Carbon Risk and Capital Market Resilience: Firm-Level Evidence and Policy Implications from Thailand

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EXECUTIVE SUMMARY

This paper investigates the financial implications of greenhouse gas (GHG) emissions for listed firms in Thailand using a balanced panel of 122 firms between 2022 and 2024. The analysis provides robust evidence that higher emissions are consistently associated with lower profitability (ROA), weaker shareholder returns (ROE), and diminished market valuation (Tobin's Q). These findings confirm that carbon risk is not only an environmental concern but a financially material issue in Thailand's capital market. Emission-intensive firms are systematically penalized, both operationally and by forward-looking investors, reinforcing the efficiency and value-relevance hypotheses.

For policymakers, especially the Securities and Exchange Commission (SEC) of Thailand, these results are highly relevant. They demonstrate that investors already recognize and price climate-related risks, but fragmented disclosure standards and limited oversight constrain market efficiency. By leveraging the empirical insights from this study, the SEC can take a leadership role in aligning Thailand's capital market with global sustainable finance practices and the national net-zero transition.

Key benefits for the SEC of Thailand include:

1. **Providing an empirical foundation for fiscal and market-based instruments.** The underperformance of emission-intensive firms provides strong evidence that markets reward low-carbon strategies. This gives the SEC a credible basis for supporting complementary fiscal and market tools—such as carbon taxes, credit incentives, or emissions trading schemes—that can accelerate decarbonization while ensuring that firms remain financially viable.

2. **Bolstering international credibility of Thailand's capital market.** By demonstrating the financial impact of emissions, the research aligns Thai market practices with global sustainable finance trends. This positions the SEC to showcase Thailand's progress to foreign institutional investors, strengthening the country's competitiveness in attracting cross-border capital flows and ESG-driven investments.

3. **Strengthening the SEC's role in Thailand's net-zero transition.** The SEC has a strategic role in ensuring that financial regulation supports Thailand's carbon neutrality (by 2050) and net-zero (by 2065) commitments. This study provides the empirical foundation needed to design policies that integrate financial stability with environmental sustainability, thereby cementing the SEC's leadership in the low-carbon transition.

In summary, the findings equip the SEC of Thailand with robust evidence and actionable insights to strengthen disclosure requirements, design market-based incentives, and enhance

its supervisory role. These benefits ensure that Thailand's capital market remains resilient, globally credible, and aligned with the transition to a sustainable low-carbon economy.

ABSTRACT

This study investigates the financial implications of carbon emissions among 122 publicly listed firms in Thailand from 2022 to 2024, with complete environmental disclosures. By linking greenhouse gas (GHG) emissions to Return on Assets (ROA), Return on Equity (ROE), and Tobin's Q, the results reveal a consistent and significant underperformance of carbon-intensive firms across both accounting-based and market-based measures. These findings are robust across models and time, underscoring that poor environmental performance is not only a reputational issue but a financially material risk. Crucially, the persistence of this relationship despite recent regulatory and economic shifts suggests that markets have already internalized emissions-related risks into firm valuations.

From a policy perspective, these findings strongly support the integration of environmental considerations into financial regulation. First, the evidence of valuation penalties for high emitters justifies the adoption of fiscal instruments such as carbon taxes, emissions trading schemes, and targeted tax relief to incentivize corporate decarbonization. Second, the significant association between emissions and Tobin's Q highlights the need for mandatory and standardized carbon disclosure, enabling investors to efficiently price climate risks. Finally, the interaction between leverage, emissions, and performance provides a rationale for expanding green finance facilities—such as preferential credit or guarantees—for low-emission, financially prudent firms.

1 INTRODUCTION

Climate change is no longer a distant environmental issue but a material financial risk influencing firm valuations, capital flows, and long-term competitiveness. Globally, governments, institutional investors, and corporate stakeholders are intensifying pressure on firms to reduce their carbon footprints. Greenhouse gas (GHG) emissions are increasingly recognized not only as environmental externalities but also as financially material liabilities with enduring implications for corporate performance. In response, many firms have embedded strategic carbon management—combining emission reduction and alignment with the Paris Agreement [1] and the United Nations Sustainable Development Goals (SDGs) [2]—alongside traditional financial performance evaluations. This shift in corporate governance reflects a growing convergence between environmental objectives and strategic management, positioning environmental stewardship as both a competitive advantage and a safeguard for sustainable risk mitigation.

In emerging markets such as Thailand, systematic carbon pricing and rigorous GHG monitoring are relatively recent developments. The country, still in the early stages of its low-carbon transition within the ASEAN context, faces the dual challenge of sustaining economic growth while meeting long-term environmental commitments [3]. Thailand signed and ratified the Paris Agreement in 2016 [4], pledging to reduce GHG emissions by 20-25% from business-as-usual levels by 2030 [5], and subsequently committed to carbon neutrality by 2050 and net-zero emissions by 2065 [6]. Despite these pledges, only 30% of listed companies currently report verified carbon footprint data [7]. Recent policy initiatives, including the draft Climate Change Act [8], the planned Emissions Trading System (ETS), the introduction of a carbon tax, and measures to address the Carbon Border Adjustment Mechanism (CBAM), signal a shift from voluntary efforts toward an enforceable, principle-based framework aligned with the polluter-pays doctrine.

Thailand warrants scholarly attention for three reasons. First, as the second-largest economy in Southeast Asia and a major emitter in the industrial and energy sectors, it holds strategic importance for understanding climate policy impacts in the region. Second, the country's ongoing environmental policy reforms—spanning carbon pricing, ETS establishment, and carbon taxation—provide a timely setting to assess how regulatory interventions shape corporate behavior and financial outcomes. Third, its role as a key ASEAN economy undergoing a low-carbon transition offers comparative insights relevant to other emerging markets.

While evidence from developed economies frequently shows a positive association between proactive carbon management and financial performance, findings from emerging markets remain mixed due to heterogeneity in institutional capacity, investor awareness, and

regulatory enforcement. In Thailand, empirical studies are scarce, predominantly descriptive, and often limited to specific sectors, leaving a gap for comprehensive, firm-level quantitative analysis. This study addresses that gap by examining the relationship between GHG emissions and corporate financial performance among firms listed on the Stock Exchange of Thailand (SET) using panel data regression to estimate market-wide effects.

This paper contributes to the sustainability finance literature in three ways: (i) it provides one of the first large-sample, firm-level quantitative assessments of the carbon-finance nexus in Thailand; (ii) it generates empirical evidence to inform climate policy design, investment strategy, and corporate governance; and (iii) it offers comparative insights applicable to other emerging economies pursuing low-carbon transitions.

The remainder of the paper is organized as follows: Section 2 reviews the relevant literature; Section 3 develops the study's hypotheses; Section 4 outlines the research methodology; Section 5 presents and discusses the empirical findings; and Section 6 concludes with implications for policy and practice.

Before proceeding to the literature review, we summarize the notation and variable definitions used throughout the paper as follows.

Abbrev.	Label	Definition / Formula
ROE	Return on Equity	$\text{ROE} = \dfrac{\text{Net Income after Tax}}{\text{Total Assets} - \text{Total Liabilities}}$
ROA	Return on Assets	$\text{ROA} = \dfrac{\text{Net Income after Tax}}{\text{Total Assets}}$
ROS	Return on Sales	$\text{ROS} = \dfrac{\text{Operating Income (EBIT)}}{\text{Net Sales}}$
Tobin's Q	Tobin's Q Ratio	$\text{Tobin's Q} = \dfrac{\text{Market Capitalization} + \text{Total Liabilities}}{\text{Total Assets}}$
MktCap	Market Capitalization	Total company market capitalization
Leverage	Leverage Ratio	$\text{Leverage} = \dfrac{\text{Total Assets}}{\text{Total Assets} - \text{Total Liabilities}}$
PF	Profitability Factor	$\text{PF} = \dfrac{\text{Total Revenue from Business Activities}}{\text{Total Assets}}$
IF	Investment Factor	$\text{IF} = \dfrac{\text{Total Assets, YoY \% Change}}{100}$

2 LITERATURE REVIEW

In recent years, the link between GHG emissions and corporate financial performance (CFP) has drawn sustained scholarly attention, reflecting intensifying climate concerns and the shift toward sustainable business models. Research spans national and industry contexts, highlighting variations driven by legal frameworks, regulatory oversight, capital market maturity, and stakeholder expectations. While findings vary, most studies indicate that strong environmental performance—particularly through emission reduction, transparent disclosure, and effective environmental management—correlates positively with profitability, firm value, and cost of capital. However, the strength and direction of this relationship depend on institutional quality, policy enforcement, firm characteristics, and investor sensitivity to environmental issues.

A systematic review by Sitompul et al. [9] synthesized 22 empirical studies (2016-2022) using the PRISMA methodology, finding that 59% reported a positive association between carbon strategies and financial performance, with half of these significant at conventional levels. The literature draws on stakeholder theory, institutional theory, legitimacy theory, and the resource-based view to explain these dynamics. Common dependent variables include ROA, ROE, Tobin's Q, and market value, with independent variables such as carbon intensity, disclosure scores, and emissions data, typically analyzed using panel regressions with controls for size, leverage, and capital intensity. Some evidence points to non-linear and time-lagged effects, suggesting benefits may materialize over the long term. Overall, internal drivers (profitability, innovation, risk reduction) and external pressures (regulation, investor expectations) both shape carbon management outcomes, while barriers such as short-termism and policy uncertainty can limit their financial impact.

Studies examining the interplay between carbon emissions, environmental disclosure, and financial impacts have been conducted across multiple countries. The country-specific findings from the relevant literature are summarized as follows.

In the United States, environmental performance is tightly linked to financing conditions and firm value: firms with salient environmental concerns face higher equity and debt financing costs and reduced access to capital [10], higher carbon emissions and non-disclosure attract valuation penalties [11], and lower emissions intensity is associated with higher Tobin's Q [12]. Overall, carbon risk is priced, and credible mitigation enhances market performance.

In the United Kingdom, carbon performance is likewise linked to financial outcomes: higher corporate emissions are associated with weaker financial performance, while carbon disclosure mediates and attenuates this negative relation [13]. Among FTSE 350 firms (2011–2020), proactive emissions reduction is positively related to performance—especially in the post-Paris Agreement period—with CSR strategy and governance quality reinforcing the

effect [14], suggesting that transparency and credible mitigation are rewarded by the market.

In the European Union, firm-level evidence links carbon performance to valuation and profitability: across 1,493 listed firms (2008–2022), higher Scope 1 carbon intensity is associated with lower market-to-book ratios and weaker earnings value relevance, whereas Scope 3 effects are insignificant and formal institutions show no clear role [15]. Using 497 firms (2006–2017), stronger environmental scores and certified management systems (e.g., ISO 14001) are positively related to ROA, while poorer carbon performance and rising emissions are negatively related to ROA, ROE, and ROS [16], indicating that markets reward credible, firm-controlled mitigation.

In Australia, emissions are likewise tied to financing and performance: among ASX-listed firms, higher NGERS-reported emissions are associated with weaker ROA/ROE and lower market-based metrics (e.g., Tobin's Q) [17], and with higher costs of equity and weighted average cost of capital (WACC) [18]. Moreover, board independence, environmental committees, meeting frequency, and gender diversity are associated with lower Scope 1–2 emissions intensity, whereas ownership concentration is not [19]. Overall, carbon risk is priced, and governance can mitigate it.

In Japan, using 2006–2008 firm data, Saka and Oshika [20] show that higher emissions intensity is associated with lower firm value. In China, firm-level evidence links carbon performance to financial and valuation outcomes. Analyzing 364 high-emitting listed firms (2014–2018), Tang, Zhang, Li, and Guan [21] find that stronger carbon performance—lower emissions per revenue—is associated with higher firm value (Tobin's Q). Meng, Gou, and Chen [22] show that better carbon performance raises financial performance over the long run (measured primarily by ROA, with ROE as a robustness check), while stronger financial performance has a contemporaneous positive effect on carbon performance; both effects vary by ownership structure.

In Malaysia, Vaicondam et al. [23] analyze 379 Bursa Malaysia-listed firms (2016–2020) using panel regressions (fixed/random effects) with ROA and ROE as outcomes, GHG emissions and carbon emission intensity (CEI) as key regressors, and controls for size, leverage, and industry. They find that higher GHG emissions are significantly negatively associated with ROA and ROE, whereas CEI is not significant, suggesting that reducing absolute emissions may support stronger financial performance in an emerging-market setting.

In Brazil, evidence is mixed. De Lima et al. [24] find no statistically significant differences in ROIC/ROE/ROA between B3's ICO2 firms and Ibovespa peers using Mann-Whitney tests and cluster analysis. By contrast, Senna and de Araujo Moxotó [25] report for 73 ICO2 firms a positive association between Carbon emissions and EPS/ROE/ROA (OLS/GLS), implying that short-run financial gains can coexist with higher emissions in a weak-penalty context and motivating clearer policies (carbon taxes, green-innovation incentives, transparent emissions

reporting).

In South Africa, higher Carbon emissions are associated with weaker ROE/ROI/ROS among 63 firms reporting to CDP (formerly the Carbon Disclosure Project) in 2015—especially in high-emitting sectors—while effects are mixed for low emitters and weaken with firm growth [26]. Using two-step system GMM for JSE firms participating in CDP during 2014-2018, Ganda [27] finds that stronger carbon performance raises ROA, firm value, and Tobin's Q in the short run but turns negative for ROA and firm value in the long run—remaining positive for Tobin's Q—with capital-structure ratios acting as transmission channels.

Cross-country evidence indicates that carbon-emission reductions most reliably reward shareholders: Gallego-Álvarez, Segura, and Martínez-Ferrero [28] and, independently, Lewandowski [29] document ROE gains with no significant ROA effect, consistent with the resource-based view that carbon strategies function as strategic assets; extending this, Trinks, Mulder, and Scholtens show that higher carbon efficiency is associated with $\approx 1\%$ higher ROA per 0.1 efficiency gain and $\approx 0.6\%$ lower systematic risk, with no relation to Tobin's Q or total risk [30]; broadening further, van Emous, Krušinskas, and Westerman [31] report that emission reductions correlate positively with ROA/ROE/ROS but not with Tobin's Q or the current ratio, with effects stronger among high-ESG firms and only weakly moderated by country conditions; and in a larger global panel (2,768 firms; 36 countries; 35 industries; 2002–2022), Ibishova, Misund, and Tveterås [32] find verified GHG reductions positively associated with ROA and ROE—especially among high emitters and under stricter regulation—while aggregate ESG scores do not consistently predict performance, implying short-run costs but positive longer-run net effects and reinforcing the case for credible, auditable decarbonization aligned with financial value creation.

Drawing on the preceding studies, we compile and synthesize the evidence in Table 1 to present a systematic overview of carbon-emission measures, financial metrics, and the direction of effects across country and regional contexts.

Overall, the extant literature demonstrates a consistent empirical tradition of linking carbon emissions to corporate financial outcomes through firm-level panel regressions. Greenhouse gas (GHG) emissions are commonly modeled as the key explanatory variable, while dependent variables span accounting-based indicators such as return on assets (ROA) and return on equity (ROE), together with market-based measures including Tobin's Q and other valuation multiples. Standard specifications typically incorporate controls for firm size, leverage, and growth opportunities, and address unobserved heterogeneity with firm and year fixed effects or random-effects estimators. Building on this methodological foundation, our study extends the evidence base to Thai listed firms by integrating firm-level GHG disclosure with financial statement data, systematically testing robustness across alternative panel specifications, and quantifying the emissions–performance nexus in a country at the early

stage of its low-carbon transition. In doing so, the analysis not only extends prior evidence to an emerging-market context but also frames the Thai experience within the broader policy debate on net-zero goals and emissions trading system (ETS) design. By explicitly linking carbon risk to firm profitability and market valuation, the study generates actionable insights for regulators, investors, and corporate managers seeking to align financial performance with the imperatives of Thailand's low-carbon transition.

TABLE 1: SUMMARY OF EMPIRICAL FINDINGS BY COUNTRY AND FINANCIAL METRICS

Country/Region	GHG Emission Measure	Financial Metric	Effect (Emission-focused)
United States [10, 11, 12]	Emissions (levels/intensity) Environmental concerns	Cost of capital Firm value Tobin's Q	Negative
United Kingdom [13, 14]	Emissions (levels/intensity)	Profitability Firm value	Negative
European Union [15, 16]	Scope 1 carbon intensity Scope 3 emissions	Market-to-book ROA/ROE/ROS	Mixed to Negative
Australia [17, 18, 19]	NGERS-reported emissions Scope 1–2 intensity	ROA/ROE Tobin's Q Cost of equity WACC	Negative
Japan [20]	Emissions intensity	Firm value	Negative
China [21, 22]	Emissions intensity (per revenue)	Tobin's Q ROA/ROE	Negative
Malaysia [23]	Emissions (levels/intensity)	ROA/ROE	Mixed to Negative
Brazil [24, 25]	Emissions (levels)	ROIC/ROE/ROA EPS	Negative or Positive
South Africa [26, 27]	Emissions (levels/intensity)	ROE/ROI/ROS/ROA Firm value Tobin's Q	Mixed to Negative
Global [28, 29, 30, 31, 32]	Emission reduction Carbon efficiency	ROE/ROA/ROS Tobin's Q Systematic risk Current ratio	ROE: Positive ROA: Mixed ROS: Positive Risk: Lower Tobin's Q/CR: n.s.

Note: n.s. = non-significant.

3 HYPOTHESIS DEVELOPMENT

The theoretical link between corporate environmental performance and financial outcomes is grounded in stakeholder theory, the resource-based view (RBV), and legitimacy theory. Stakeholder theory suggests that firms enhancing their environmental responsibility can strengthen reputations and foster trust among investors, consumers, and regulators. From the RBV perspective, environmental capabilities are considered strategic intangible assets that may generate sustained competitive advantage, while legitimacy theory emphasizes that environmentally responsible practices mitigate regulatory and reputational risks by preserving the firm's social license to operate.

In line with these perspectives, prior empirical research generally reports a negative association between carbon emissions and financial performance indicators such as return on assets (ROA), return on equity (ROE), and Tobin's Q [11, 12, 13, 28], although effect sizes and robustness vary across settings. Despite this growing body of evidence from developed and several emerging markets, no systematic study has yet been undertaken in the Thai context, where institutional frameworks, regulatory mechanisms, and capital market structures differ significantly. This absence of country-specific evidence underscores the need to formulate and test hypotheses on the relationship between carbon emissions, firm performance, and market valuation in Thailand.

The first hypothesis proposed in this study is as follows.

HYPOTHESIS I

H_1: *Carbon emissions (GHG) are negatively associated with Return on Assets (ROA).*

Return on Assets (ROA) serves as a core indicator of a firm's operational efficiency and profitability relative to its total assets. A negative association between GHG emissions and ROA suggests that emission-intensive firms may face reduced asset productivity and profitability due to higher energy usage, compliance costs, and reputational damage. Drawing on stakeholder theory, legitimacy theory, and the resource-based view, poor environmental performance may attract regulatory scrutiny and stakeholder backlash, thereby undermining financial performance. In the Thai context, where ESG frameworks and carbon regulations are still emerging, understanding this link is crucial for assessing how environmental risks are priced into firm fundamentals [33].

Recent empirical evidence offers preliminary support for this hypothesis within the Thai setting. An ASEAN-wide panel regression analysis of 220 firms—including 49 listed on the Stock Exchange of Thailand (SET)—covering the period 2018-2022 reports that GHG emissions intensity exerts a marginally significant negative effect on ROA. This finding

indicates a weak yet consistent inverse relationship between carbon intensity and asset profitability among Thai firms [34]. Supporting this view, a separate study of 721 Thai-listed companies (across both SET and the Market for Alternative Investment, MAI) over the period 2016-2020 finds a statistically significant positive relationship between energy-conservation scores—used as a proxy for carbon efficiency—and ROA, suggesting that firms demonstrating higher environmental efficiency are also more effective in utilizing their asset base to generate profits [35]. Further, Connelly and Limpaphayom [36] investigate 200 SET-listed firms and reveal that the extent of environmental capital disclosure—often indicative of poor environmental performance or high emissions—is negatively associated with ROA. Their findings reinforce the perspective that weak environmental practices are detrimental to firm profitability.

Despite these insights, several limitations merit attention. First, the ASEAN-level study includes only a partial sample of Thai firms and reports marginal significance, thus raising concerns about the generalizability of the results to the broader Thai market. Second, the reliance on energy-conservation scores as proxies for carbon emissions may introduce measurement bias, as such scores may not fully capture actual emission levels. Third, the study by Connelly and Limpaphayom predates the widespread adoption of ESG standards and formal carbon disclosure requirements in Thailand, potentially limiting the applicability of its findings under current regulatory and investor expectations.

While the first hypothesis centers on Return on Assets (ROA) as an indicator of operational efficiency, the second hypothesis directs attention to Return on Equity (ROE), which captures a firm's ability to generate net income for its shareholders. Although ROA and ROE are interrelated, they reflect distinct dimensions of corporate performance: ROA assesses the efficiency with which assets are employed to generate profits, whereas ROE evaluates the effectiveness of equity capital in creating shareholder value. Accordingly, the second hypothesis of this study is formulated as follows.

HYPOTHESIS II

H_2 : *Carbon emissions (GHG) are negatively associated with Return on Equity (ROE).*

Return on Equity (ROE) measures a firm's capacity to generate net income from shareholder equity, serving as a key indicator of shareholder value. A negative relationship between ROE and GHG emissions implies that emission-intensive firms may yield lower profitability for equity holders, stemming from reduced operational efficiency, regulatory compliance costs, and higher financing expenses. According to stakeholder theory, legitimacy theory, and the resource-based view, poor environmental performance can erode corporate reputation and raise the cost of equity, ultimately compressing net returns. Empirical evidence

from a cross-country sample of over 2,500 emerging-market firms shows that higher carbon emissions significantly reduce both ROE and Tobin's Q, driven by elevated environmental risks and adverse capital market reactions [33]. These findings provide a rationale for investigating ROE as a mechanism through which carbon emissions influence firm value in the Thai capital market.

Recent evidence from a dynamic panel study of Thai publicly listed firms between 2014 and 2023 indicates that environmental disclosure scores—typically inversely related to carbon-intensive operations—exert a statistically significant negative effect on ROE when estimated using a system-GMM approach. This suggests that firms more active in environmental reporting (often those with higher emissions or compliance burdens) tend to exhibit lower ROE [37]. Conversely, a contemporaneous analysis of 1,528 SET-listed firms from 2020 to 2022 finds a significant positive association between environmental performance and ROE, highlighting discrepancies in results that may stem from differences in model specification, measurement approaches, and sample periods [38]. Additionally, an energy-conservation study covering SET and MAI firms from 2016 to 2020 reports that higher energy-conservation scores are positively associated with ROE in non-energy-intensive sectors, whereas the effect is not statistically significant in energy-intensive industries—suggesting that the ROE-carbon relationship may be heterogeneous across sectors [35]. Complementing these findings, a global panel study of over 16,000 firms reveals that the implementation of carbon-pricing mechanisms leads to a reduction in ROE—estimated at approximately 123 basis points for high-emission firms—particularly in countries with heavy reliance on fossil fuels. This result underscores the adverse financial implications of carbon intensity for equity returns under stringent climate policies [39].

Although these studies collectively suggest a possible negative relationship between emissions or poor environmental performance and ROE, the Thai-specific evidence remains indirect and fragmented. Existing domestic research predominantly employs proxies such as energy-efficiency scores or broad ESG disclosure indices, which often conflate environmental, social, and governance elements. Notably, no Thai study to date directly examines firm-level GHG emissions intensity in relation to ROE. This lack of specificity underscores the empirical gap concerning how standardized carbon emissions data relate to shareholder profitability in the Thai corporate con

A forward-looking measure, Tobin's Q reflects the ratio of a firm's market value to the replacement cost of its assets. In contrast to accounting-based indicators such as ROA and ROE—which focus on historical earnings efficiency—Tobin's Q captures investor expectations regarding future growth potential and intangible value drivers, including environmental reputation, governance quality, and strategic positioning. From the perspective of stakeholder theory, legitimacy theory, and the resource-based view, firms with elevated GHG emissions may experience suppressed market valuation if investors anticipate future regulatory burdens, reputational setbacks, or a diminished ability to sustain competitive advantage.

HYPOTHESIS III

H_3 : *Carbon emissions (GHG) are negatively associated with Tobin's Q.*

Tobin's Q, the ratio of a firm's market value to the replacement cost of its assets, serves as a forward-looking indicator of growth prospects and intangible value. The hypothesized negative association between GHG emissions and Tobin's Q is grounded in shareholder-value theory, stakeholder theory, legitimacy theory, and signaling theory. Firms with high carbon emissions may be perceived by investors as carrying long-term risks—such as environmental liabilities, regulatory penalties, or reputational damage—thereby lowering their market valuation relative to asset base. From a signaling perspective, high emissions signal weak environmental governance and inefficiency, which can trigger market-based valuation discounts. While empirical support in the ASEAN region remains mixed, Elago et al. [34] find that GHG emissions intensity lacks significance in explaining Tobin's Q for 220 ASEAN firms, including 49 Thai firms, over 2018-2022. However, ESG performance scores exhibit a significant negative relationship, suggesting that sustainability concerns may influence valuation but are not yet fully captured through emissions alone.

Empirical studies support this view. Miah, Hasan, and Usman [33] report that carbon emissions are significantly negatively associated with Tobin's Q across firms in 22 emerging economies, due to heightened environmental risk and investor concerns. Similarly, Park, Khue, and Lee [40] show that firms regulated under carbon trading schemes exhibit lower Tobin's Q when emissions are high, suggesting that market participants factor in the cost of compliance and future liabilities. Moreover, Faria, Terjesen, and Tindall [41] provide a theoretical foundation for the "Green Tobin's Q," incorporating environmental risk directly into firm valuation models. Nguyen and Mulikh [42] report similar findings in a broader study on sustainability practices across Southeast Asia's "Tiger Cub" economies. Their results show that higher environmental performance scores are associated with reductions in Tobin's Q in the banking sector—possibly due to the substantial costs of regulatory compliance and green transitions in regions with weaker institutional support. Conversely, a Thailand-specific

event study by Moolkham [43] finds that firms with higher SET ESG Ratings experience both immediate and sustained increases in firm value (a proxy for Tobin's Q), indicating that markets do positively respond to credible environmental disclosures, even in the absence of explicit GHG metrics.

Although these findings provide tentative support for Hypothesis 3 in the Thai context, significant empirical gaps remain. First, none of the existing studies directly examine the effect of firm-level GHG emissions intensity on Tobin's Q, relying instead on ESG proxies or sectoral aggregates. Second, the coverage of Thai firms in these studies is either limited or subsumed within broader ASEAN samples, reducing the specificity of the conclusions. Third, the heterogeneity in results across sectors and studies underscores the influence of evolving disclosure practices and regulatory frameworks in shaping market reactions. This study addresses these gaps by leveraging standardized, firm-level GHG emissions data to examine whether carbon-intensive firms listed on the SET and MAI are systematically undervalued in the market, as reflected in Tobin's Q.

Assessing the dynamic interplay between environmental impact and financial performance also necessitates consideration of higher-order statistical properties—particularly the covariance structure between emissions and valuation metrics. In multivariate analysis, the covariance matrix captures both the variance of individual variables (e.g., emissions, profitability) and their joint dependencies. Temporal stability in this matrix implies that the underlying relationships between financial and environmental indicators remain robust to external shocks or regulatory shifts, thereby enhancing the reliability of risk estimation and predictive modeling.

This structural constancy is particularly salient in regulatory environments undergoing rapid ESG transformation, such as Thailand, where firms are subject to evolving disclosure mandates and heightened market scrutiny. Should systemic shocks—such as interest rate fluctuations, the introduction of carbon pricing mechanisms, or shifts in global sustainability trends—substantially modify the dependencies among key financial and environmental variables, econometric models grounded in historical data may lose their predictive power. Conversely, the presence of stable covariance patterns implies that firms' financial and environmental behaviors respond in a consistent and systematic manner over time, thereby justifying the continued use of historical relationships in econometric estimation.

HYPOTHESIS IV

H_4 : The covariance matrices of firm-level financial and GHG variables remain constant over time, indicating no structural change in the joint distribution of these variables.

To the best of our knowledge, no prior study has explicitly examined the temporal stability of the joint covariance structure between financial performance indicators and GHG-related

variables in the Thai capital market. Given the recent availability and relatively short time span of firm-level GHG emissions data in Thailand, it is essential to assess whether the covariance structure observed over a limited period can reasonably support the assumption of long-run constancy. Our study addresses this gap by employing firm-level panel data from 2022 to 2024 to formally test the null hypothesis of structural invariance in systemic risk profiles and financial-environmental interdependencies. Establishing such stability is crucial for validating the assumptions underlying panel-based econometric models, enhancing the credibility of emissions-related financial research, and informing both investors and regulators about the resilience of ESG-financial integration frameworks in dynamic capital market settings.

4 METHODOLOGY

4.1 DATA DESCRIPTION

This research investigates firms listed on the Stock Exchange of Thailand (SET) that disclose sustainability reports with greenhouse gas (GHG) emissions. The final sample comprises 122 out of 923 listed companies with complete records from 2022 to 2024, coinciding with the introduction of SET's mandatory disclosure requirements on sustainability-related data.

Firm-level data—including total assets, liabilities, year-over-year (YoY) changes in total assets, market capitalization, revenue, net income after tax, and GICS sector classification—were obtained from Refinitiv Workspace and used to construct the financial metrics for analysis. The independent variables consist of market capitalization (MktCap), leverage ratio, profitability factor (PF), and investment factor (IF). To capture corporate financial performance, three dependent variables are employed: return on equity (ROE), return on assets (ROA), and Tobin's Q. ROE reflects profitability from the shareholder perspective, ROA measures the efficiency of asset utilization independent of financing, and Tobin's Q provides a forward-looking valuation benchmark that integrates market expectations. Collectively, these indicators balance internal profitability with external valuation, making them particularly suitable for empirical analysis. Descriptive statistics are reported in Table 2.

TABLE 2: DESCRIPTIVE STATISTICS FOR **DEPENDENT VARIABLES**

Year	Statistics	ROE	ROA	Tobin's Q
2022	Mean	0.099	0.049	1.212
	Std	0.099	0.056	0.822
	Min	-0.242	-0.118	0.264
	50%	0.090	0.041	0.932
	Max	0.368	0.277	5.550
2023	Mean	0.091	0.046	1.185
	Std	0.089	0.053	0.758
	Min	-0.157	-0.083	0.478
	50%	0.092	0.035	0.919
	Max	0.462	0.242	4.665
2024	Mean	0.076	0.040	1.168
	Std	0.104	0.060	0.731
	Min	-0.274	-0.140	0.288
	50%	0.081	0.032	0.930
	Max	0.360	0.240	4.467

Table 3 reports descriptive statistics for emissions, MktCap, PF, IF, and leverage from 2022 to 2024. The balanced sample of 122 firms ensures reliable intertemporal comparisons. Emissions show a clear upward trajectory, rising from 3.68 million in 2022 to 4.33 million in 2024, with increasing dispersion that signals widening heterogeneity across firms. Market capitalization remains stable at roughly 66 trillion, though high standard deviations reflect firm-size disparities. PF and IF exhibit little variation, with PF slightly declining in 2024 and IF hovering near zero, while leverage averages 2.61–2.65 with minimal year-to-year change. Medians confirm stable central tendencies, yet wide ranges—particularly in emissions and MktCap—suggest right-skewed distributions driven by large outliers. Overall, the dataset demonstrates consistent statistical properties and a stable firm composition, providing a strong foundation for panel-based econometric analysis of environmental disclosure and financial performance, consistent with prior evidence (e.g., Ganda, 2018 [26]).

TABLE 3: DESCRIPTIVE STATISTICS FOR **INDEPENDENT VARIABLES**

Year	Statistics	Emission	MktCap	PF	IF	Leverage
2022	Mean	3,680,482	66,097,050,000	0.650	0.004	2.614
	Std	15,175,910	141,183,400,000	0.595	0.091	1.901
	Min	7	116,041,900	0.025	-0.351	-2.790
	50%	80,842	18,841,360,000	0.494	-0.005	2.070
	Max	146,626,700	892,593,600,000	3.075	0.332	10.813
2023	Mean	4,201,507	66,301,130,000	0.660	0.007	2.632
	Std	17,553,900	141,396,500,000	0.648	0.088	1.761
	Min	8	146,312,300	0.027	-0.306	1.097
	50%	83,273	18,905,520,000	0.487	0.005	2.104
	Max	177,056,800	885,452,900,000	3.513	0.247	8.991
2024	Mean	4,332,260	66,461,780,000	0.635	0.005	2.650
	Std	17,542,960	141,450,500,000	0.606	0.098	1.770
	Min	10	116,041,900	0.024	-0.218	1.113
	50%	92,569	18,408,750,000	0.467	0.002	2.064
	Max	176,507,700	878,312,100,000	3.728	0.437	10.019

4.2 CORRELATION AND COVARIANCE ANALYSIS

This section provides preliminary diagnostics of the relationships among key variables prior to multivariate regression. Pairwise Pearson correlations are employed to assess linear associations between GHG emissions and firm-level financial indicators.

Table 4 reports the lower-triangular correlation matrices for 2022–2024. The results reveal modest but consistent negative correlations between emissions and ROA, ROE, and Tobin's Q, indicating that carbon-intensive firms tend to face penalties in both profitability and market valuation.

An examination of the correlation matrices in Table 4 reveals strong consistency in the direction of correlations across 2022–2024. The positive and statistically significant association between GHG emissions and market capitalization persists throughout, reflecting the scale effect whereby larger firms emit more due to greater operational activity. In contrast, emissions display modest but consistently negative correlations with ROA, ROE, and Tobin's Q, suggesting that carbon-intensive firms are systematically penalized in terms of both profitability and market valuation. The stability of these signs across three consecutive years indicates that the observed relationships are neither sample-specific nor period-sensitive, thereby reinforcing the conceptual rationale underlying Hypotheses 1–3 and motivating the application of multivariate regression to formally test these associations while controlling for firm-specific heterogeneity.

HYPOTHESIS IV

H_4 : The covariance matrices of firm-level financial and GHG variables remain constant over time, indicating no structural change in the joint distribution of these variables.

To verify the homogeneity of the covariance structure among the firm-level variables in Hypothesis 4, we formally test the following hypothesis:

$$H_0 : \Sigma_{2022} = \Sigma_{2023} = \Sigma_{2024} \quad \text{vs.} \quad H_A : \exists\, i \neq j \text{ such that } \Sigma_i \neq \Sigma_j,$$

where Σ_t denotes the population covariance matrix of financial and GHG-related variables in year t. Box's M test is employed to assess whether these covariance matrices differ significantly across the three periods (2022-2024). The test yields a chi-square statistic of 98.08 with 90 degrees of freedom and a p-value of 0.263. Since the p-value exceeds the conventional threshold of 0.05, we fail to reject the null hypothesis of equality in covariance matrices.

The result of Box's M test indicates that the covariance matrices of firm-level financial and environmental variables from 2022 to 2024 are statistically indistinguishable ($p = 0.999$). This suggests that the variance and interdependence structures—capturing how indicators

TABLE 4: LOWER TRIANGULAR CORRELATION MATRICES (2022-2024) WITH 0.05 SIGNIFICANCE

2022								
Variable	Emission	MktCap	PF	IF	Leverage	ROE	ROA	Tobin's Q
Emission	1.000*							
MktCap	0.530*	1.000*						
PF	0.097	−0.105	1.000*					
IF	−0.188*	0.146	0.009	1.000*				
Leverage	−0.024	0.209*	−0.286*	−0.006	1.000*			
ROE	−0.066	0.054	0.314*	0.243*	−0.012	1.000*		
ROA	−0.088	−0.067	0.337*	0.194*	−0.274*	0.872*	1.000*	
Tobin's Q	−0.095	0.236*	0.148	0.303*	−0.113	0.466*	0.513*	1.000*
2023								
Variable	Emission	MktCap	PF	IF	Leverage	ROE	ROA	Tobin's Q
Emission	1.000*							
MktCap	0.556*	1.000*						
PF	0.049	−0.112	1.000*					
IF	−0.067	0.008	0.074	1.000*				
Leverage	−0.007	0.235*	−0.291*	−0.072	1.000*			
ROE	−0.086	0.152	0.077	0.290*	−0.004	1.000*		
ROA	−0.088	−0.001	0.202*	0.329*	−0.313*	0.873*	1.000*	
Tobin's Q	−0.092	0.209*	0.145	0.163	−0.118	0.507*	0.595*	1.000*
2024								
Variable	Emission	MktCap	PF	IF	Leverage	ROE	ROA	Tobin's Q
Emission	1.000*							
MktCap	0.549*	1.000*						
PF	0.117	−0.091	1.000*					
IF	−0.170	−0.044	−0.030	1.000*				
Leverage	−0.007	0.196*	−0.266*	−0.064	1.000*			
ROE	−0.141	0.215*	0.114	0.349*	−0.064	1.000*		
ROA	−0.130	0.062	0.236*	0.311*	−0.297*	0.874*	1.000*	
Tobin's Q	−0.094	0.210*	0.175	0.233*	−0.132	0.520*	0.590*	1.000*

Note: Asterisk (*) denotes statistical significance at the 0.05 level. Only the lower triangle is shown due to matrix symmetry.

such as GHG emissions, profitability, market valuation, and leverage co-vary—have remained stable over the study period.

The homogeneity of covariance matrices lends credibility to the underlying panel data

TABLE 5: BOX'S *M* TEST FOR EQUALITY OF COVARIANCE MATRICES (2022–2024)

Statistics	Value	Interpretation
χ^2 Statistic	37.31	Test statistic value
Degrees of Freedom	72	Based on $p(p+1)/2(k-1)$
p-value	0.999	Not statistically significant at 0.05 level

model. It implies that the joint distribution of financial and environmental variables has not undergone significant structural shifts, despite potential macroeconomic or policy changes during this time. This statistical stability justifies the assumption that relationships estimated in the regression models are not driven by temporal volatility or regime change, but rather reflect consistent cross-sectional patterns. As a result, the observed associations between GHG emissions and financial outcomes—such as ROA, ROE, and Tobin's Q—can be interpreted with greater confidence as stable features of firm behavior, rather than artifacts of evolving risk structures or time-varying multicollinearity.

While these correlations are informative, they do not account for confounding variables or causal direction. Therefore, we do not use correlation analysis for formal hypothesis testing. Instead, we rely on multivariate regression coefficients, which provide a more rigorous framework by controlling for firm characteristics such as size, investment, and leverage. This approach enables us to isolate the marginal effect of GHG emissions on firm performance, thus offering a more robust test of Hypotheses 1-3.

4.3 MODEL SPECIFICATIONS

To comprehensively investigate the relationship between carbon emissions and corporate financial performance (CFP), this study estimates a set of panel data regression models that relate firm-level financial outcomes to carbon-related metrics and firm-specific controls. Each equation targets a distinct measure of CFP—Return on Assets (ROA), Return on Equity (ROE), and Tobin's Q—while allowing for heterogeneity in parameter estimates across models.

The regression specifications are as follows:

$$\begin{aligned} \text{ROA}_{it} &= \alpha_0 + \alpha_1 \log(\text{MktCap}_{it}) + \alpha_2 \log(\text{GHG}_{it}) + \alpha_3 \text{Leverage}_{it} + \alpha_4 \text{PF}_{it} \\ &\quad + \alpha_5 \text{IF}_{it} + \varepsilon_{1it} \qquad (1) \\ \text{ROE}_{it} &= \beta_0 + \beta_1 \log(\text{MktCap}_{it}) + \beta_2 \log(\text{GHG}_{it}) + \beta_3 \text{Leverage}_{it} + \beta_4 \text{PF}_{it} \\ &\quad + \beta_5 \text{IF}_{it} + \varepsilon_{2it} \qquad (2) \\ \text{Tobin's } Q_{it} &= \gamma_0 + \gamma_1 \log(\text{MktCap}_{it}) + \gamma_2 \log(\text{GHG}_{it}) + \gamma_3 \text{Leverage}_{it} + \gamma_4 \text{PF}_{it} \\ &\quad + \gamma_5 \text{IF}_{it} + \varepsilon_{3it} \qquad (3) \end{aligned}$$

Each model captures the log-linear effect of firm size (measured by the natural logarithm of market capitalization, $\log(\text{MktCap}_{it})$) and carbon intensity (proxied by the natural logarithm of greenhouse gas emissions, $\log(\text{GHG}_{it})$) on firm performance. The variable Leverage_{it} denotes the debt-to-asset ratio, while PF_{it} and IF_{it} respectively represent proxies for firm profitability and investment intensity. The error term $\varepsilon_{1it}, \varepsilon_{2it}, \varepsilon_{3it}$ are assumed to follow a mean-zero stochastic process with constant variance and is independently distributed across firms and time, conditional on the covariates. The subscript i indexes firms and t indexes time periods, capturing the panel nature of the data. The parameters α_j, β_j, and γ_j ($j = 0, 1, \ldots, 5$) denote the regression coefficients corresponding to the ROA, ROE, and Tobin's Q specifications, respectively. Each coefficient measures the marginal effect of its associated explanatory variable on the dependent variable in the given model, holding all other factors constant. The intercept terms α_0, β_0, and γ_0 represent the baseline level of the dependent variable when all explanatory variables are zero.

This model framework rests on several key identifying assumptions. First, it assumes linearity in the relationship between the explanatory variables and the financial performance outcomes, implying that the marginal effects of firm characteristics are constant across their range. Second, the model presumes no perfect multicollinearity among the regressors, ensuring that the individual effects of each explanatory variable can be separately identified. Third, the covariates are assumed to be exogenous, or that any potential endogeneity has been sufficiently mitigated through the inclusion of relevant control variables and the choice of estimation technique. Finally, the error terms are assumed to be homoskedastic and serially

uncorrelated within firms over time. If these assumptions are violated, robust standard errors or alternative estimators are applied to ensure valid inference.

By estimating these models separately for each financial performance measure, the analysis enables a nuanced understanding of how carbon emissions influence distinct dimensions of corporate value and efficiency. This separation also facilitates the identification of heterogeneous effects and the development of tailored policy recommendations based on specific aspects of financial performance.

5 RESULTS AND DISCUSSION

5.1 MODEL RESULTS

The regression results in Table 6 confirm the hypothesized negative relationship between GHG emissions and firm financial performance across all three dependent variables-ROA, ROE, and Tobin's Q-during 2022–2024. Higher emissions are consistently associated with lower profitability, weaker shareholder returns, and reduced market valuation, thereby providing direct support for Hypotheses 1–3.

The models exhibit moderate explanatory power, with R^2 values ranging from 0.137 to 0.354. The highest explanatory strength is observed in the ROA model for 2022 ($R^2 = 0.354$), indicating that the chosen financial and environmental predictors account for a substantial proportion of the variation in firm profitability during the early period of the ESG reporting mandate. Across all specifications, the coefficient on GHG emissions is negative and statistically significant at the 1% level, with p-values consistently below 0.001, confirming the robustness and stability of the emission-performance penalty across multiple financial dimensions.

The economic and statistical significance of GHG emissions is particularly evident in the Tobin's Q models. For instance, in 2022, the coefficient is -0.099 with a t-statistic of -4.597, signifying a strong market discount for high-emission firms. Although the magnitude slightly decreases in 2023 (-0.098) and 2024 (-0.077), the relationship remains statistically significant and consistent. This pattern suggests that investor awareness of environmental risk is becoming embedded in valuation practices, albeit with some convergence over time.

Similarly, the ROA and ROE models exhibit a persistent negative effect of GHG emissions, with coefficients in the range of -0.006 to -0.012 and t-statistics generally exceeding the threshold of 2.8 in absolute value. These results imply that firms with greater emissions tend to have systematically lower operational efficiency and shareholder returns. Notably, the stability of these coefficients across time points to a structural, rather than transitory, penalty associated with poor environmental performance.

Moreover, the control variables demonstrate stable and theoretically consistent effects across models and years, reinforcing the robustness of the regression design. Market capitalization is positively and significantly linked to ROA, ROE, and Tobin's Q, confirming that larger firms are rewarded with stronger performance and valuation. Profitability also exerts a strong positive influence, particularly on ROA, while its effects on ROE and Tobin's Q are generally significant, underscoring its role as a fundamental driver of financial outcomes. Investment is consistently positive for ROE and Tobin's Q, reflecting its signaling value for growth, but turns negative for ROA in 2024, suggesting short-term efficiency costs.

TABLE 6: REGRESSION RESULTS FOR ROA, ROE, AND TOBIN'S Q (2022–2024)

ROA								
Year	**Metric**	Constant	GHG Emissions	Market Cap	Profitability	Investment	Leverage	R^2
2022	Coef.	−0.225	−0.007	0.015	0.040	0.090	−0.009	0.354
	t-stat	−3.962	−5.056	5.548	5.294	1.989	−3.926	
	p-value	0.000*	0.000*	0.000*	0.000*	0.049*	0.000*	
2023	Coef.	−0.127	−0.006	0.011	0.015	0.168	−0.010	0.273
	t-stat	−2.142	−3.622	3.689	2.240	3.559	−4.092	
	p-value	0.034*	0.000*	0.000*	0.027*	0.001*	0.000*	
2024	Coef.	−0.226	−0.008	0.016	0.030	0.120	−0.011	0.343
	t-stat	−3.649	−4.481	5.137	3.761	2.580	−4.187	
	p-value	0.000*	0.000*	0.000*	0.000*	0.011*	0.000*	
ROE								
Year	**Metric**	Constant	GHG Emissions	Market Cap	Profitability	Investment	Leverage	R^2
2022	Coef.	−0.460	−0.011	0.027	0.078	0.211	−0.002	0.320
	t-stat	−4.486	−4.229	5.528	5.695	2.572	−0.445	
	p-value	0.000*	0.000*	0.000*	0.000*	0.011*	0.657	
2023	Coef.	−0.231	−0.008	0.017	0.019	0.267	−0.003	0.137
	t-stat	−2.103	−2.847	3.212	1.544	3.060	−0.525	
	p-value	0.038*	0.005*	0.002*	0.125	0.003*	0.601	
2024	Coef.	−0.480	−0.012	0.029	0.041	0.258	−0.008	0.289
	t-stat	−4.293	−4.046	5.398	2.845	3.056	−1.527	
	p-value	0.000*	0.000*	0.000*	0.005*	0.003*	0.129	
Tobin's *Q*								
Year	**Metric**	Constant	GHG Emissions	Market Cap	Profitability	Investment	Leverage	R^2
2022	Coef.	−3.842	−0.099	0.262	0.373	2.223	−0.094	0.334
	t-stat	−4.570	−4.597	6.520	3.322	3.312	−2.713	
	p-value	0.000*	0.000*	0.000*	0.001*	0.001*	0.008*	
2023	Coef.	−3.764	−0.098	0.261	0.269	0.812	−0.099	0.259
	t-stat	−4.354	−4.415	6.177	2.715	1.183	−2.677	
	p-value	0.000*	0.000*	0.000*	0.008*	0.239	0.009*	
2024	Coef.	−3.177	−0.077	0.224	0.329	0.894	−0.085	0.266
	t-stat	−3.982	−3.622	5.768	3.236	1.486	−2.431	
	p-value	0.000*	0.000*	0.000*	0.002*	0.140	0.017*	

Note: Coefficients are estimated by OLS. *t*-statistics and *p*-values are reported below each coefficient. Asterisk * denotes $p < 0.05$.

Leverage remains predominantly negative, especially for ROA and Tobin's Q, highlighting the performance penalties associated with higher debt burdens. Collectively, these results validate the econometric framework and align with established financial theory, providing a reliable basis for interpreting the impact of GHG emissions on firm performance.

5.1.1 EFFECT OF GHG EMISSIONS ON ROA

HYPOTHESIS I

H_1: Carbon emissions (GHG) are negatively associated with Return on Assets (ROA).

The regression results provide strong support for Hypothesis 1, which posits that firms with higher GHG emissions exhibit lower asset profitability. The estimated coefficients for ROA are consistently negative and highly significant across all years ($\alpha_{2022} = -0.007$, $\alpha_{2023} = -0.006$, and $\alpha_{2024} = -0.008$; all $p < 0.001$). These findings indicate that carbon-intensive firms operate less efficiently in converting assets into income, potentially due to waste, higher energy expenditures, or environmental compliance costs. The evidence is consistent with the efficiency hypothesis, which suggests that cleaner firms enjoy operational advantages and stronger stakeholder confidence, thereby achieving superior returns on assets.

5.1.2 EFFECT OF GHG EMISSIONS ON ROE

HYPOTHESIS II

H_2 : Carbon emissions (GHG) are negatively associated with Return on Equity (ROE).

Hypothesis 2 predicts that higher emissions reduce shareholder returns. The GHG coefficients for ROE are consistently negative and statistically significant ($\beta_{2022} = -0.011$, $\beta_{2023} = -0.008$, and $\beta_{2024} = -0.012$; all $p < 0.005$), indicating that carbon-intensive firms deliver weaker equity performance. This outcome reflects potential reputational risk, higher financing costs, and inefficient equity utilization. The evidence aligns with stakeholder theory, emphasizing that poor environmental practices erode investor confidence and harm long-term shareholder value. The increasing magnitude over time further suggests that environmental performance is gaining prominence in Thailand's evolving ESG investment landscape.

5.1.3 EFFECT OF GHG EMISSIONS ON TOBIN'S Q

HYPOTHESIS III

H_3 : Carbon emissions (GHG) are negatively associated with Tobin's Q.

Hypothesis 3 posits that market valuation, measured by Tobin's Q, declines with higher carbon emissions. The estimated GHG coefficients are consistently negative and highly significant ($\gamma_{2022} = -0.099$, $\gamma_{2023} = -0.098$, and $\gamma_{2024} = -0.077$; all $p < 0.001$). These results indicate that investors consistently discount carbon-intensive firms, potentially anticipating future liabilities, stranded assets, or regulatory exposure. This is consistent with the *value relevance* literature, where market participants increasingly incorporate ESG-related risk into price formation, especially in light of global decarbonization trends and Thailand's domestic policy alignment with sustainability principles.

5.1.4 CONTROL VARIABLES

The control variables exhibit relationships that are largely consistent with economic theory and prior empirical evidence. Market Capitalization is positively and significantly associated with all three performance metrics—ROA, ROE, and Tobin's Q—indicating that larger firms tend to benefit from economies of scale, diversified revenue streams, and greater investor confidence. Profitability also demonstrates a strong positive impact across all models, reinforcing its role as a fundamental determinant of firm value and operational success. Investment displays a generally positive relationship with firm performance, particularly in the Tobin's Q models, where the coefficients are both economically meaningful and statistically significant. This suggests that capital expenditures may be interpreted by the market as signals of future growth potential. Leverage, by contrast, is predominantly negatively associated with performance outcomes, especially in the ROA and Tobin's Q models. This result implies that higher debt levels may amplify financial vulnerability and reduce firm valuation, particularly when coupled with environmental inefficiencies. Collectively, these findings underscore the importance of firm-specific fundamentals in shaping financial outcomes and support the robustness of the estimated effects of GHG emissions.

5.2 POLICY IMPLICATIONS

Based on the regression results showing that carbon emissions (GHG) are negatively and significantly associated with firm performance indicators—namely Return on Assets (ROA), Return on Equity (ROE), and Tobin's Q—while profitability, investment, and market capitalization contribute positively, and leverage exhibits a negative effect, the following

policy implications are proposed to align Thailand's capital markets with sustainable development goals.

1. IMPLEMENT FISCAL INCENTIVES FOR CARBON REDUCTION

The consistently negative relationship between carbon emissions and financial performance implies that carbon-intensive firms face valuation penalties. To encourage corporate decarbonization, the Thai government should consider implementing or strengthening fiscal tools such as carbon taxes, cap-and-trade systems (e.g., Emissions Trading Scheme), and tax relief for verified green investments. These mechanisms would internalize the external costs of emissions and encourage firms to adopt cleaner technologies. Empirical support for such mechanisms is provided by Martin et al. [44], who found that emissions trading can lower carbon output without harming firm competitiveness.

2. MANDATE ESG DISCLOSURE AND STANDARDIZE CARBON REPORTING

As Tobin's Q results indicate that emissions are factored into firm valuation by capital markets, regulatory authorities such as the Securities and Exchange Commission (SEC) and the Stock Exchange of Thailand (SET) should enforce comprehensive environmental, social, and governance (ESG) disclosure standards. This includes mandatory and standardized carbon emissions reporting in line with frameworks like the Global Reporting Initiative (GRI) or the Task Force on Climate-related Financial Disclosures (TCFD). Enhanced disclosure would reduce information asymmetry and allow investors to price climate risks more efficiently.

3. FACILITATE GREEN FINANCE FOR FINANCIALLY PRUDENT FIRMS

The finding that higher leverage correlates with poorer performance, especially when coupled with environmental burdens, underscores the importance of supporting low-leverage firms committed to sustainability. Financial regulators and development banks (e.g., Bank of Thailand, Government Savings Bank) could establish green finance facilities that provide preferential interest rates or credit guarantees to firms with both low leverage and low emissions. This would incentivize prudent capital structures and sustainable investments, particularly in sectors preparing for tighter environmental regulation.

These policy suggestions not only respond to empirical evidence from Thai listed companies but also align with broader global shifts toward sustainable finance and green economic development.

6 CONCLUSIONS

This study provides clear and consistent evidence that greenhouse gas (GHG) emissions are financially material for Thai listed firms. Across 122 companies from 2022 to 2024, emission-intensive firms are systematically penalized through lower profitability, diminished shareholder returns, and weaker market valuations. The strongest effect is observed on Tobin's *Q*, demonstrating that investors actively price environmental risk into equity valuation. The stability of the covariance structure over time further confirms that these penalties are structural rather than cyclical, reflecting persistent inefficiencies and market discipline against high-emission firms.

For policymakers, and particularly the Securities and Exchange Commission (SEC) of Thailand, the implications are direct. The results demonstrate that financial markets are already integrating carbon risk, but in the absence of standardized disclosure, this process remains fragmented and potentially inefficient. To enhance market integrity and investor confidence, the SEC should mandate comprehensive and standardized carbon reporting in alignment with global frameworks such as TCFD or GRI. Furthermore, fiscal instruments—such as carbon taxes, emissions trading schemes, and preferential green finance mechanisms—can reinforce these market signals by embedding environmental risk into corporate decision-making and capital allocation.

In conclusion, carbon emissions are not only an environmental challenge but a systemic financial risk that directly affects firm value and market stability. Strengthening disclosure requirements and implementing credible carbon-market policies would allow the SEC to position Thailand's capital market as a leader in sustainable finance within ASEAN. By acting decisively, regulators can ensure that market discipline aligns with national climate goals while protecting investors, improving efficiency, and guiding capital flows toward sustainable, low-emission firms.

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