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CO_2 emissions and bank stability – evidence from Southeast Asia countries

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Abstract: This study examines the impact of CO_2 emissions on the financial stability of commercial banks in Southeast Asia, measured by the Z-score. Recognizing climate change as a systemic threat, the research highlights how climate change can erode banks' stability. Using panel data from 22 banks across Malaysia, the Philippines, Thailand, and Indonesia during 2012–2023, the study employs robust econometric models, including system GMM, to capture dynamic and nonlinear effects. The findings reveal a significant U-shaped relationship between CO_2 emissions and banking stability: higher CO_2 emissions initially decrease bank stability, but beyond a certain threshold, further increases in emissions positively affect stability, possibly due to enhanced regulatory frameworks, technological innovation, and improved risk management associated with the transition to a low-carbon economy. The study also sheds light on the impact of bank-related variables such as bank size, leverage, and loan-to-deposit ratio, as well as macroeconomic variables like GDP and CPI on bank stability. This research contributes empirical evidence on climate-finance linkages in emerging markets and offers insights for policymakers and financial institutions to integrate environmental risks within supervisory frameworks and risk management strategies to ensure their stability.

Keywords: *Climate change, Bank stability, CO_2 emissions.*

1. Introduction

Climate change and related environmental shocks are increasingly recognized as systemic threats to both economies and financial systems. In particular, higher levels of CO_2 emissions and climate risk factors have been shown to undermine banking stability. These effects manifest through both physical risks—such as natural disasters and extreme weather events—and transition risks, which stem from regulatory, technological, and market adjustments in the shift toward a low-carbon economy. Both types of risk can disrupt borrowers' financial capacity, damage collateral, or increase operational costs, thereby raising credit risk for lending institutions, eroding the bank's stability [1].

Banks' loan portfolios are a primary transmission channel through which climate-related risks impact the financial system. Firms operating in carbon-intensive industries are especially vulnerable to climate regulations and physical events, which may lead to increased default risk [2]. Empirical research has demonstrated a clear linkage between the carbon intensity of loan portfolios and bank stability, proxied by Z-score. Studies in China and Egypt have shown that banks with higher exposure to carbon-heavy sectors tend to experience more significant loan defaults [3, 4]. In Europe, sectors like energy and utilities are found to carry disproportionate climate transition risks, reflected in the high carbon footprints of their associated loans [5].

At a broader level, cross-country evidence consistently shows that climate change has a negative impact on bank performance and stability indicators. Several international and regional studies confirm that rising CO_2 emissions are associated with deteriorating financial soundness, including higher NPLs, lower profitability, and declining capital adequacy [6]. While green financing and renewable energy policies may help mitigate some of these effects, climate-related disruptions continue to pose substantial

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systemic risks. Consequently, regulatory authorities across the globe are increasingly mandating climate-related stress testing and integrating environmental risk factors into prudential supervision frameworks. Institutions such as the European Central Bank (ECB), the Bank of England, and the European Banking Authority (EBA) have introduced specific guidelines and supervisory expectations related to climate and environmental risks.

Southeast Asia is a critical yet underexplored area. As one of the most climate-vulnerable regions globally, Southeast Asian countries face frequent and severe weather-related shocks—including floods, storms, and rising sea levels—that threaten economic stability and increase financial sector risks [7]. Elevated CO_2 emissions, driven largely by industrial expansion and reliance on fossil fuels, exacerbate these risks by contributing to environmental degradation and triggering stricter regulatory responses. These factors translate into higher credit risks, asset quality deterioration, and increased non-performing loans within banks heavily exposed to carbon-intensive sectors [8]. Despite these pressing challenges, research on the interaction between CO_2 exposure and bank stability in the Vietnamese banking sector remains limited. This study aims to address that gap by exploring the relationship between the carbon footprint and bank stability, proxied by Z-score. In doing so, it contributes to a growing body of literature on climate finance and offers evidence-based insights for regulators, banks, and policymakers concerned with financial system resilience in the face of climate change.

The structure of the paper is organized as follows. Section 2 provides a literature review on climate change and the impact of CO2 emissions on bank stability. Section 3 provides the research methodology, model results and discussion, and Section 5 gives the conclusion and limitations of the research

2. Literature Review

Over the past decade, a growing body of academic literature has emerged examining the intersection between environmental risk—particularly CO_2 emissions—and financial sector vulnerability. One of the most recurrent findings across these studies is the adverse impact of climate-related risks on banks' asset quality, as evidenced by rising non-performing loan (NPL) ratios. Early contributions, such as Guan, et al. [4] laid the foundation by introducing the concept of "carbon intensity of loans," highlighting that banks with greater exposure to carbon-intensive borrowers experienced significantly higher NPLs in China. Their findings point to a direct link between environmental unsustainability and financial fragility, particularly in economies undergoing rapid industrial expansion with limited environmental safeguards.

This finding has since been corroborated in other emerging market contexts. Mahmud [9] showed that Egyptian banks heavily involved in fossil fuel and emission-intensive industries faced a greater probability of loan defaults. In their study, loan quality deteriorated as climate-related transition risks—such as regulatory tightening and global decarbonization trends—adversely affected firms' solvency. Similarly, Di Febo [10] analyzed banks in the Eurozone and found that loans to carbon-intensive sectors like utilities, energy, and manufacturing accounted for a disproportionate share of credit risk. Their research emphasized the importance of sectoral exposure in assessing banks' climate vulnerability, particularly with regard to transition risks. Masunda [11] assessed the impact of climate risk on the financial sector stability of the selected SADC countries with similar climate-related shocks (rising CO_2 emissions) and found a negative relationship between climate risk and financial stability (Z-score) but a positive impact of climate risk on lending activities.

While these studies primarily focused on individual countries or regions, a number of cross-country analyses have further generalized these relationships. Agbloyor, et al. [12] investigated data from 122 countries and identified a nonlinear, inverted U-shaped relationship between CO_2 emissions and banking stability. Initially, as emissions rose in line with industrial growth, banks benefited from expanding economic activity. However, beyond a certain threshold, the negative consequences of environmental degradation—including declining public health, resource depletion, and natural disasters—began to outweigh the benefits, undermining banking performance. This insight is particularly useful in understanding the dynamic and non-monotonic nature of climate-financial linkages.

In addition to credit risk, climate change also impacts banks through changes in credit supply. Li and Wu [13] drawing on data from more than 400 Chinese commercial banks, demonstrated that increased climate risk leads to a reduction in credit supply. This reduction is primarily due to increased risk aversion, tighter lending standards, and declining deposit bases—especially in regions more exposed to environmental volatility. Their findings also suggest that state-led climate adaptation policies and accommodative monetary policy can partially mitigate the contraction in credit, though not completely offset it. Interestingly, banks with larger capital buffers or greater digital penetration showed greater resilience to climate-induced financial tightening.

A subset of studies has also explored how climate policy uncertainty influences financial stability. Dai and Zhang [14] found that rising ambiguity about future climate regulation increases banks' insolvency risk, as measured by Z-scores, using data from 210 Chinese commercial banks (2009–2020). Similarly, Do, et al. [15] investigated the impact of natural disasters on the U.S. banking system and discovered that banks located in disaster-prone areas had significantly weaker financial performance indicators, including lower ROA and capital adequacy ratios. Their study, utilizing data from the Spatial Hazard Events and Losses Database, reinforces the idea that physical climate events can erode banks' financial buffers.

Scholars have also paid increasing attention to the direct impact of natural disasters on loan quality and bank resilience. Özsoy, et al. [16] found that droughts in Turkey significantly worsened credit quality and bank profitability. Using Z-scores, ROA, and NPL ratios, they showed how environmental shocks translate into financial distress. Similarly, Schüwer, et al. [17] analyzed the aftermath of Hishamuddin, et al. [18] in the United States and observed a 0.12 standard deviation decline in bank Z-scores for institutions exposed to the disaster area, confirming the causal relationship between extreme weather events and reduced financial soundness.

In summary, the existing literature strongly supports the hypothesis that CO_2 emissions—through both physical and transition risks—have a detrimental effect on banking stability. However, gaps remain in understanding the scope, strength, and conditionality of this relationship across different contexts. This study addresses these shortcomings by focusing on the Southeast Asia banking sector, aiming to empirically assess the impact of carbon exposure on bank stability while accounting for macroeconomic conditions and sectoral characteristics.

3. Methodology

The research model is developed based on prior studies, including those by Agbloyor, et al. [12]; Le, et al. [6], Kamran, et al. [19]. These studies assess the impact of CO_2 emissions and several key financial factors on banking stability. Therefore, the research model in this study is designed and adjusted accordingly to focus on analyzing the relationship between CO_2 emissions and the stability of commercial banks in the ASEAN region, while controlling for relevant financial variables. The proposed research model is presented as follows:

$$\text{Z-Score}_{i,t} = \beta_1 \text{TotalCO2}_{i,t} + \beta_2 \text{CO2sq}_{i,t} + \beta_3 \text{LDR}_{i,t} + \beta_4 \text{CPI}_t + \beta_5 \text{GDP}_t + \beta_6 \text{SIZE}_{i,t} + \beta_7 \text{ROE}_{i,t} + \beta_8 \text{LEV}_{i,t} + \varepsilon_{i,t}$$

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Table 1.
Description of model variables.

Variable	Code	Description	Data source	Reference
Dependent Variable	Zscore	$\frac{(\frac{E_{n,i,t}}{TA_{n,i,t}} + ROA_{n,i,t})}{\sigma(ROA_{n,i,t})}$	Authors' calculation from financial statement data, obtained from the Workspace database of the London Stock Exchange.	Li and Wu [13]; Chiaramonte, et al. [20] and Agbloyor, et al. [12]
Independent variable	Total CO2	Total carbon dioxide emissions per capita	World Bank	Wu, et al. [21] and Dafermos, et al. [22]
	CO2sq	Squared CO_2 emissions	Authors' calculation	Wu, et al. [21] and Dafermos, et al. [22]
Control variables	SIZE	Total bank's assets	Workspace database of London stock exchange	Wu, et al. [21] and Misra and Dhal [23]
	LEV	$\frac{Total\ liabilities_{i,t}}{Total\ assets_{i,t}}$	Authors' calculation from financial statement data, obtained from the Workspace database of the London Stock Exchange.	Adrian and Shin [24]; Berrospide and Edge [25] and Acharya, et al. [26].
	LDR	$\frac{Loan_{i,t}}{Deposit_{i,t}}$	Authors' calculation from financial statement data, obtained from the Workspace database of the London Stock Exchange.	Hodula and Polouček [27] and Le, et al. [6]
	ROE	$\frac{Earnings\ after\ tax_{i,t}}{Equity_{i,t}}$	Authors' calculation from financial statement data, obtained from the Workspace database of the London Stock Exchange.	Chiaramonte, et al. [20] and Laeven and Levine [28]
	GDP	Gross Domestic Product	World Bank	Le, et al. [6]
	CPI	Consumer Price Index	World Bank	Agbloyor, et al. [12] and Le, et al. [6]

Source: Synthesis from research results.

CO_2 emissions are considered a critical variable and play a central role in analyzing the stability of commercial banks. This variable reflects the extent of environmental pressures and the transition risks that banks face in the context of accelerating climate change. From the perspective of modern financial theory, CO_2 emissions represent not only an indicator of industrialization but also a source of both physical risks and transition risks to the financial system. This viewpoint is reinforced by various empirical studies, including those of Agbloyor, et al. [12] which reveal that climate change poses substantial burdens on economic growth, particularly within the financial sector. Moreover, findings by Agbloyor, et al. [12] indicate that in the early stages, rising CO_2 emissions can drive economic growth and improve debt repayment capacity through industrialization, thereby enhancing banking stability. While there has been limited research testing the non-linear impact of CO_2 emissions on banking stability, this study provides evidence of a non-linear relationship between CO_2 emissions and financial stability: when emissions surpass a certain threshold, the adverse consequences of climate change—such as asset damage, business disruptions, and the rising costs of regulatory compliance—may weaken banks' financial foundations, increase credit risks, and ultimately undermine bank stability.
Based on this rationale, the following hypothesis is proposed:

H_1: CO_2 emissions have a nonlinear relationship with banking stability.

4. Results and Discussion

The research data were collected and computed based on the annual reports of 22 commercial banks (CBs) in Malaysia, the Philippines, Thailand và Indonesia over the period 2012–2023. Upon completion of the data processing stage, the variables were compiled and analyzed using descriptive statistical methods to highlight the key characteristics of the research dataset. The descriptive statistics of the variables included in the model are presented in the following table:

Table 2.
Descriptive statistics of variables.

Variable	Obs.	Mean	Std. dev.	Min.	Max.
Zscore	264	43.65516	29.45314	6.149454	163.3497
TotalCO2	264	4.69263	2.895036	0.8777713	8.289891
CO2sq	264	30.37026	27.47803	0.7704825	68.72229
Size	264	24.52677	0.9877791	22.56729	26.8118
LDR	256	1.046188	1.406125	0.4787172	21.3683
ROE	264	0.116966	0.0547019	-0.2550029	0.3162052
LEV	264	0.8876518	0.0248982	0.8112799	0.944664
CPI	264	2.573424	1.76806	-1.138702	6.412513
GDP	264	489.3541	280.2265	261.9205	1371.171

Source: Synthesis from research results.

To identify the most appropriate model specification, the study employs regression analyses using Ordinary Least Squares (OLS), Fixed Effects Model (FEM), and Random Effects Model (REM). OLS is initially applied as a preliminary analysis to provide a general overview of the relationships among variables. Subsequently, FEM and REM are implemented to control for unobserved heterogeneity specific to individual banks, which may otherwise bias the results. To determine the optimal model, the Hausman test is conducted to compare FEM and REM, thereby facilitating the selection of the model that best fits the empirical data. Furthermore, to address potential endogeneity among the explanatory variables, the study adopts the two-step Generalized Method of Moments (GMM) estimator, which is widely recognized for its effectiveness in correcting estimation bias and enhancing the robustness of the results. The GMM estimation outcomes are presented in these following table.

Table 3.
Two-step system GMM results.

Group variable: bank	Number of obs. = 238
Time variable: Year	Number of groups = 22
Number of instruments = 14	Obs. per group: min = 7
F (**9, 21**) = 89.97	avg = 10.82
Prob > F = 0.000	max = 11

Zscore	Coefficient	Std.err.	t	P > |t|	[95% conf.	interval]
Zscore. L1	0.8091246	0.1132646	7.14	0.000	0.5735779	1.044671
TotalCO2	-2.368575	1.1419	-2.07	0.051	-4.743287	0.0061365
CO2sq	0.3315225	0.0944393	3.51	0.002	0.1351252	0.5279198
Size	1.156309	0.5664118	2.04	0.054	-0.216091	2.334227
LDR	7.409445	2.565712	2.89	0.009	2.073755	12.74513
ROE	10.25459	1.319123	7.77	0.000	7.511328	12.99786
LEV	-71.39506	18.21845	-3.92	0.001	-109.2824	-33.50772
CPI	-0.5299337	0.1307561	-4.05	0.001	-0.8018559	-0.2580115
GDP	-0.0042615	0.0031439	-1.36	0.190	-0.0107996	0.0022766
_cons	39.83981	19.08777	2.09	0.049	0.1446265	79.535

The impact of CO_2 emissions on banking system stability is evident through their effects on bank stability (Z-score). The results show that TotalCO_2 carries a negative coefficient (-2.368575), significant at the 5% level, indicating that higher levels of CO_2 emissions are associated with a decline in banks' overall financial stability. This result is consistent with Mahmood, et al. [29] and Nabil [30] who confirm the negative impact of CO2 emissions on bank stability in Pakistan. This may happen because higher emissions reflect greater exposure to environmental risks, increased credit risk for banks and as a result, it may negatively impact bank stability. An intriguing finding arises when introducing the

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squared CO_2 term (CO2sq), which captures non-linear effects. The model reveals a U-shaped relationship when the coefficient of the squared CO_2 is positive (0.3315, $p = 0.002$). These results imply that beyond a certain threshold, increasing CO_2 emissions contribute to enhancing stability. When economic emissions reach very high levels, governments and markets usually introduce stricter regulations, promote technological innovation, and enhance environmental risk management. Banks' adaptation through green financial innovation, sustainable investment, and ESG-oriented governance can foster long-term positive impacts. These findings reinforce the argument that banks operating in high-emission economies are entering a transition phase in which the ability to adapt to environmental risks plays a critical role in maintaining systemic stability.

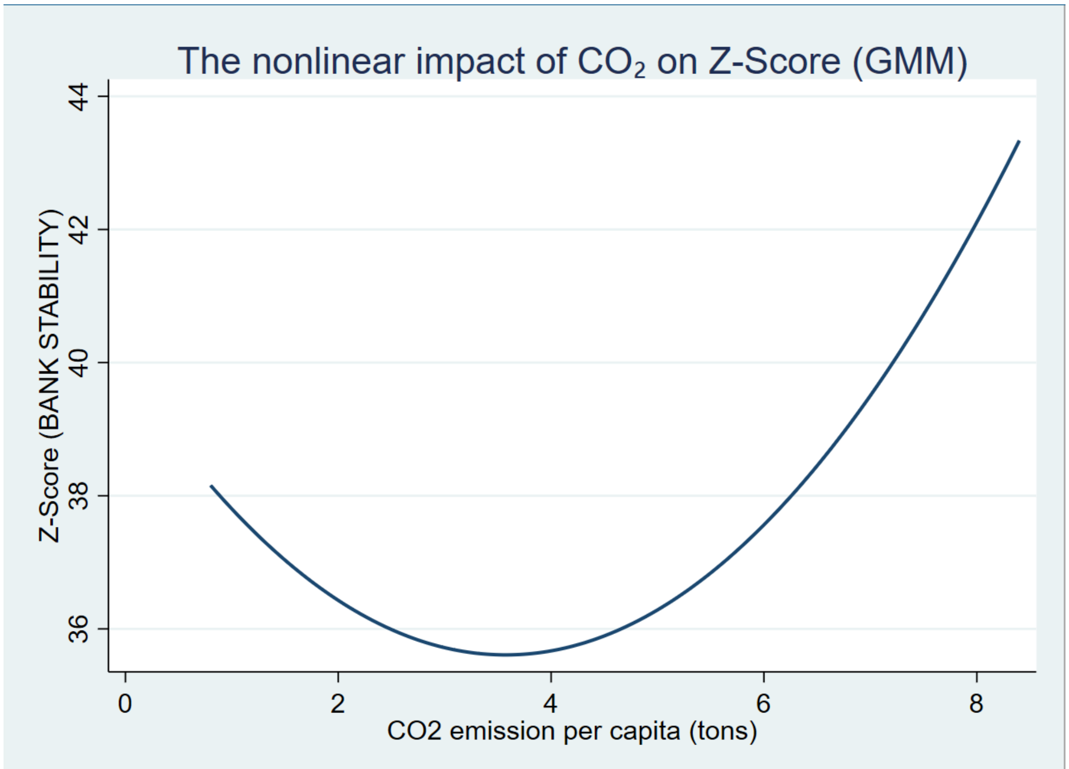

Figure 1.
The nonlinear impact of CO_2 on Z-score.
Source: Results from the GMM model

Bank size emerges as an important determinant in the model, suggesting that larger banks tend to exhibit greater stability. The result shows size exhibits a positive coefficient (1.1563, significant at 5%), affirming that bank size contributes to a more solid financial foundation and enhances resilience to economic shocks [25, 31].

Similarly, the Loan-to-Deposit Ratio (LDR) demonstrates a positive contribution to financial stability with a coefficient of 7.41. These results suggest that efficient use of mobilized funds can help improve bank stability as measured by the Z-score, possibly due to credit being extended in healthier economic conditions and to more creditworthy borrowers, which enables banks to make profits from mobilized capital.

The model also shed light on the effects of financial leverage (LEV) to bank stability. LEV exhibits a strongly negative coefficient (-71.39, $p < 0.01$), indicating that high leverage undermines the bank's financial foundation and increases its vulnerability to external shocks. This occurs because excessive reliance on borrowed funds makes a bank more vulnerable to adverse shocks, increases the volatility of returns, and diminishes its loss absorption capacity. When leverage is high, profit fluctuations and potential losses are magnified relative to the bank's equity base, making insolvency more likely [32].

Return on Equity (ROE) shows a strong positive effect (coefficient 10.2545, $p < 0.01$). This result is consistent with expectations, as ROE measures the efficiency of equity utilization—an essential element of financial stability. Banks with high ROE typically accumulate capital more effectively, improve their capital adequacy, and are better equipped to absorb market fluctuations. This relationship is also found in Nwachukwu and Nwosu [33] and Schüwer, et al. [17].

For the macroeconomic variables, while the impact of GDP on the Z-score is statistically insignificant, the Consumer Price Index (CPI) shows a negative effect with financial stability (-0.5299, $p = 0.009$), implying that prolonged inflationary pressure can erode bank profitability and weaken their financial standing [34, 35].

5. Conclusion

This study has empirically examined the impact of CO_2 emissions on the financial stability of commercial banks in Southeast Asia, measured by Z-score. Utilizing panel data from 22 banks across Malaysia, the Philippines, Thailand, and Indonesia during 2012–2023, the analysis reveals a significant nonlinear relationship between carbon emissions and banking stability. Initially, rising CO_2 emissions negatively impact bank stability as high CO_2 emissions might trigger environmental risks, which erode bank stability. However, beyond a certain emission threshold, the increase of CO2 emissions improves bank stability; potentially due to intensified risk management, regulatory adaptation, and the rise of green finance initiatives. In addition to environmental variables, this research highlights the positive impacts of bank size, loan-to-deposit ratio, and return on equity, and the detrimental effect of leverage on financial resilience. The insignificant effect of GDP and the negative influence of sustained inflation also underscore the importance of both microeconomic and macroeconomic factors in shaping banking system vulnerability. The findings emphasize that climate-related financial risks are becoming material factors affecting banking sector soundness, highlighting the need for policymakers and regulatory institutions to integrate environmental considerations into financial supervision and risk management frameworks to ensure long-term stability. Despite the robust design, this study has some limitations. First, the sample is restricted to 22 commercial banks from four Southeast Asian economies, which may limit the external validity and generalizability of results to other regions or banking sectors with different regulatory structures. Second, CO_2 emissions are used as a singular proxy for environmental risk, omitting other climate-related variables such as water stress, biodiversity loss, and detailed measures of physical climate risk. Third, the analysis focuses on annual panel data over a relatively short period (2012–2023), which may not fully capture longer-term trends and delayed effects of climate policies or economic transformation. Future research should broaden the country and bank coverage, extend the observation period, and incorporate multidimensional climate risk indicators to offer more comprehensive insights into the climate–finance nexus.

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Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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