting practices within six climate-sensitive industries in Indonesia.

Design/Methodology/Approach: Employing content analysis and K-means clustering by sector and year, this research investigates 198 firm-years covering the period from 2016 to 2022.

Research findings: The findings reveal three distinct clusters that illustrate variations in corporate behavior concerning the adoption of carbon management accounting practices. These discrepancies are attributable to divergent corporate perceptions of risks, opportunities, and stakeholder expectations related to climate change. Furthermore, the study delineates three phases that reflect the progression of carbon management accounting in Indonesia.

Theoretical contribution/ Originality: This research offers valuable insights for effectively addressing the risks and opportunities associated with climate change. This research brings a fresh perspective by examining how companies adapt and transform their management accounting practices to address the risks posed by climate change.

Practitioner/Policy implication: The findings indicate that as climate change regulations become clearer, including sanctions and incentives, companies become more proactive in implementing carbon management accounting. Conversely, when environmental regulations lack clarity or are less stringent, companies tend to deviate, prioritizing economic performance over environmental performance.

Keywords: Carbon Management Accounting; Carbon Management Strategy; Cluster Analysis; Sensitive Industries

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DOI: 10.18196/jai.v26i2.25627

CITATION:
Kawulur, H. R. (2025). Management accounting practice in climate change era: Lesson learned from sensitive industries. *Journal of Accounting and Investment, 26*(2), 460.480.

ARTICLE HISTORY
Received:
21 Jan 2025
Revised:
19 Feb 2025
06 Apr 2025
Accepted:
20 May 2025

JAI Website:

Introduction

In the face of growing concerns over climate change risk and opportunities, corporations are increasingly under pressure to address their sustainability performance and implement effective management accounting practice (S. Y. Lee, 2012). This pressure comes from a variety of stakeholders, including primary stakeholders such as investors, customers, and employees, as well as secondary stakeholders like non-governmental organizations, activist groups, and governments (Cadez et al., 2019). Governments and society demand that companies behave more responsibly toward the environment.

Meanwhile, corporations face market challenges as climate change drives investors to include environmental performance indicators as key investment criteria. Additionally, consumer preferences have become more dynamic, favoring eco-friendly products. Consequently, the pressures and challenges posed by the climate change era necessitate business transformations to maintain corporate performance.

The literature has acknowledged management accounting as a strategic formulation to overcome business risk. Management accounting In the era of climate change, management accounting provides direction to strategic decision-making processes and improves management practices (Schaltegger et al., 2016). Therefore, effective carbon management practice has become a critical component of corporate social responsibility and boosting company performance (Damert et al., 2017). Addressing carbon management practices not only helps mitigate the environmental impact of business operations, but it can also enhance a company's reputation, attract environmentally-conscious consumers and investors, and improve employee morale and retention (Fawzy et al., 2020). By proactively managing their carbon footprint, corporations can demonstrate their commitment to sustainability and position themselves as an agent of change in this climate risk era (Zhang et al., 2019). Furthermore, the effectiveness of corporate carbon management practices can improve short-term and long-term financial performance (Bui et al., 2022; Damert et al., 2017; Le, 2022). Practically, the success of corporate carbon management accounting practices will depend on the company's ability to meaningfully address stakeholder concerns, demonstrate tangible emissions reductions, and align with broader societal expectations for environmental sustainability. While many companies have made commitments to improve their carbon performance, the quality of their carbon management accounting practices remain a concern due to green washing critique (Cao et al., 2022; Mateo-Márquez et al., 2022).

Existing environmental management accounting research suggests that the extent of corporate carbon management practice remains of concern. Carbon management accounting at the corporate level encompasses a broad concept that includes the calculation, reporting, and strategic formulation for emission reduction within companies (Qian & Schaltegger, 2017; Stechemesser & Guenther, 2012a). Over the years, research in this area has evolved through several approaches. First, scholars have sought to identify accurate measurement methods to determine a company’s total emissions (Li et al., 2023; Zhou et al., 2018). It involves integrating the concept of eco-efficiency, linking emissions to market-based elements such as profit. By comparing emissions with profit, researchers aim to capture the efficiency between environmental and economic dimensions (Luo & Tang, 2020). Furthermore, life cycle analysis has been employed to enhance the precision of emission calculations across different levels of the organization (Yuan et al., 2024). In parallel, other researchers have combined carbon accounting mechanisms with lean carbon management practices to improve both the accuracy of emissions calculations and overall emissions management (Yu et al., 2023).

Second, more attention has also been directed toward the disclosure of environmental dimensions in corporate annual and sustainability reports (Cao et al., 2022; Linares - Rodríguez et al., 2022; Luo et al., 2022; Siddique et al., 2021). This line of research

investigates key drivers of environmental disclosure and its impact on firm performance. The ultimate goal is to help companies shape a greener image, attract investors, and demonstrate ethical behavior to stakeholders. However, these two streams of research, "calculation and reporting," have faced criticism. Some scholars argue that measurement and disclosure alone do not necessarily contribute to actual emissions reductions (Cao et al., 2022; Guo et al., 2020; Xu et al., 2023).

It has led to a third focal point in carbon management accounting, which is the implementation of emission reduction strategies. On the one hand, although still limited in number, there have been studies offering concepts and best practices related to corporate responses to climate change risks. For instance, Cadez and Czerny, (2016) evaluated nineteen emission mitigation practices among 158 large European companies, offering valuable insights into strategy implementation. Similarly, Yuan et al. (2024) utilized carbon footprint accounting to identify emission-generating activities within firms, thereby encouraging the adoption of targeted mitigation practices. Schmidt and Laner (2025) further assessed the effectiveness of mitigation strategies in reducing corporate carbon emissions. On the other hand, prior research often overlooks the heterogeneity of company characteristics—such as industry sensitivity, developing country area, levels of environmental risk, environmental regulations, and stakeholder pressure. This gap has left corporate responses to climate risks limited and remains poorly understood (Fawzy et al., 2020).

This research is motivated by the need to understand how corporations navigate and respond to stakeholder pressures regarding carbon management practices in polluting sectors. It includes examining strategic decisions within industries characterized by substantial environmental impacts, as well as evaluating the efficacy of current corporate carbon management frameworks, and investigating the different types of carbon management practice in terms of company industrial characteristics and business risk. Accordingly, this study focuses on the research question regarding the characteristics of carbon management accounting practices in Indonesian companies, based on clusters, sectors, and their development over time.

Furthermore, this study aims to examine the implementation of carbon management accounting practices across the six highest-emission sectors in Indonesia. It seeks to provide a comprehensive overview of the development of carbon management accounting practices over different periods, considering business risks and regulatory stringency. More specifically, the research clusters companies based on their mitigation strategies/practices, followed by cluster analyses by industry and year.

This study offers several contributions: First, it provides a comprehensive overview of the development of sustainable business practices across emission-sensitive sectors in response to climate change risks. Second, it evaluates the extent to which industries support Indonesia's Net Zero Emissions vision for 2060 and identifies improvements needed to advance low-emission practices. Third, for academics and practitioners, the findings offer valuable insights into how companies respond to climate change risks while maintaining business continuity.

Literature Review

Accounting Management Practice in responding to climate change

In the era of climate change, management accounting practices focus on measuring, reducing, and reporting carbon emissions to support better decision-making, often referred to as carbon management accounting (Qian & Schaltegger, 2017; Ratmono et al., 2021; Stechemesser & Guenther, 2012a). This concept emphasizes the processes of managing carbon emissions through systems capable of calculating emissions, implementing strategic measures to manage those emissions, and reporting them in ways that provide reliable information to stakeholders (Stechemesser & Guenther, 2012a).

Stechemesser and Guenther (2012b) and Schaltegger et al. (2016) argue that although research on carbon accounting remains limited, it generally revolves around three main streams. The first stream focuses on carbon accounting at the national scale. In this context, carbon accounting concentrates on calculating emissions within a country, emissions consumption by the population, and related emission reduction processes (Schmidt & Laner, 2025; Waterworth & Richards, 2008; Zhou et al., 2018). Scholars in this area develop methodologies for accurate emission calculations and design national emission reduction strategies, such as utilizing input-output emission analysis (Dong et al., 2022). A subsequent phase in national-scale carbon accounting involves comparing emissions between developed and developing countries, as well as adapting carbon strategies in developed nations and designing better emission management policies (Grover et al., 2023).

The second stream addresses carbon accounting at the project level. Here, the focus shifts to calculating emissions within emission-reduction projects. Researchers examine the types of emissions to include in carbon accounting and assess both monetary aspects by comparing the costs and profits of emission-generating activities, as well as non-monetary aspects by measuring the potential emission reductions achieved through mitigation strategies (Yu et al., 2023; Yuan et al., 2024).

The third stream is carbon accounting at the corporate level, which includes methods for calculating, reporting emissions, and implementing initiatives for emission reduction (Bui, 2017; Cadez & Czerny, 2016). A lack of methodologies for accurate emission calculations marked the early stages of corporate carbon accounting. Researchers developed their calculation methods, integrating both monetary and non-monetary factors of emissions (Hoffmann & Busch, 2008). As research progressed, scholars began to focus on reporting emissions (Alsaifi, 2021; Firmansyah et al., 2022; Freedman & Jaggi, 2005; He et al., 2013; Lewis et al., 2013; Liao et al., 2015; Luo et al., 2013; Qian & Chen, 2021). Once emissions can be calculated, effective communication tools are necessary to convey the company's environmental performance. As a result, researchers have worked on establishing unique and structured emission disclosure standards, and several global organizations have aimed to create universal global disclosure standards.

The final phase focuses on emission reduction strategies and their impact on corporate sustainability performance (Bui & Nurul, 2022; Du et al., 2025; Haque & Ntim, 2022; Lee & Lee, 2022; Lee & Min, 2015; Luo & Tang, 2020; Oyewo, 2023; Shi et al., 2022; Wang & Gao, 2024). In this phase, researchers design, evaluate, and analyze strategic steps and their effects on the economic, environmental, and social dimensions, as well as the supporting factors that enable companies to adopt greener practices.

Accordingly, this research focuses on another key element of carbon management accounting: corporate carbon management strategy, which encompasses the practices companies adopt to address climate change demands from stakeholders. Drawing upon the stakeholder theory, this study aims to elucidate the diverse corporate responses in the implementation of carbon management accounting practices. Stakeholder theory posits that a firm's success is fundamentally contingent upon its ability to address and fulfill the interests of its stakeholders (Freeman, 1984). As stakeholder priorities increasingly shift from traditional financial indicators toward non-financial concerns such as carbon emissions, corporate objectives have likewise evolved to encompass not only economic performance but also environmental responsibility (Hörisch et al., 2014). In this context, stakeholder theory suggests that, within the broader discourse on climate change, firms are likely to modify their management accounting practices by adopting carbon management strategies that align with stakeholder expectations, thereby fostering a favorable corporate image (Cadez et al., 2019).

In this research, corporate carbon management strategy refers to a set of actions undertaken by companies in response to climate change, often described as carbon management practices (Kolk & Pinkse, 2004). These actions involve continuous efforts by organizations to manage carbon emissions (Weinhofer & Hoffmann, 2010) and encompass a range of complex activities aimed at reducing the environmental impact of business operations while creating competitive advantages (Damert et al., 2017). Despite many perspectives, the common theme of carbon management strategy lies in the practical measures companies take to manage their carbon emissions effectively.

Carbon management strategies are multifaceted and encompass different objectives. According to Weinhofer and Hoffmann (2010), these strategies can be categorized into three types of activities: carbon offsetting, carbon reduction, and carbon independence. Carbon offsetting addresses the short-term impacts of climate change. It involves actions taken by companies to balance their carbon emissions through carbon trading or emission reduction projects (Jia & Lin, 2020; Weng & Xu, 2018; Zhao et al., 2017). This approach is often employed to mitigate immediate environmental concerns and maintain stakeholder trust. Carbon reduction reflects long-term goals for mitigating climate change. It involves activities related to transforming processes and products to achieve lower carbon emissions (Dangelico & Pujari, 2010; García-Granero et al., 2018; Jiang et al., 2020). These efforts aim to align corporate operations with sustainable development goals and reduce the overall carbon footprint of business practices. Carbon independence goes beyond addressing climate change; it also aims to enhance overall corporate performance (Chen & Ma, 2021; Khalil & Nimmanunta, 2021). Companies can achieve this by implementing business transformation initiatives that ensure resource supply independence, such as

investing in renewable energy sources (Fan et al., 2022; Jiang et al., 2022; Li et al., 2021). This approach not only supports environmental goals but also builds resilience in corporate operations. The integration of these strategic dimensions underscores the importance of tailored and holistic approaches to carbon management accounting practice. Companies must balance short-term and long-term objectives while aligning their strategies with stakeholder expectations and regulatory frameworks.

Research Method

This study analyzes management accounting practices within industries that significantly impact emissions development in Indonesia. The classification of sensitive industries is based on data released by the Ministry of Environment and Forestry, which includes the energy, transportation, raw materials, industrial, infrastructure, and agricultural sectors that are listed in the Indonesia Stock Exchange (IDX). This research adopts a longer observation period, from 2016 to 2022, to provide a comprehensive understanding of carbon strategy development in Indonesia. The sampling technique used in this study is purposive sampling. Companies included in the sample are required to report sustainability reports and explicitly identify emissions as a material issue within their reports. Based on these criteria, the study includes 198 firm-year observations. Table 1 records the purposive sampling criteria.

Table 1 Sample Selection Criteria

Sampling Criteria	2016	2017	2018	2019	2020	2021	2022	Firm-Year
Energy, transportation, basic materials, industrials, infrastructure, and agriculture companies listed in IDX	230	247	271	291	306	330	348	2023
Companies without access to sustainability and annual reports	(86)	(94)	(104)	(112)	(115)	(124)	(136)	(771)
Companies without emissions as a material issue	(137)	(144)	(155)	(156)	(157)	(150)	(155)	(1054)
Total observations	7	9	12	23	37	56	57	198

Based on Figure 1, the study involves several stages to evaluate corporate management accounting practices. First, by using content analysis, it utilizes the carbon management strategy indicators proposed by Weinhofer & Hoffmann, (2010) to assess the extent to which industries have implemented emissions management activities to mitigate risks associated with climate change. Weinhofer and Hoffmann, (2010) identify several mechanisms for emissions management activities: offsetting through carbon trading or

carbon reduction projects, reducing emissions through environmentally friendly processes and products, and achieving carbon independence by disengaging from emission-producing energy sources through zero-emission processes and products. These emissions management activities are evaluated through a content analysis of each company's sustainability report. Each disclosed emission management indicator is scored as 1, while the absence of disclosure is scored as 0. The study adheres to best practices in emissions management outlined by Cadez and Czerny (2016) and Fawzy et al. (2020) as a guide for the content analysis.

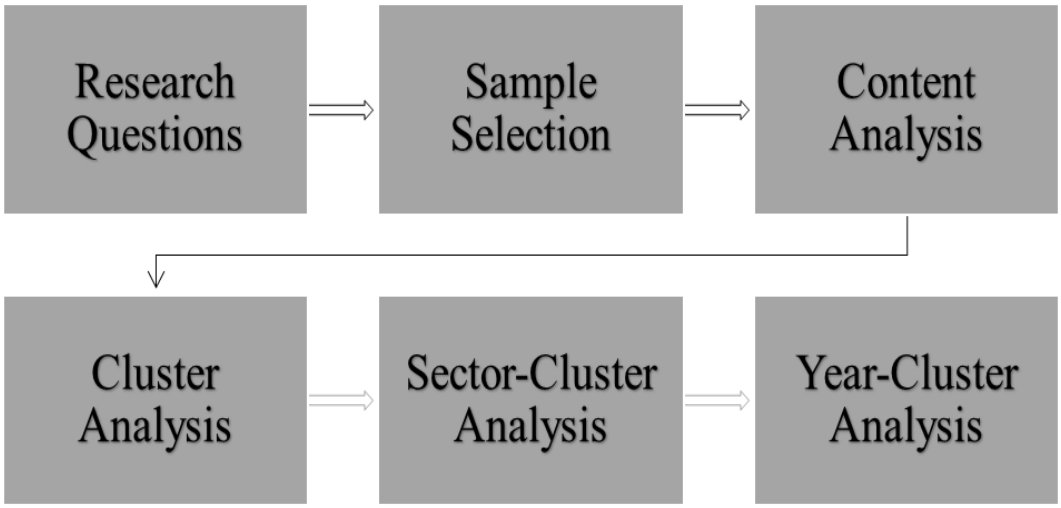

Figure 1 Research Design

Second, the study applies a cluster analysis using the K-means clustering algorithm and data analysis statistic tools. This method is widely employed in prior research due to its advantages, including its ability to analyze a collection of observations (x1, x2, ..., xn) and its simplicity, fast convergence, and scalability (Kwedlo & Czochanski, 2019; Meguelati et al., 2019). Based on the result of content analysis in the first stage, the study categorizes the 198 firm-year observations into optimal clusters determined through the elbow method in K-means clustering. This process clusters the companies with similar emissions management capabilities. To enhance the comprehensiveness of the second stage, we introduce a sector-cluster analysis. The clusters formed in the second stage are further examined by identifying the sectors included within each group. Following this stage, a content analysis is conducted to provide evidence of best practice emission strategies implemented by each sector. This analysis offers an overview of the development of carbon emission management across various industrial sectors in Indonesia.

Third, the study evaluates the development of corporate emissions management activities, including the commitment of top-level management to implementing environmental management systems, the disclosure of carbon performance, and environmental regulations, using year-cluster analysis. Using data from the second stage cluster analysis, we further examine how the clusters evolved between 2016 and 2022. Additionally, we conduct a content analysis to assess whether the sampled companies

implemented ISO 14001 and ISO 50001, disclosed the Scope 1, 2, and 3 emissions, and how many environmental regulations were issued by the government during the period (the greater the number, the stricter the regulatory environment). The discussion of this development is divided into three stages: Period 1 (2016–2018) marks the initial establishment of the Paris Agreement, which serves as a foundation for global nations, including Indonesia, to manage carbon performance through business strategy implementation; Period 2 (2019–2020): introduction of national regulations on emission quality standards and air pollution index standards issued by the Ministry of Environment and Forestry; Period 3 (2021–2022): characterized by stricter environmental regulations on emissions, including the Carbon Economic Value.

Result and Discussion

Cluster Analysis

The first step in cluster analysis is determining the optimal number of clusters to be formed from the entire dataset. This study employs the elbow method to identify the optimal number of clusters by observing the point at which the distortion value begins to diminish. As shown in Figure 2, the reduction in distortion starts to plateau at cluster 3, in contrast to clusters 1 and 2, which exhibit significant decreases in distortion. Additionally, a noticeable angle change forming an "elbow" is observed at cluster 3. Thus, based on the elbow method, three clusters are selected for further analysis. Each cluster represents a group of companies within the sample that share relatively similar characteristics in implementing carbon strategies.

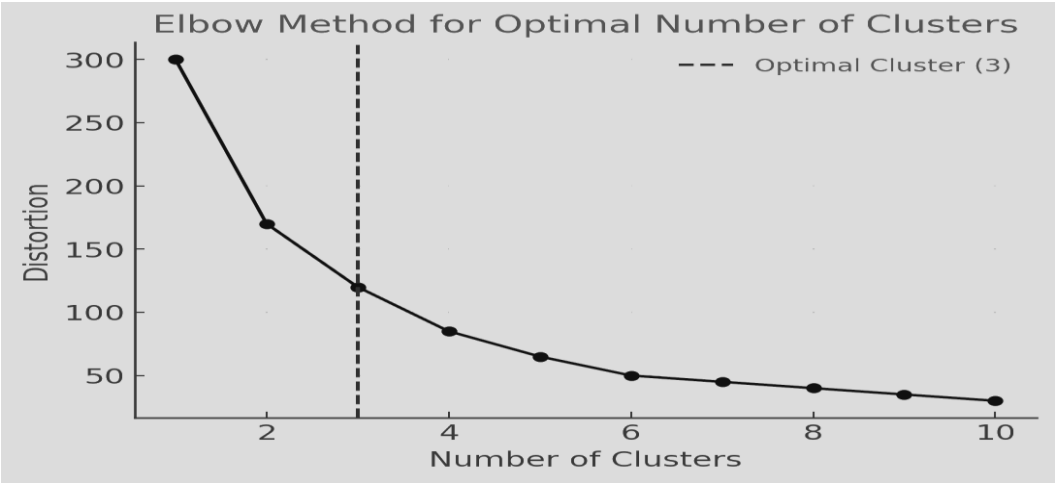

Figure 2 Optimal Number of Clusters

The next step is to determine the characteristics or profile of each cluster by calculating the mean value for each type of carbon strategy implemented by the companies. Table 2 summarizes the overall results of the strategy implementation across the sample. Cluster 0 comprises 100 firm-year observations, representing 51% of the total sample. Companies

grouped in Cluster 0 exhibit a high mean value (0.90) in compensating for excess carbon emissions, indicating that most companies in this cluster have implemented some form of compensation in adherence to environmental policies. However, carbon emission trading demonstrates a low mean value (0.00), suggesting that no companies in this cluster engage in carbon trading. The low-emission process has a mean value of 1.00, meaning all companies in this cluster utilize low-emission operational processes. Similarly, low-emission products have a high mean value (0.78), indicating that most companies use low-emission materials in their production processes. The emission-free process shows a high mean value (0.92), signifying that nearly all companies in this cluster invest in renewable technologies for product processing. However, emission-free products have a low mean value (0.00), meaning none of the companies use emission-free materials in production.

Tabel 2 Cluster Analysis

	Cluster 0	Cluster 1	Cluster 2
Carbon Compensation	0.90	0.75	0.81
Carbon Trading	0.00	0.00	0.00
Environmental Friendly Process	1.00	0.49	1.00
Environmental Friendly Product	0.78	0.00	0.84
Zero Emission Process	0.92	0.21	1.00
Zero Emission Product	0.00	0.00	1.00
Sample Size	100	61	37
Cluster Performance	Moderate	Low	High

Cluster 1 consists of 61 firm-year observations, representing 31% of the total sample. Companies in Cluster 1 demonstrate high performance (0.75) in compensating for excess carbon emissions, indicating that most companies in this cluster have undertaken activities to reduce carbon emissions by compensating for the excess. However, carbon emission trading shows a low value (0.00), meaning no companies in this cluster engage in carbon trading as a means to reduce emissions. The low-emission process has a moderate mean value (0.49), indicating that some companies in this cluster have implemented production processes that generate lower emissions. Conversely, low-emission products have a low mean value (0.00), meaning no activities involve the use of low-emission materials in production. The emission-free process has a low mean value (0.21), reflecting that only a few companies in this cluster have transitioned to renewable energy sources. Similarly, emission-free products show a low mean value (0.00), indicating that no companies in this cluster use emission-free materials in production.

Cluster 2 comprises 37 firm-year observations, accounting for 19% of the total sample. Companies grouped in Cluster 2 demonstrate high performance (0.81) in compensating for excess carbon emissions, indicating that most companies in this cluster offset their emissions through various investment activities. Carbon emission trading shows a low value (0.00), signifying that none of the companies in this cluster engage in carbon trading. The low-emission process has a high mean value (1.00), meaning all companies in this cluster have implemented diverse activities to reduce emissions. Similarly, low-emission

products exhibit a high mean value (0.84), indicating that most companies use environmentally friendly materials. The emission-free process has a high mean value (1.00), reflecting that all companies in this cluster have switched to renewable energy sources. Additionally, emission-free products demonstrate a high mean value (1.00), showing that all companies use natural raw materials to create emission-free products.

Sector Cluster Analysis

Additional analysis focuses on exploring the development of management accounting across different sectors, as shown in Table 3, Panel A. The study investigates and compares carbon management practices in each cluster based on sectoral characteristics. The results reveal that Cluster 0, characterized by moderate carbon management performance, comprises the basic materials, agriculture, and infrastructure sectors. Notable industries within this cluster include chemical, mineral, construction materials, palm oil, and gas and electricity utilities, reflecting increasing corporate awareness of climate change. These companies have implemented various emission management practices such as reduce, reuse, and recycle (3R) strategies, adopting energy-efficient technologies and compensating for excess emissions. Content analysis reveals best practices, such as construction material companies using eco-friendly raw materials and adhering to emission standards, mineral companies employing energy-saving technologies to cut emissions, and agricultural companies using recycled materials for fertilizers while avoiding open burning for land clearing.

Table 3 Sector and Year Cluster Analysis-Panel A Sector Cluster Analysis

Cluster	Basic material	Agriculture	Energy	Industrial	Infrastructure	Transportation	Total
0	39	27	13	1	16	4	100
1	15	3	32	2	3	6	61
2	14	1	6	7	9	0	37
Climate Risk	Moderate	High	High	High	Moderate	High	
Panel B Year Cluster Analysis							
		Period 1			Period 2	Period 3	
Cluster	2016	2017	2018	2019	2020	2021	2022
0	4	6	7	16	17	27	23
1	3	3	5	8	10	16	16
2	0	0	0	0	6	14	17
Emission Regulation	Low			Moderate		High	
Environment Management System	Not Applicable			ISO 14001		ISO 14001 and ISO 50001	
Carbon Disclosure	Scope 1			Scope 1 and Scope 2		Scope 1, Scope 2, and Scope 3	

Several companies with low carbon management performance are grouped in Cluster 1, predominantly consisting of energy sector companies involved in the coal, oil, and gas industries. Content analysis reveals that emission management activities in this cluster are limited to emission compensation through internal reforestation initiatives, with no strategic efforts to reduce emissions in production processes or diversify into low-emission or emission-free products. Although emissions are identified as a material issue, there is no evident commitment from top-level management to address climate change risks, leading companies to continue conventional business practices.

Further sectoral analysis reveals that, although limited in number, each sector included in the study has representation in Cluster 2. Content analysis of sustainability reports indicates that companies in coal, metal, gas utility, chemical, and cement industries demonstrate strong climate risk commitments. Support from top-level management demonstrated through investments in emission-free technologies, has empowered companies to undertake a wide range of emission mitigation activities. These include carbon capture technologies, fuel efficiency measures, emission-free power plants, and other innovative carbon management practices. Companies in Cluster 2 are identified as large-scale enterprises that lead their respective industries and share a common characteristic by recognizing climate change as a material issue and potentially threatening their business sustainability.

Year Cluster Analysis

In the final stage, this study analyzes the development of management accounting during several critical periods in Indonesia, as reported in Table 3, Panel B. Period 1 represents the initial phase when Indonesia ratified the Kyoto Protocol, requiring national contributions to reducing carbon emissions. During this period, 28 companies, mostly classified under Cluster 0 and Cluster 1, or approximately 14% of the total observations, exhibited low to moderate performance. In Period 2, emission management regulations began to take shape, and the government actively encouraged companies to adopt mitigation measures. During this period, 57 companies, representing 29% of the total observations, were distributed across the clusters. This period demonstrated progress in carbon management accounting practices, with, in general, achieving moderate performance (Cluster 0). Period 3 reflects a stage where carbon emission regulations, including sanctions and incentives, were established. This period encompasses the majority of the observations, with 113 companies (57% of the total). Significant improvements in emission management performance were observed across clusters, with Cluster 0 maintaining moderate and Cluster 2 showing remarkable advanced performances.

Discussion

The findings indicate that companies implementing carbon management accounting practices can be categorized into three distinct groups. In general, Cluster 0 consists of companies focused on improving low-emission processes and products and compensating for excess carbon emissions. According to Cadez and Czerny (2016), Lee (2012), and

Weinhofer and Hoffmann (2010), companies in Cluster 0 are classified as anticipatory or reducer. Anticipatory companies perceive emissions issues as both risks and opportunities that can improve performance (Cadez & Czerny, 2016). When anticipatory companies see high market opportunities, they adapt their business processes by formulating internal policies or lobbying the government to meet market demands. Conversely, anticipatory companies facing great climate change risks must go beyond lobbying or pollution control; emissions become an urgent issue for survival, requiring cross-division collaboration to design more effective business strategies. Companies in this cluster are also encouraged to disclose their mitigation strategies and carbon emissions performance to address stakeholder demands (Cadez et al., 2019). Lee (2012) and Weinhofer and Hoffmann (2010) classify reducer companies as those engaging in moderate carbon management activities. Their mitigation efforts remain at an early stage, typically setting emission reduction targets and implementing specific measures in production processes. These companies are not focused on creating new products or exploring new markets but instead maintain the characteristics of their existing products.

Cluster 0, characterized by moderate performance, comprises sectors operating in basic materials, agriculture, and infrastructure. In Indonesia, environmental regulations have played a significant role in shaping carbon management practices within these industries. For instance, policies encourage the basic materials sector to use recycled raw materials and engage in reforestation to create green spaces, while the agricultural sector is prohibited from using slash-and-burn methods for land clearing. Similarly, the mineral sector is required to integrate carbon capture technologies into its operations. These regulations have driven companies to adopt more sustainable and emission-friendly practices, significantly influencing their operational strategies and environmental accountability.

Companies in Cluster 1 demonstrate limited carbon emission mitigation activity, with no significant mitigation actions beyond compensation practices. According to Cadez & Czerny (2016), Lee (2012), and Weinhofer & Hoffmann (2010), companies in Cluster 1 are classified as stable, preserver, or observer. In cases where management accounting systems categorize climate change risks and business opportunities as low, these companies continue to operate as usual without considering the carbon emissions they produce. Motivation to manage emissions is absent at both the top management and middle management levels. Management accounting systems in these companies focus on production and logistics functions, and initiatives to manage carbon emissions are not prioritized at either the strategic or operational levels (Bui, 2017).

Cluster 1, which demonstrates low performance, is generally comprised of companies in the energy sector. These findings differ from those of Wahyuni & Ratnatunga (2015), who observed that coal mining companies implemented various carbon management practices to reduce, compensate, and create eco-friendly operational environments through processes, products, and supply chain management, supported by significant investments in renewable technologies. Further content analysis indicates that the energy sector companies are predominantly government-owned coal enterprises. The study by Wahyuni & Ratnatunga (2015), which focused on the 2010–2013 period, observed lower

coal prices compared to the 2020–2022 period covered by this study. The higher coal prices during 2020–2022 incentivized companies to expand production capacity in pursuit of financial gains. Furthermore, a 2020 regulation issued by the Ministry of Energy and Mineral Resources relaxed licensing requirements for mineral and coal mining operations, facilitating expansion into new operational areas. These developments left limited room for companies to prioritize or commit to decarbonization efforts.

Companies in Cluster 2 exhibit advanced emission management capabilities. These companies combine various mitigation practices, including compensating for excess emissions, modifying processes and products to be emission-friendly, investing in emission-free energy sources, and transitioning the business into emission-free products. These efforts aim to achieve a high level of sustainability performance. According to Cadez, Cadez & Czerny (2016), Lee (2012), and Weinhofer & Hoffmann (2010), companies in Cluster 2 can be classified as all-round enhancers or proactive. Proactive companies view opportunities in the eco-friendly business market as highly significant, leading to a transformation of the products offered to consumers. Consequently, these companies focus on each production process to reduce emissions in the final products. Compensation activities are maintained through offsets in emission-reduction projects. Additionally, environmental policy lobbying that benefits the companies is a common practice in proactive clusters. Overall, these companies adopt carbon management accounting due to market pressures. It aligns with Bui's (2017) findings in New Zealand, where companies facing higher climate-related risks adopt more extensive emission management practices and make significant investments to transform their businesses, including diversifying into new business units. Moreover, companies in Cluster 2 integrate climate change risks into their strategic and operational accounting processes. Unlike Bui (2017), this study encompasses a broader range of industries and a more recent observation period, revealing a greater variety of management practices.

Consistent with stakeholder theory, our findings reveal that at each period, companies exhibit varying behaviors in the implementation of carbon management accounting practices. These differences arise due to variations in risk perception, commitment, and stakeholder support regarding emission issues, leading to diverse forms of carbon management accounting practices being adopted. For instance, in the initial phase, when the low-emission era had just begun, key stakeholders such as the government had yet to establish adequate regulations to promote an environmentally friendly business climate. As a result, companies during this period responded by adopting stable, preserver, or observer-type management practices (Cluster 0), characterized by a lack of visible top-level management commitment to emission reduction. Consequently, at this stage, companies were still adapting to the new environmental emphasis on emissions, and their activities were primarily confined to internal emission compensation efforts, such as reforestation initiatives. Companies began recognizing climate change as an operational risk, but emission reduction activities remained low, typically limited to energy-saving initiatives like reducing electricity usage, and there are no large-scale investments in low-emission technologies. Only a few companies implemented environmental management systems, and those systems had not yet achieved international certification. These findings indicate that Period 1 marked the early development of carbon management

accounting in Indonesia. The results align with Bui's (2017) findings, which noted that in the absence of strict carbon regulations, companies tend to adopt reactive approaches. Instead of innovating, companies delayed their response, observed the industry trends, and made minor adjustments to their sustainability practices as a form of legitimacy for stakeholders (Kawulur et al., 2024).

In contrast to Period 2, during this stage, companies adapted to stakeholder demands and aligned their business activities with climate change risks by implementing anticipatory or reducer strategies (Cluster 1). At this point, environmental regulations had begun to take shape, leading to a shift in stakeholder perceptions regarding emission issues. Stakeholders started providing resources for mitigation practices, such as investments in environmentally friendly technologies to improve energy efficiency and the use of natural materials in production processes. Furthermore, top-level management commitment became more tolerant as companies adopted ISO 14001-certified environmental management systems to monitor emission levels and furnish management with the necessary information to formulate effective mitigation strategies. These systems enabled companies to measure direct emissions (Scope 1 and Scope 2), allowing them to take proactive measures to maintain environmental performance. These findings are consistent with Bui (2017), during subsequent stages of carbon management accounting, companies adopt strategic measures, such as forming environmental committees to address emission risks and exploring opportunities in the growing green market by focusing on low-emission processes and products.

In the final period, corporate responses to stakeholder demands became increasingly diverse, with companies implementing all-around enhancers or proactive strategies (Cluster 2). At this stage, carbon tax regulations were in the finalization phase, and the government began introducing emission-related sanctions and incentives. However, unlike in other countries, mechanisms for carbon trading and emission reduction projects had yet to be legally regulated. Companies displayed heightened awareness of climate change risks and opportunities. There is board level commitments to addressing climate issues aligned with sustainability initiatives from companies by combining compensation, reduction, and independence mechanisms to break free the business from carbon emissions. Environmental management systems evolved, integrating ISO 14001 for environmental management and ISO 50001 for energy management, enabling companies to monitor emissions from processes, products, and supply chains. Investments in renewable technologies became widespread as part of companies' long-term strategic plans to enhance sustainability performance. Companies also expanded their carbon calculations to include Scope 1, Scope 2, and Scope 3 emissions. Overall, this period marked substantial advancements in carbon management accounting, with the system evolving beyond emission reduction efforts to foster new business models that promote sustainable competitive advantage and enhance overall company performance. The findings differ from those of Bui (2017), who noted that companies tended to revert to reactive emission management approaches during the later stages of carbon management accounting. In New Zealand, this behavior was driven by the legalization of carbon trading systems and the high uncertainty surrounding climate-related sanctions

and incentives, prompting companies to focus on emission compensation through carbon trading, primarily for economic gain.

Conclusion

This study aims to explore the development of corporate management accounting in addressing climate change risks within sensitive industries in Indonesia. The findings identify three clusters with distinct characteristics in carbon emission management. First, Cluster 0 demonstrates moderate carbon management accounting capabilities, focusing on three primary practices: internal compensation for excess emissions, implementing energy-saving processes, and using recycled materials in production. Companies in this cluster generally face high business risks, including those in the energy, transportation, chemical, gas, and electricity utility industries. Second, Cluster 1 exhibits low carbon management accounting capabilities, concentrating solely on compensation activities without aligning their management accounting systems with climate change risks. This cluster is dominated by companies in the energy sector, particularly coal, oil, and gas industries. Third, Cluster 2 represents companies with high carbon management accounting capabilities, characterized by radical business transformations through a combination of diverse carbon emission management activities. Companies in this cluster utilize management accounting systems to create competitive advantages through low-emission processes and products.

The study also identifies three periods of management accounting development. The first period (2016–2018) marks the early stage of carbon management accounting in Indonesia. During this period, management accounting systems remained focused on conventional product development, running businesses as usual without significant changes to operational processes. Companies struggled to measure carbon emission performance due to the lack of proper environmental management systems. Businesses exhibited a "wait-and-see" approach, observing the appropriate mitigation practices and accounting management systems that should be implemented. The second period (2019–2020) shows the initial growth of carbon management accounting within Indonesian companies. Companies began to recognize the importance of emission management, aligning their management accounting systems with climate change risks and mitigation demands from stakeholders. Corporate commitment became visible through investments in low-emission technologies, environmental management systems for monitoring, and the disclosure of both direct and indirect carbon emissions as a foundation for evaluating environmental performance. The third period (2021–2022) reflects the successful implementation of carbon management accounting by most companies in Indonesia. Long-term sustainability goals became a priority, shifting practices beyond compensation and emission reduction to creating emission-free operations. It was achieved through substantial investments in renewable technologies, energy, and environmental management systems, and transparent carbon performance reporting to stakeholders.
This study provides several implications. The findings indicate that as climate change regulations become clearer, including sanctions and incentives, companies become more proactive in implementing carbon management accounting. Conversely, when

environmental regulations lack clarity or are less stringent, companies tend to deviate, prioritizing economic performance over environmental performance. Additionally, the results demonstrate that most Indonesian companies are in the development stage of responding to climate risks, opportunities, and pressures. It underscores the need for top-level management to possess the knowledge and skills to guide their companies toward competitiveness in the era of climate change. This study contributes to the carbon management accounting literature by promoting low-emission business practices. Applying stakeholder theory offers insights into the varying motivations behind companies' implementation of emission management strategies. The findings provide a deeper understanding of how carbon management accounting is applied in the context of differing environmental risks and the stringency of government regulations.

This study has several limitations. First, in terms of data, it focuses on environmentally sensitive sectors in Indonesia, which limits the complexity of the overview of carbon management accounting practices. Other sectors, such as finance, were not included in the sample. As a result, the study lacks a comparative analysis between carbon management practices in sensitive and non-sensitive industries. Second, the absence of standardized disclosure of emission management strategies in sustainability reports posed challenges for the researcher during content analysis, potentially increasing the risk of information bias.

Therefore, future research is encouraged to expand the sample by including all sectors listed on the Indonesia Stock Exchange. The analysis could also be extended to compare the characteristics of sensitive and non-sensitive industries. Moreover, to obtain more valid information on emission strategies, manual content analysis could be replaced with more robust global emission databases such as the Climate Disclosure Project or Refinitiv Eikon.

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Conflicts of Interest

The author declares no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.