Journal of Finance - Marketing Research; Vol. 3, Issue 4; 2025
ISSN: 3030-4296
DOI: https://doi.org/10.52932/jfmr.v3i4en

Journal of Finance - Marketing Research
http://jfm.ufm.edu.vn

FIRMS UNDER GREEN TRANSITION PRESSURE: THE LINK BETWEEN CARBON EMISSIONS AND BANKRUPTCY RISK

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ARTICLE INFO

DOI:
10.52932/jfmr.v3i4en.1020

Received:
July 13, 2025
Accepted:
October 14, 2025
Published:
November 25, 2025

Keywords:
Carbon emissions; Climate risk; Corporate bankruptcy risk; Ohlson's O-score.

JEL codes:
G22, G24, G28, G3, G32, G33

ABSTRACT

Climate change has been reshaping the way firms approach financial strategies and risk management. This study explores the relationship between carbon emissions and corporate bankruptcy risk, using Ohlson's O-score as a proxy for financial deterioration, with the O-score treated as a continuous measure of default risk. Drawing on a panel dataset comprising 15,146 firm-year observations from publicly listed companies in Vietnam during the period 2012-2023, the study employs ordinary least squares with firm and year fixed effects (multi-dimensional FE) and cluster-robust standard errors at the firm level to examine the impact of two carbon emission indicators, CarbonSales and CarbonAssets, on firms' probability of bankruptcy. The regression results indicate a positive and statistically significant relationship between carbon emissions and Ohlson's O-score, implying that higher emissions are associated with an increased risk of bankruptcy. This finding remains robust after controlling for financial variables such as firm size, profitability, leverage, and cash flow and is consistent across the two alternative emission normalizations (CarbonSales and CarbonAssets). Methodologically, the paper contributes by integrating firm-level carbon-emission intensity into a standard bankruptcy-risk model with multi-dimensional fixed effects and by assembling a large emerging-market panel for Vietnam (15,146 firm-years, 2012-2023) that links emissions to O-score. Relative to prior work, our evidence from Vietnam fills a gap on emerging markets, where firm-level emission data are rarely combined with bankruptcy models. The results suggest that climate-related risks are quantifiable financial factors that should be integrated into corporate risk management frameworks and macro-financial policy design. Our findings inform banks' green-credit screening, supervisors' systemic-risk assessment, and the design of climate-related early-warning systems during the green transition.

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1. Introduction

Climate change has emerged as a global risk factor, exerting substantial impacts on the financial stability of both firms and national economies. One of the key mechanisms through which climate change affects the corporate sector is by increasing firm-level financial vulnerability, including the risk of bankruptcy. Carbon emissions, both a cause and an indicator of climate-related activities, have become central to discussions on sustainable finance, regulatory pressures, and investor behavior. As economies transition toward low-carbon development, firms with large carbon footprints may face heightened exposure to both the physical consequences of climate change and policy responses during the transition process (Feng et al., 2024; Liu et al., 2025). In Vietnam's enterprise landscape, characterized by a bank-centered financial system, rapidly expanding yet still shallow capital markets, and a production base concentrated in emission-intensive manufacturing, materials, energy, and utilities, climate risk is transmitted to firms through tighter lending conditions (e.g., green-credit screening), higher refinancing costs, and disruption risks to export-oriented supply chains. Theoretically, we posit two complementary channels for Vietnamese firms: a transition-risk channel operating via credit supply and regulatory pressure, and a physical-risk channel operating via cash-flow volatility and asset impairment, both of which raise default risk measured by the O-score. Within this context, understanding the relationship between carbon emissions and corporate bankruptcy risk becomes especially important for stakeholders such as investors, creditors, regulators, and policymakers, particularly for Vietnam.

Globally, a growing body of academic literature has examined the relationship between carbon risk and financial distress, primarily focusing on developed economies (Jung et al., 2018; Pizzutilo et al., 2020). These studies reveal that high-carbon-emitting firms tend to incur higher capital costs, are assessed as riskier by financial institutions, and experience greater volatility in earnings and cash flows. Climate-related risks are typically categorized into two major types: physical risk and transition risk (TCFD, 2017). Both categories can disrupt business operations, either through extreme weather events or through regulatory, consumer preference, or technological shifts. However, evidence from bank-dominated emerging markets remains limited, leaving open whether these mechanisms operate similarly for Vietnamese enterprises.

In emerging markets such as Vietnam, this research topic is particularly relevant due to the country's high vulnerability to climate change and its commitment to achieving net-zero emissions by 2050. Vietnam has actively engaged with global climate frameworks, exemplified by its ratification of the Paris Agreement and subsequent national-level actions. However, empirical studies investigating the effects of climate-related risks, especially carbon emissions, on the financial distress of Vietnamese firms remain limited. Most existing research in Vietnam has focused on environmental factors influencing firm performance or ESG disclosures, leaving a substantial gap in understanding bankruptcy risk from the perspective of carbon exposure. To anchor the discussion in Vietnam's practical context, our dataset comprises publicly listed enterprises on the HOSE and HNX exchanges, where external finance is predominantly bank-based. In our sample, emission-intensive sectors (materials, industrials, utilities, and energy) account for a large share of firm-year observations, providing direct empirical grounding for the Vietnamese setting. Descriptive patterns show substantial dispersion and right-skewness in

carbon intensity across firms and over time, consistent with heterogeneous exposure to climate-related risks.

From a methodological standpoint, Ohlson's O-score model (Ohlson, 1980) remains one of the most widely used accounting-based tools for predicting corporate bankruptcy. The model incorporates a set of financial ratios and binary variables to estimate the probability of firm default. However, it has rarely been applied in conjunction with environmental or carbon-related variables. This study seeks to fill that gap by extending the Ohlson O-score model with firm-level carbon efficiency indicators, specifically carbon emission intensity, which reflects the degree to which firms rely on emission-intensive operations and carbon-related assets. Linking this framework to Vietnam's practice, where bank loans constitute the principal source of external finance, we interpret higher carbon intensity as tightening firms' access to credit and elevating refinancing and compliance costs, thereby increasing O-scores through both the transition-risk and physical-risk channels.

The study utilizes panel data consisting of over 15,146 firm-year observations from publicly listed companies in Vietnam between 2012 and 2023. We employ linear regression models with multi-dimensional fixed effects. The dependent variable is the bankruptcy risk as measured by Ohlson's O-score, while the key independent variables are firm-level carbon emission indicators. Control variables include firm size, financial leverage, cash flow, tangible fixed assets, and other firm characteristics. The sample covers non-financial firms on HOSE/HNX; carbon indicators are normalized by sales and by total assets to capture operating and balance-sheet exposure; variables are winsorized at the 1st–99th percentiles; standard errors are clustered at the firm level; and firm fixed effects are included to absorb time-invariant heterogeneity. The analysis incorporates industry- and year-fixed effects, as well as industry-year interactions for robustness checks. The results consistently indicate that higher values of CarbonSales and CarbonAssets are positively and significantly associated with Ohlson's O-score, suggesting a higher probability of bankruptcy. These findings remain robust across all model specifications, even after adding various control variables and fixed effects.

This research contributes to the existing literature in three main ways. First, it is among the first empirical studies to examine the relationship between carbon emissions and bankruptcy risk in an emerging market context using the Ohlson O-score model. Second, it integrates new firm-level carbon indicators into traditional bankruptcy prediction frameworks. Third, by focusing on Vietnam, the study offers context-specific insights that are valuable for policy development, especially as the country accelerates efforts to align with international climate commitments. Fourth, we articulate and test a Vietnam-specific theoretical–practical framework, bank-centered finance, green-credit screening, and high exposure to climate hazards, using granular firm-year evidence from 2012-2023.

The remainder of the paper is structured as follows. Section 2 provides a literature review on climate risk and bankruptcy. Section 3 outlines the research design, data sources, and empirical methodology. Section 4 presents the regression results and robustness checks. Section 5 discusses policy implications and the practical relevance of the findings. Finally, Section 6 concludes with limitations and suggestions for future research.

2. Literature review

The growing recognition of climate change as a systemic financial risk has spurred the rapid

development of interdisciplinary research, with a particular focus on the impact of carbon emissions on firm-level financial outcomes. Within this context, a critical stream of the literature has explored how carbon intensity, emission performance, and environmental disclosures influence firm value, bankruptcy risk, capital costs, and investor perception. Framing these elements within the green transition, we define the transition as a policy-, technology-, and market-driven reallocation of capital from high- to low-carbon activities, operationalized through instruments such as carbon pricing, disclosure mandates, green taxonomies, and bank green-credit guidelines. Under this regime, firm carbon emissions are not only environmental outcomes but also economic signals that proxy (i) exposure to policy penalties and compliance costs, (ii) technological obsolescence/asset stranding, and (iii) demand substitution toward greener products, each eroding cash flows and elevating default risk.

Numerous empirical studies have confirmed a positive relationship between firm-level carbon emissions and the likelihood of financial distress. Kabir et al. (2021) provided international evidence that firms with higher emissions are more likely to default, particularly in carbon-intensive industries and in countries with stringent environmental regulations. Similarly, Capasso et al. (2020) found that exposure to carbon risk increases bankruptcy risk, especially after the signing of the Paris Agreement. Duong et al. (2022) also supported these findings, demonstrating that sound carbon risk management is associated with lower credit default swap (CDS) spreads, reflecting investor confidence in firms with proactive climate strategies. Wang et al. (2022) further asserted that carbon risk is a key determinant of firms' financial vulnerability under policy, market, and reputational shocks related to the low-carbon transition. These results are theoretically consistent with a cash-flow channel (lower margins from abatement and carbon costs), a cost-of-capital channel (higher required returns from lenders and investors), and a collateral channel (devaluation of carbon-intensive assets), all of which tighten firms' distance-to-default.

While the Ohlson's O-score model (Ohlson, 1980) remains a widely used tool for predicting corporate bankruptcy due to its simplicity and strong predictive power, it has only recently been extended to incorporate environmental variables. Feng et al. (2024) integrated climate exposure into the Ohlson model and found that firms operating in sectors with higher carbon intensity exhibited a greater probability of bankruptcy. This approach aligns with the broader trend of re-evaluating traditional financial risk models by incorporating ESG factors into risk analysis frameworks. Nguyen et al. (2023) further advanced this literature by proposing a cumulative climate risk factor capable of explaining financial distress probabilities across global firms. These studies collectively suggest that integrating carbon indicators into traditional bankruptcy prediction models improves their relevance and forecasting accuracy in the context of increasingly complex climate risks. Conceptually, the O-score aggregates profitability, leverage, liquidity, and growth signals; the green transition affects these very levers, via compliance expenditures that depress profitability, investment needs that raise leverage, and cash-flow volatility that weakens liquidity, thereby providing a coherent theoretical basis for embedding carbon metrics into bankruptcy models.

Environmental disclosure also plays a critical role in mitigating carbon risk and reducing capital costs. Bui et al. (2020) and Kim et al. (2022) showed that higher carbon intensity significantly raises the cost of equity; however, firms that transparently disclose their emissions can partially offset this increase.

Bernardini et al. (2021), studying European utility firms, found that lower-emitting firms achieved higher risk-adjusted returns. From the perspective of debt financing, Jung et al. (2018) and Mueller & Sfrappini (2022) revealed that banks apply higher interest spreads to firms with poor environmental performance, particularly after the Paris Agreement. Nonetheless, firms with robust climate risk governance may enjoy reduced borrowing costs. Furthermore, the distinction between direct (Scope 1) and indirect (Scope 2) emissions is meaningful for risk pricing: financial institutions tend to focus more on Scope 1 emissions, whereas equity investors typically evaluate broader ESG metrics, including Scope 2 and 3 (Bolton & Kacperczyk, 2021). Within a green-transition framework, disclosure quality acts as an information-friction modifier: credible reporting reduces uncertainty about future compliance costs and abatement trajectories, lowering required returns and dampening default risk.

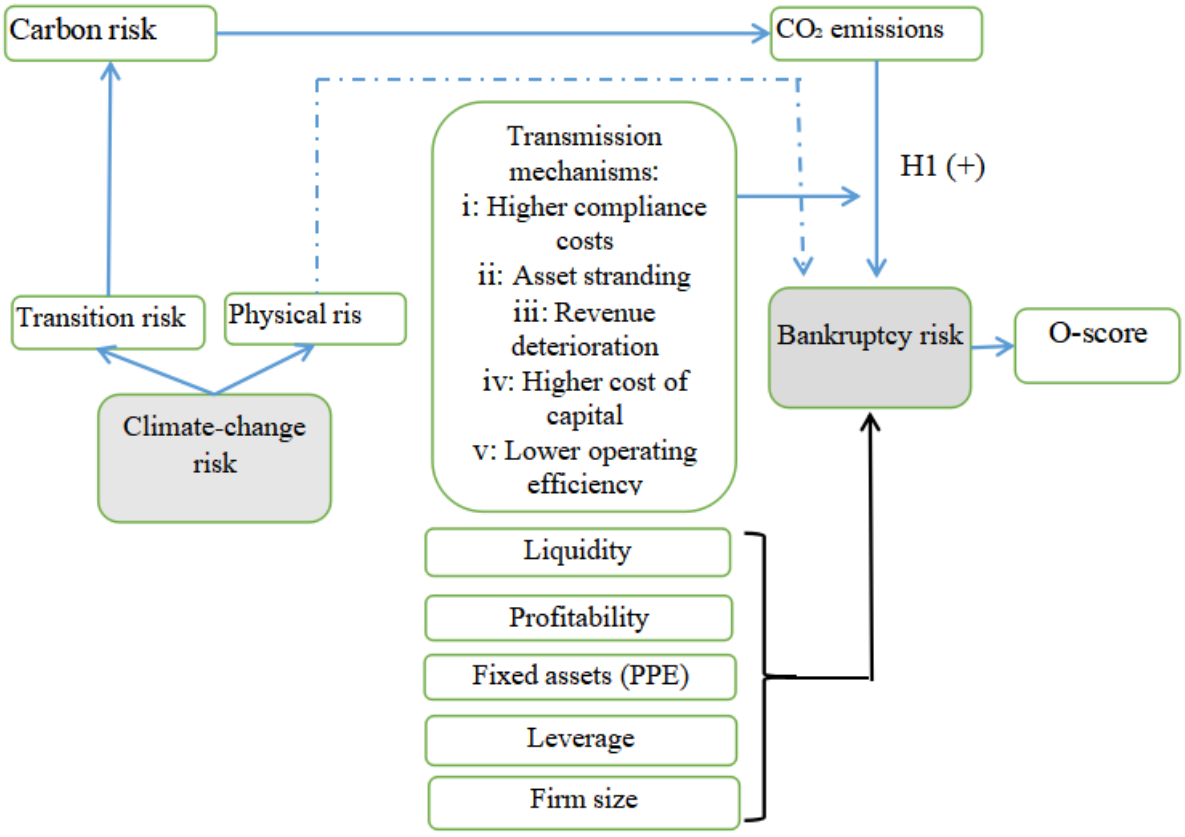

Figure 1. Theoretical framework diagram

A recently emphasized concept is the "carbon transition risk premium," which reflects the market's repricing of carbon-intensive assets amid anticipated policy shifts and global decarbonization trends. Gao et al. (2024) found that firms with higher Scope 1 and 2 emissions tend to yield higher stock returns, suggesting that investors require a risk premium for holding climate-exposed assets. This premium varies across regions; European markets, for instance, tend to price this risk lower due to stronger policy frameworks and higher disclosure standards. Pástor et al. (2022) and Farago and Hjalmarsson (2023) also affirmed that firms with ESG integration typically face lower downside risk and more stable returns,

reinforcing the strategic advantage of sustainable finance. Despite methodological differences, studies consistently agree that climate risk is increasingly being priced into both equity and credit markets. However, Choi and Luo (2021), and Ge and Lin (2024) raised concerns about the heterogeneity and inconsistency of emissions data, calling for global standardization of carbon metrics. Taken together, asset-pricing evidence implies that higher expected carbon costs translate into higher discount rates, linking emissions to bankruptcy risk through the cost-of-capital channel. Studies on air transportation document persistent financial fragility, measured by Altman-type distress scores, linked to energy and emissions exposure (Gritta et al., 2011), and policy work shows that carbon-pricing/ETS costs materially compress airline margins, increasing insolvency pressure (Malina et al., 2012). Cross-industry analyses that include transport, logistics and other services further find that firms with poorer environmental performance or higher carbon intensity face higher loan spreads and credit risk, implying greater ex-ante bankruptcy risk (Chava, 2014; Jung et al., 2018). Asset-pricing evidence also shows a carbon risk premium across sectors, including services, indicating that markets capitalise the default risk associated with emissions (Bolton & Kacperczyk, 2021).

Nonetheless, most existing research is concentrated in developed markets such as the United States, Europe, and Australia, while empirical studies on emerging economies remain limited. Nguyen and Phan (2020) emphasized the differential impact of carbon risk on financially constrained firms, a common feature in developing countries. Furthermore, inconsistencies in legal systems and environmental enforcement complicate cross-country comparisons. In Vietnam, despite strong government commitments to global climate goals (e.g., net-zero emissions by 2050), firm-level emissions disclosure remains limited. Only a few studies, such as Nguyen and Vien (2023) and Thai et al. (2023), have explored the financial impacts of emissions on Vietnamese firms, and none have incorporated carbon indicators into formal bankruptcy models. This leaves a significant research gap, particularly as Vietnam faces both physical climate risks and policy transition pressures amid rapid industrialization.

In sum, academic literature increasingly provides evidence that carbon emissions and climate risk are critical determinants of corporate financial performance, capital costs, and bankruptcy probability. High-emitting firms are more susceptible to reputational damage, higher financing costs, and default risk, particularly in policy-constrained environments. This study documents a statistically robust association between firm-level carbon intensity and Ohlson's O-score in Vietnam, indicating that climate-related information can be informative for monitoring bankruptcy risk. We do not recalibrate or augment the O-score itself, nor do we claim forecast improvements; a formal assessment of predictive accuracy would require out-of-sample validation and model-comparison exercises that are beyond the scope of this paper. While developed markets have made considerable progress, there remains a substantial gap in emerging economies such as Vietnam, where disclosure practices, enforcement, and environmental performance at the firm level remain uneven. Against this backdrop, our study explicitly focuses on Vietnamese publicly listed, non-financial firms on HOSE/HNX from 2012-2023 (15,146 firm-year observations). We measure bankruptcy risk using Ohlson's O-score and construct two carbon-intensity indicators, emissions scaled by sales (CarbonSales) and by total assets (CarbonAssets), estimated within multi-dimensional fixed-effects regressions with firm-clustered standard errors. The paper's distinct contributions are fourfold:

(i) it develops an integrated theoretical framework that links green-transition pressures to default through compliance-cost, cost-of-capital, and asset-stranding channels, yielding testable predictions; (ii) it provides novel emerging-market evidence by embedding firm-level carbon metrics into the O-score model and documenting their association with bankruptcy risk; (iii) it assembles and validates a new panel of Vietnamese firm-level emissions matched to financial statements, enabling policy-relevant analysis for green credit screening and early-warning systems. Future research should prioritize national-level empirical analyses and consider the interaction between disclosure quality, corporate structure, and industry characteristics in evaluating financial resilience to climate-related risks.

3. Research methodology

3.1. Data

This study employs a panel dataset comprising 1,993 publicly listed non-financial firms listed on the HOSE and HNX exchanges in Vietnam over the period 2012 to 2023, yielding a total of 15,146 firm-year observations. Financial institutions (banks, insurance, and securities companies) are excluded because their balance-sheet structures and regulatory regimes make O-score–based bankruptcy comparisons not directly comparable to non-financial corporates; firms with missing key variables are also removed. Financial data were obtained from the FiinPro-X database, while corporate CO_2 emissions data were collected from the General Economic Census conducted by the General Statistics Office of Vietnam during the corresponding years and matched to listed firms by legal name and enterprise code. The 2012-2023 window is selected because (i) 2012 is the first year with consistent firm-level emissions records that can be reliably linked to listed companies, and (ii) the span covers both pre- and post-Paris Agreement years alongside Vietnam's accelerated green-transition policies, providing meaningful variation in climate-policy intensity; 2023 is the latest year for which both financial and emissions data are available. All regression analyses were conducted using Stata 18. The dataset was cleaned by removing missing, noisy, or outlier observations and by winsorizing continuous variables at the 1st and 99th percentiles to ensure robustness and accuracy of the results.

3.2. Measurement of bankruptcy risk

The dependent variable in this study is corporate bankruptcy risk, which is measured using Ohlson's O-score (Ohlson, 1980), a widely used model for estimating the probability of firm failure based on financial indicators. The formula for Ohlson's O-score is as follows:

$$\begin{aligned} \text{O-score}_{i,t} = {} & -1.32 - 0.41\ \text{SIZE}_{i,t} + 6.03 \\ & \text{TLTA}_{i,t} - 1.439\ \text{WCTA}_{i,t} + 0.08\ \text{CLCA}_{i,t} \\ & - 2.37\ \text{NITA}_{i,t} - 1.83\ \text{FUTL}_{i,t} + 0.285 \\ & \text{INTW}_{i,t} - 1.72\ \text{OENEG}_{i,t} - 0.52\ \text{CHIN}_{i,t} \end{aligned} \quad (1)$$

In the Ohlson (1980) model, bankruptcy risk is calculated based on nine financial variables of firm i in year t, specifically as follows.: $\text{SIZE}_{i,t}$ is the logarithm of total assets; $\text{TLTA}_{i,t}$ is the ratio of total liabilities to total assets; $\text{WCTA}_{i,t}$ is working capital (current assets minus current liabilities) divided by total assets; $\text{CLCA}_{i,t}$ is current liabilities over current assets; $\text{NITA}_{i,t}$ is net income over total assets; $\text{FUTL}_{i,t}$ is the ratio of pre-tax income plus depreciation to total liabilities; $\text{INTW}_{i,t}$ is a binary variable equal to 1 if the firm reported net losses in two consecutive years, and 0 otherwise; $\text{OENEG}_{i,t}$ equals 1 if total liabilities exceed total assets, and 0 otherwise; and $\text{CHIN}_{i,t}$ measures the change in net income as ($\text{Net Income}_t - \text{Net Income}_{t-1}$) divided by the sum of the absolute values of Net Income_t and Net Income_{t-1}. Suitability of Ohlson's O-score for Vietnam. We adopt Ohlson's O-score as the main measure of bankruptcy risk because it is

(i) accounting-based and therefore observable for every listed firm under VAS/IFRS, which is crucial in a market with thin trading and limited market-implied default measures; (ii) well aligned with Vietnam's bank-centered financial system, where lending and supervision focus on leverage, liquidity, profitability, and loss history, the very components of the O-score; and (iii) portable across institutional settings when used as a continuous ranking of financial fragility rather than as a literal U.S.-calibrated failure probability. To enhance applicability to an emerging-market context, we exclude financial firms, winsorize inputs, and estimate models with firm and year fixed effects (plus industry–year interactions) to absorb accounting-policy differences and macro shocks. We also cross-validate with alternative distress proxies (e.g., Altman Z-score, interest-coverage and loss indicators) to verify that high O-scores coincide with weaker fundamentals.

3.3. Measurement of carbon risk

Carbon risk is proxied by two intensity measures: CarbonSales (CO_2e per unit of net revenue) and CarbonAssets (CO_2e per unit of total assets). These indicators follow the approach adopted by Wang et al. (2022) and Feng et al. (2024), aiming to capture firms' exposure to climate transition risk. Firm-year CO_2e is constructed by linking HOSE/HNX–listed, non-financial enterprises to microdata from the General Statistics Office's Enterprise Surveys and General Economic Census, which report energy use by fuel type and purchased electricity across all 63 provinces and 2-digit ICB industries. Multi-establishment records are aggregated to the enterprise level and matched to listed entities by legal name and tax/enterprise code. Emissions are compiled for Scope 1 (direct fuel combustion) and Scope 2 (purchased electricity) using a uniform conversion based on the Intergovernmental Panel on Climate Change (IPCC, 2006) and the emission factors for energy sources published by the Vietnamese Ministry of Natural Resources and Environment (2022); biogenic and process emissions are not covered. Comparability across firm size and ownership is addressed by using intensity ratios, by including firm fixed effects and standard financial controls. Data quality procedures remove missing/inconsistent observations, enforce non-negativity, winsorize intensities at the 1st–99th percentiles, align financial denominators to the same fiscal year, and exclude cases with zero denominators. These steps provide transparent, replicable, and Vietnam-appropriate measures of firm-level carbon risk.

3.4. Control variables

Control variables include: FirmSize (firm size), Profitability, Tangibility (fixed assets), CashFlow (net cash flow), Leverage (financial leverage). These variables are selected based on prior studies, including Kabir et al. (2021) and Capasso et al. (2020), to account for firm-level financial characteristics that may influence bankruptcy risk.

3.5. Empirical model

The empirical model is estimated using a linear regression framework with multi-dimensional fixed effects (FE), allowing for the control of industry and year fixed effects while adjusting standard errors at the firm-cluster level. This approach mitigates biases arising from unobserved but time-invariant or industry-invariant heterogeneity. The use of a multi-dimensional fixed effects linear regression model is particularly suited to high-dimensional panel data, enhancing the reliability of statistical inference in empirical research. This modeling strategy is informed by the works of Gao et al. (2024), Nguyen et al. (2023), and Wang et al. (2022), with the aim of clarifying the predictive role of carbon indicators in assessing financial risk under the current green transition and sustainable finance agenda.

The regression model is specified as follows:

$$\text{Corporate Bankruptcy}_{i,t} = \beta\text{Carbon Risk}_{i,t} + \gamma X_{i,t} + \delta_j \times \delta_t + \varepsilon \quad (2)$$

Where: Corporate Bankruptcy$_{i,t}$ represents the bankruptcy risk of firm *i* at time *t*, measured by the Ohlson's O-score. A higher value of Ohlson's O-score$_{i,t}$ indicates a greater likelihood of financial distress. Carbon Risk$_{i,t}$ denotes the firm's carbon emissions, expressed either as emissions per unit of total sales (*CarbonSales*) or per unit of total assets (*CarbonAssets*). $X_{i,t}$ represents the vector of control variables.

Table 1. Variable descriptions

Variables	Measurement	Expectation	Source
Ohlson	Ohlson's (1980) O-Score		Ohlson's (1980)
CarbonSales	Total Emissions/Total Sales	+	Wang et al. (2022), Feng et al. (2024)
CarbonAssets	Total Emissions/Total Assets	+	Wang et al. (2022), Feng et al. (2024)
FirmSize	Log of Total Sales	-	Kabir et al. (2021)
Profitability	Net Income/Total Assets	-	Capasso et al. (2020)
Tangibility	PPE/Total Assets	-	Kabir et al. (2021)
CashFlow	Operating Cash Flow/Total Assets	-	Bellovary et al. (2007)
Leverage	Total Liabilities/Total Assets	+	Chopra et al. (2020)

Macroeconomic controls. We do not include national macroeconomic variables (e.g., GDP growth, CPI inflation, policy rate, exchange rate, energy prices) in the baseline because our single-country panel with year fixed effects, augmented by industry–year interactions in robustness, absorbs common macro shocks that are identical for all firms within a year. Adding country-level series would be largely collinear with the time dummies and would not contribute to identifying cross-firm effects of carbon exposure on bankruptcy risk, which is the study's scope. Consistent with this design choice, results are unchanged when macro controls are appended in sensitivity checks available upon request.

4. Research findings

4.1. Descriptive statistics

Appendix 1 *(see Appendix 1 online)* presents the descriptive statistics for the variables employed in this study. The dependent variable, Ohlson's O-score, has a mean value of –0.586 and a large standard deviation of 15.246, indicating considerable variation in bankruptcy risk levels across firms. The key variables related to climate risk, CarbonSales and CarbonAssets, have mean values close to zero and low standard deviations, suggesting that their distributions are concentrated around the median. FirmSize, measured as the logarithm of total revenue, has a mean of 5.871, with a wide range from –6.749 to 13.046, reflecting substantial heterogeneity in firm size. Both Profitability and CashFlow exhibit small positive mean values, but their minimum values are strongly negative, indicating the presence of firms with severe financial losses.

The Leverage variable has a mean of 0.599, but its maximum value exceeds 104 times total assets, highlighting the extremely high financial leverage used by some firms in the sample. Overall, these descriptive statistics

reveal significant heterogeneity in financial characteristics and carbon emission levels among firms in the dataset.

Appendix 2 *(see Appendix 2 online)* presents the Pearson correlation matrix among the variables used in the research model, based on a sample size of 15,146 observations. Overall, the correlation coefficients are below the threshold of 0.85, indicating no severe multicollinearity issues (Gujarati & Porter, 2009). A notable correlation is observed between Ohlson's O-score and Leverage ($r = 0.83$, $p < 0.001$), highlighting the critical role of leverage in predicting financial distress. Additionally, the low correlations between CarbonSales, CarbonAssets, and other control variables reinforce the independence of the key explanatory variables, supporting the reliability of the multivariate regression analysis.

Multicollinearity diagnostics *(see Appendix 3 online)*. In both specifications (using CarbonSales or CarbonAssets), VIFs range from 1.00–2.28, with a mean VIF of 1.44. All conventional thresholds (VIF < 5 or < 10; tolerance > 0.20) are satisfied, indicating no material multicollinearity. The highest VIFs are for Profitability (2.28) and Leverage (2.05), reflecting only moderate correlation with the other regressors; the corresponding tolerances (0.438 and 0.488) remain high. CashFlow (1.25), FirmSize (~1.03), and Tangibility (~1.02) are essentially orthogonal. Notably, the emissions variables CarbonSales/CarbonAssets have VIF ≈ 1.00, implying that the emissions-intensity measure provides information distinct from the financial controls. Conclusion: multicollinearity does not affect the estimates, and results are consistent across the two emissions normalizations.

We formally tested for heteroscedasticity using the Breusch–Pagan and White tests on pooled OLS residuals, and the modified Wald test for groupwise heteroscedasticity after fixed effects. All tests reject homoskedasticity ($p < 0.01$). Accordingly, all baseline regressions are estimated with industry and year fixed effects and firm-clustered Huber–White standard errors (high-dimensional FE via absorb(industry year), vce(cluster firm_id)). This treatment is robust to arbitrary heteroscedasticity and within-firm serial correlation, and our coefficient signs and significance remain materially unchanged, ensuring reliable inference.

4.2. Regression Results

The results in Table 2 present the estimated impact of carbon emissions on corporate bankruptcy risk using Model (2). Bankruptcy risk is measured by the Ohlson's O-score, and the model is estimated through linear regression with multi-dimensional fixed effects (FE), applying firm-clustered standard errors and controlling for industry and year fixed effects. In each specification, the two main climate-related variables, CarbonSales and CarbonAssets, are sequentially introduced, alongside control variables including FirmSize, Profitability, CashFlow, Leverage, and Tangibility.

Table 2. Impact of carbon emissions on bankruptcy risk: fixed-effects regressions (dependent variable: Ohlson's O-score)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Ohlson's O-score							
CarbonSales	3.914***	1.199***	3.805***	0.811***				
	(0.476)	(0.476)	(0.370)	(0.278)				
CarbonAssets					2.843***	0.895***	2.736***	0.610***
					(0.340)	(0.327)	(0.262)	(0.205)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
FirmSize		-0.360***		-0.358***		-0.360***		-0.358***
		(0.044)		(0.043)		(0.044)		(0.043)
CashFlow		-5.262***		-5.237***		-5.262***		-5.237***
		(1.907)		(1.928)		(1.930)		(1.928)
Leverage		7.526***		7.534***		7.526***		7.543***
		(0.056)		(0.075)		(0.072)		(0.075)
Tangibility		0.008		0.015		0.008		0.015
		(0.277)		(0.276)		(0.275)		(0.276)
Profitability		-0.676		-0.663		-0.676		-0.663
		(0.967)		(0.976)		(0.967)		(0.976)
Industry FEs	Yes	Yes	No	No	Yes	Yes	No	No
Year FEs	Yes	Yes	No	No	Yes	Yes	No	No
Industry-by-Year FEs	No	No	Yes	Yes	No	No	Yes	Yes
N	12480	12475	12479	12474	12511	12475	12510	12474
adj. R^2	0.004	0.693	-0.000	0.693	0.004	0.693	-0.000	0.693

Notes: *This table presents the results of the baseline model:*

$$Corporate\ Bankruptcy_{i,t} = \beta Carbon\ Risk_{i,t} + \gamma X_{i,t} + \delta j \times \delta t + \varepsilon,$$

where $Corporate\ Bankruptcy_{i,t}$ *is Ohlson's O-score with a higher value indicating a greater likelihood of financial distress,* $Carbon\ Risk_{i,t}$ *is corporate carbon emissions scaled by total sales (Carbon Sales) or total assets (Carbon Assets), and* $X_{i,t}$ *is the vector of controls, including Firm Size, Profitability, Tangibility, Cash Flow, and Leverage. All specifications include industry and year, or industry×year fixed effects. Standard errors, clustered at the firm-level, are in paratheses.*

Symbols ***, **, *and* * *denote significance at 1, 5, and 10 per cent levels, respectively.*

Across all eight model specifications (Columns 1–8), the results consistently show that both CarbonSales and CarbonAssets have positive and highly statistically significant effects ($p < 0.01$) on the Ohlson's O-score, indicating that higher carbon emissions increase the likelihood of bankruptcy. Specifically, the coefficients for CarbonSales range from 0.811 to 3.914 depending on the fixed effects structure employed. Interpreting the fixed-effects linear model, a one-unit increase in carbon intensity is associated with a 0.811–3.914 point rise in Ohlson's O-score, holding other factors constant. These findings align with those of Feng et al. (2024) and Ding et al. (2023), which demonstrate the detrimental impact of carbon emissions on firms' financial health and rising financial risk, particularly under increasing regulatory pressure and compliance costs related to environmental policy. Comparing with evidence from large emerging economies, such as China, Australia, European countries , we find the same positive direction of effect but identify enterprise-level features that characterize the Vietnamese market: (i) energy- and materials-intensive production structures that make compliance and abatement investments relatively costly; (ii) strong exposure to export supply chains, where partner due-diligence and border

carbon requirements heighten operational and reputational risks; and (iii) uneven disclosure capacity and technology adoption across firms, which amplifies dispersion in carbon intensity and in financial resilience. Taken together, the Vietnamese results are consistent with international studies while revealing country-specific, firm-side channels, higher compliance costs, potential asset stranding of fixed capital, and supply-chain pressures, that magnify the link between emissions and bankruptcy risk for carbon-intensive enterprises. Relative to peer countries, the impact of carbon on bankruptcy risk in Vietnam may be higher due to energy- and materials-intensive production structures, uneven emissions disclosure and monitoring capacity, and elevated physical climate hazards; it may be lower in sectors experiencing rapid technology upgrading, increased renewable energy adoption, or targeted transition support that reduces compliance and abatement costs.

Regarding the control variables, Leverage (measured as total liabilities over total assets) displays a positive coefficient with high magnitude (approximately 7.58) and strong statistical significance ($p < 0.001$), consistent with theoretical expectations. This underscores the central role of financial leverage in explaining bankruptcy risk. The result aligns with classical financial distress theory (Altman, 1968) and is further supported by Kabir et al. (2021), who found that firms with higher debt exposure are more likely to face insolvency, especially when confronted with environmental shocks. In Vietnam, where bank loans dominate external finance, this leverage effect is particularly salient: green-credit screening and climate-related collateral haircuts increase the effective cost of debt for high-emission borrowers, reinforcing the leverage–distress link.

A noteworthy finding is that both Profitability and CashFlow exhibit negative and statistically significant coefficients, confirming that firms with higher profitability are less likely to face bankruptcy. This result is consistent with the free cash flow theory and empirical studies such as Jung et al. (2018) and Capasso et al. (2020), which highlight the protective role of earnings and internal cash flow against external risks, including climate-related threats. In the Vietnamese context, stronger internal cash generation also eases the financing of abatement and compliance investments (e.g., energy-efficiency upgrades), thereby lowering transition risk and default probability relative to cash-constrained peers (Nguyen & Phan, 2020).

For FirmSize, our estimates indicate a negative association with the O-score (small in economic magnitude), in line with Capasso et al. (2020) who argue that larger firms benefit from diversification, easier access to funding, and greater capacity to absorb compliance costs; however, the effect can be attenuated in Vietnam's heavy industries, where large incumbents are also among the highest emitters. Tangibility (PPE/Assets) is negatively related to bankruptcy risk, consistent with Kabir et al. (2021) that collateral mitigates lender risk; yet, in capital-intensive, carbon-heavy sectors, tangible assets may be exposed to asset-stranding, which tempers the protective effect, aligning with transition-risk mechanisms discussed by Wang et al. (2022).

Furthermore, model specifications incorporating stricter fixed effects controls (Columns 2, 4, 6, and 8) show a substantial improvement in explanatory power, with the adjusted R^2 increasing to 0.693, compared to near-zero values in models without such controls. This indicates that industry and temporal characteristics play a significant role in the relationship between carbon emissions and bankruptcy risk, consistent with the findings of Wang et al. (2022), who emphasized that climate risk is sector-specific and contingent on evolving policy contexts. In our single-country setting, year effects capture macro shocks (e.g., post-Paris policy tightening, energy-price

cycles), while industry (and industry-year) effects absorb sectoral exposure to the green transition, improving identification of firm-level mechanisms.

Overall, the regression results reinforce the argument that carbon emissions constitute a quantifiable financial risk factor with tangible implications for firms' financial health. Persistently high emission levels not only damage a firm's environmental reputation but also erode its solvency and increase the probability of bankruptcy, particularly amid the intensifying global green transition. Taken together, the variable-by-variable patterns, positive effects for emissions and leverage; negative effects for profitability, cash flow, size, and (to a lesser extent) tangibility, are directionally consistent with prior international evidence while highlighting Vietnam-specific channels operating through bank lending, disclosure gaps, and sectoral composition.

5. Conclusions and implications

5.1. Conclusions

This study investigates the relationship between carbon emissions and financial bankruptcy risk using the Ohlson O-score model and empirical data from publicly listed firms in Vietnam. The quantitative findings reveal that higher emissions are associated with an increased probability of bankruptcy, implying that climate risk should be embedded in both corporate financial management frameworks and macro-level credit assessment systems. Moreover, the study demonstrates the potential to expand traditional accounting-based models to quantify climate risk, thereby bridging the gap between finance and sustainable development.

5.2. Policy implications and practical relevance

The findings of this study indicate a positive and statistically significant relationship between high carbon emissions and corporate bankruptcy risk, as measured by the Ohlson's O-score. This result not only validates the link between environmental risk and firms' financial conditions, but also carries meaningful implications for policy, governance, and investment strategy amid the ongoing green transition. In Vietnam's bank-centered, export-oriented economy, where listed firms are concentrated in materials, industrials, energy, and utilities and where emissions disclosure is still uneven, these implications speak directly to near-term compliance pressures (e.g., supply-chain reporting and CBAM-related requirements for carbon-intensive exporters) and to the need for credible firm-level transition plans.

From a macroeconomic perspective, the connection between emissions and bankruptcy probability underscores the necessity of incorporating environmental factors into financial stability monitoring frameworks. High-emitting firms may constitute latent sources of systemic risk, especially in emerging economies with limited financial buffers. Thus, applying indicators such as the Ohlson's O-score in combination with emissions data in early warning credit risk systems becomes imperative (Bolton & Kacperczyk, 2020; TCFD, 2017). For Vietnam, a practical step is for the State Bank of Vietnam and market regulators to integrate an "O-score × carbon-intensity" dashboard into sectoral surveillance, prioritizing carbon-exposed industries (steel, cement, power-related supply chains) and provinces with high physical-risk exposure (flood and heat).

For financial institutions, carbon emissions can serve as a quantitative signal to forecast default risk. Credit rating models should integrate environmental variables like CarbonSales or CarbonAssets to enhance predictive accuracy and enable more efficient capital allocation (Jung et al., 2020). Furthermore, green credit policies can utilize indicators such as the

Ohlson's O-score to prioritize firms that require support, thereby aligning environmental objectives with financial goals more coherently. In practice, Vietnamese banks can (i) embed these metrics into loan origination and portfolio stress-testing, (ii) re-evaluate collateral where assets face potential stranding, and (iii) offer transition-linked lending (rate step-downs tied to verified emission reductions) for SMEs and SOEs implementing energy-efficiency and fuel-switch projects.

From a regulatory standpoint, the results call for a more flexible approach to policy instruments such as carbon taxes, which should account for firms' financial resilience. When a firm is both highly polluting and financially fragile (i.e., high Ohlson's O-score), transition support policies must accompany regulatory measures to avoid triggering liquidity crises, while still maintaining the trajectory toward sustainable emission reductions. For Vietnam, this implies sequencing: finalize and operationalize a green taxonomy and MRV standards, phase in carbon-pricing/market mechanisms with sectoral pilots, and pair them with concessional finance, tax incentives, and technical assistance so that financially constrained but viable emitters can comply without destabilizing employment or credit markets.

At the firm level, the identified link between emissions and bankruptcy risk offers a strategic warning. Emissions control and transparency should be considered essential components of long-term financial strategy. This includes ESG integration, investment in clean technologies, and the development of emission reduction roadmaps aligned with financial stability objectives. Enhanced environmental transparency also contributes to improved market credibility and reduced capital costs (Alshahrani et al., 2023; Capasso et al., 2020). For Vietnamese enterprises specifically, priority actions include building auditable GHG inventories (Scope 1–2 and material Scope 3 for exporters), undertaking energy audits, adopting rooftop solar and efficiency retrofits where feasible, preparing CBAM-compatible reporting, and aligning transition plans with bank covenants to safeguard access to credit.

For investors, carbon emissions have become an essential risk-screening criterion. Indicators such as the Ohlson's O-score can serve as tools for assessing dual risks, financial and environmental, thus optimizing portfolio construction, especially in the context of the growing momentum behind ESG investing. Domestic investors can use the combined metrics to differentiate firms with credible, costed transition pathways, an increasingly relevant screen for SOE equitization and new listings, while engaging laggards on disclosure and capital-expenditure alignment with Vietnam's power and industrial transition.

Finally, from an academic perspective, this study contributes to the interdisciplinary integration of finance and climate research. By incorporating a traditional bankruptcy model like Ohlson's O-score with carbon variables, the study demonstrates the potential to extend environmental risk analysis beyond conventional ESG frameworks, thereby laying the groundwork for a scientifically rigorous and practically applicable climate-financial monitoring system.

5.3. Limitations

Nonetheless, studying has certain limitations. Corporate-level emissions data remains inconsistent; the scope of analysis is restricted to the Vietnamese market; and the O-score model does not fully capture non-financial factors such as ESG governance or adaptive capacity in the green transition. Future research can be extended in three directions: (1) testing the model on cross-country datasets; (2)

integrating ESG data into financial forecasting frameworks; and (3) examining the mediating role of environmental disclosure transparency in the relationship between carbon risk, cost of capital, and bankruptcy probability. These avenues will contribute to refining the financial risk assessment framework in the era of green economic transformation.

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