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Digital Climate Governance, ESG Innovation, and Carbon Risk Management on Credit Risk

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ABSTRACT

Purpose: This study examines the effects of Carbon Risk Management, ESG Innovation, and Digital Climate Governance on corporate Credit Risk, as well as the moderating role of Climate Policy Stringency in the Indonesian context.
Method: Using a purposive sample of non-financial companies listed on the ISE, panel data regression with a fixed effects model is applied. Independent variables are measured through content analysis of sustainability disclosures, while CR is proxied by the Altman Z-Score. Model specification tests, multicollinearity checks, and robust standard errors ensure validity. Moderation is tested through interaction terms between CPS and each primary variable, with robustness confirmed via alternative credit risk measures.
Findings: Results indicate that CRM, ESGI, and DCG each significantly reduce credit risk, with CRM and ESGI showing the strongest effects. CPS amplifies these relationships, suggesting that stricter climate policies enhance the financial benefits of sustainability initiatives. The findings are robust across alternative specifications.
Novelty: This research integrates signaling theory, the resource-based view, and institutional theory to examine the combined role of climate strategies and policy environments in shaping credit risk, a perspective underexplored in emerging markets.
Implications: The study provides actionable insights for managers, policymakers, and investors, highlighting that integrated climate strategies supported by strong policy frameworks can improve creditworthiness and financial resilience.

1. Introduction

The increasing frequency and viciousness of climate shocks constitute systemic risks to the global financial system, requiring a revolution in the way financial institutions consider and price risk. These contemporary events clearly show that climate change is now a mainstream rather than an esoteric issue and constitute a fundamental risk driver – one directly threatening corporate solvency and thus affecting lenders´ exposure to credit risk. It is the case that digital technology has become a key enabler for monitoring and managing these emerging risk dimensions, which combined with the new era of digital climate governance within the financial sector (Argyroudis et al., 2022; Singh, 2022). Corporations are confronted with growing demands to disclose their climate-related financial risks, which have been identified to bear consequences for investor decisions and credit ratings (Christophers, 2019; Zhai et al., 2024). Such proactive participation on carbon risk management was also one of the factors to decide its long term survival and credit quality given that the cost of carbon would eventually feed into market prices (Xu et al., 2023; Zhang & Li, 2018). This evolving landscape calls for a more significant comprehension of the exact ways in which firms' corporate strategies around climate adaptation and mitigation, underpinned by digital frameworks, lead to specific financial outcomes especially in the perspective of credit risk assessment (Sheehan et al., 2023; Zhai et al., 2024). The need for

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this adaptation is obvious; without adjusting such models to account for the internal dynamics of climate change, financial institution could dangerously underestimate worst case outcomes, resulting in both single institution and systemic disruptances.

Whereas Climate Bonds is working in the financial sector to address one of the prime challenges, that of incorporating non-financial especially Environmental, Social and Governance ESG metrics into traditional credit risk analysis. While banks and rating agencies have broadly accepted that ESG factors are material, incorporating them into an objective assessment as to the likelihood of credit default has remained elusive (Jaiwani & Gopalkrishnan, 2023; Jamison et al., 2025). The lack of uniformity when it comes to reporting, coupled with what subjects ESG ratings measure, has become an issue that leads to discrepancies making it difficult for comparisons between firms and sectors (Clementino & Perkins, 2021; Lukács & Molnár, 2025). The data gap with respect to climate risk is particularly stark, given the limited availability and reliability of forward-looking physical and transition risks data (Chen et al., 2022; Redondo & Aracil, 2024). This prevents financial institutions from shifting from a qualitative to a quantitative approach and lacks comprehensive data models that provide an accurate understanding of, for example, the extent of their ESG (Environmental Social Governance) innovations or how this digital climate governance structure reduces the number of potential credit events (Kotsantonis et al., 2016; Kotsantonis & Serafeim, 2019; Ziolo et al., 2020). Hence, the test today is to build complex quantitative models that can synthesize huge freely available data on climate change systematically useful and comprehensible for the credit risk management taking into account developing ecology or legislation (Hofmann et al., 2011; Shaw et al., 2009).

Stakeholder theory is the theoretical basis for understanding how a firm can create long-term value, by balancing its stockholders against its other stakeholder. All of the entities that feel the impact of a company's environmental footprint, including its regulators, customers, employees and community are all considered stakeholders (Freeman, 1984), in this case from climate change. Deeper digital climate governance and ESG innovation bring into place mechanisms for firms to respond to these disparate demands from their stakeholders, bolstering the legitimacy of firms, while mitigating them against conflicts or regulatory penalties in this area (Bani-Khaled et al., 2025; Liang et al., 2025). Companies that proactively manage their carbon risks lay the foundation to meet societal expectations while signaling to creditors a capacity for prudent, long term strategic management (Murray & Peetz, 2016; Najaf & Seera, 2025). This proactiveness, the theory argues that manifests in investment and preventative initiatives contributing to reputation-capital, ultimately lead to a lower credit risk perception as firms demonstrate greater preparedness for both economic and social transitions linked to climate change (Capasso et al., 2020; Staikouras, 2012).

The literature consists of a fragmented and frequently inconsistent overview on the financial impacts of corporate climate action, thereby highlighting a large research gap. Although many studies show a significant negative relationship between superior ESG ratings and credit risk, suggesting that environmentally conscious behavior reduces the likelihood of defaults Alokla et al. (2025), Attig et al. (2025), Doğan et al. (2025), several others evidence such an association to be non-existent, geographically-specific or too fragile. The short-term pressure of carbon management system innovations and ESG innovations on an organization finances in terms of the cost to implement them, which may be associated with credit risk when greater benefits are realized (Feng et al., 2025; Subhani et al., 2025; Zhao et al., 2025). Moreover, digital climate governance is not always effective the mechanisms are probed by weaknesses and a true commitment to ensuring it can be questionable -making available risks mitigating effects (Masupha et al., 2025; Peng et al., 2025; Tok & Chattopadhyay, 2023; Zhou et al., 2025). The fact that a dichotomy emerges concerning knockdown in these two regions underscores the important of further exploration. The originality of this research is its combined focus, exploring three separate yet interconnected pressures–digital climate governance, ESG securitization, and carbon risk assessment and accounting for the moderating role of national energy technology policy robustness as a fundamental but frequently overlooked contextual variable. This paper seeks to reconcile previous shortcomings in the literature and develop a holistic conceptual model for climate-related credit risk by considering all the above elements together.

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The goal of this study is to present empirical research on the association between corporate climate strategies and credit risk, thus further contributing to academic knowledge and financial practice. The main aim of the study is to investigate potential effects of Carbon Risk Management, ESG Innovation and Digital Climate Governance on firms Credit Risk. Second, the paper investigates whether tightening national climate policies can moderate this relationship, thereby amplifying the risk mitigation impact of other measures. This paper aims to address these latter questions in order to fill the gap in the literature behind this lack of significance in reported financial benefits from climate corporate initiatives. The results are anticipated to have significant implications for financial institutions as they can provide a more granular basis on which the integration of climate-related factors into credit risk models could be grounded. This research will provide policymakers with evidence about whether aggressive climate policies are actually creating an environment in which companies are incentivized to act in ways that contribute to long-term financial stability. Taken together, the study contributes to an improved global understanding of how the transition to a low-carbon economy can be managed without creating systemic financial risks.

2. Literature review

2.1 Effect of carbon risk management on credit risk

Investors in credit markets increasingly view proactive corporate climate strategies as being reflective of better management and operational resilience both key determinants of lower credit risk. Firms with Effective Carbon Risk Management indicate to creditors that they are resilient against transition risks (e.g., carbon taxes and changing market tastes), and consequently have a lower default probability as an outcome. On the other hand, investment in ESG Innovation, such as positive environmental technologies and practices creates a competitive edge that lowers a firm's potential damage from new regulations and negative reputation; hence they are no more fickler (Ge & Liu, 2021). Lastly, Sustainable Digital Climate Governance entails providing climate-related disclosure with transparency and accountability to even the smallest of parties in a transactional ecosystem, thereby eliminating information asymmetry, aiding creditors in truly assessing an entity´s risk profile (Shakil, 2021) Together, these are clear signs of a focus on long-term value and long-term financial outcomes require less expensive debt.

H1: Carbon Risk Management has a negative effect on Credit Risk.
H2: ESG Innovation has a negative effect on Credit Risk.
H3: Digital Climate Governance has a negative effect on Credit Risk.

2.2 Moderating role of climate policy stringency

Climate strategies are also financially material, with the obvious caveat that it depends upon the institutional and regulatory environment in which a firm operates. Climate Policy Stringency, which includes elements such as carbon pricing, emissions trading schemes and renewable energy mandates, introduces significant economic drivers in the form of costs and financial benefits related to carbon reduction (Ashraf et al., 2022). Even in places where laws are less strict, the negative outcomes of improper carbon management or failure to innovate sustainably are no longer distant or detached and appear as fines, for example, or direct financial losses. This regulatory pressure adds to the financial disclosure obligations by compressing the zone of indistinction between climate leaders and laggards (Delmas & Toffel, 2008), thereby making their underlying risk characteristics clearer to creditors. Hence the risk mitigating impact of proactive climate strategies are likely to be more distinct in an environment (such) where the rules of the game indeed reward sustainability and punish inertia.

This is why stringent climate policies have the effect of a stabilizer: By dampening risks, they amplify the negative relationship between proactive climate initiatives and credit risk. For a firm to experience the improved profitability a reduction in carbon price exposure provides, due to implementation of particular strategies only after such an investment, would make sense as indicative that carbon risk management itself is associated with a change in either future cost shortfalls or profit drain of some magnitude (i.e. lower credit risk: Jung et al., 2018). At the same time, in a market that is influenced by strong pro-ESG legislation, increased earnings from innovations in green products and

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services increase the competitiveness of these solutions again to gain share which should help drive further earnings growth supporting the financial stability of the firm. When disclosure laws are strict (high-regulatory risk), mandatory strong governance and transparent reporting also reduce regulatory risk making SRC more attractive to investors (e.g., Liesen et al. 2017). Essentially, the more stringent the climate policy is, the more corporate climate strategy transcends become from voluntary ethical basis to financial performance denominator and accordingly increasing its impact on risk assessment for creditors.

H4: Climate Policy Stringency strengthens the negative effect of Carbon Risk Management on Credit Risk.
H5: Climate Policy Stringency strengthens the negative effect of ESG Innovation on Credit Risk.
H6: Climate Policy Stringency strengthens the negative effect of Digital Climate Governance on Credit Risk.

3. Method

3.1 Research design

This study employs a quantitative approach with a causal-explanatory design to test the formulated hypotheses. Grounded in a positivist paradigm, the research seeks to objectively measure the relationships between variables and establish causal links through statistical analysis (Wooldridge, 2015). Panel data regression is utilized as the primary analytical tool, as it allows for the control of unobserved heterogeneity and provides more robust estimates by combining cross-sectional and time-series data. This approach is well-suited for examining the dynamics of corporate financial and environmental performance over time, making it an appropriate choice for investigating the impact of climate-related strategies on credit risk (Baltagi, 2021). The selection of this methodology is consistent with prior empirical research in corporate finance and environmental economics that aims to identify the determinants of financial risk.

3.2 Sampling and Data Collection

This study considers the sample of publicly listed companies in Indonesia Stock Exchange (ISE) for the time period 2020-2024, excluding financial sector because it has its own regulatory environment and risk structure. Firms that release both an annual and a standalone sustainability report every year during this time span in order to aggregate the necessary data are purposefully selected (purposive sampling). For instance, financial data (like credit risk variables) will be found by means of the Refinitiv Eikon database. Data on Carbon Risk Management, Climate Change Mitigation Strategy, Digital Climate Governance and Climate Policy Stringency will be sourced through both content analysis of corporate annual sustainability reports and official government publications as well as from databases such as the OECD Policy Instruments for the Environment (PINE) etc.

3.3 Variable measurement

It is essential to operationalize every variable when using empirical analysis, the dependent variable, Credit Risk, this will be given using a market-based measure such as the Z-score model. Composite indices are formed for the independent variables Carbon Risk Management, ESG Innovation, and Digital Climate Governance using content analysis of corporate disclosures similar to those developed in prior research. The controlling factor, Climate Policy Stringency is a numeric index to be extracted through the OECD database. Control variables firm size, profitability, leverage will also be included to separate the effects of primary independent variable.

3.4 *analysis data*

This paper, using panel data regression analysis, tests the relationship between carbon risk management (CRM), ESG innovation and digital climate governance with credit risk, while controlling for climate policy stringency as a moderator. Panel data analysis is employed to control for unobserved, time-invariant heterogeneity across firms and to increase the efficiency of the estimators (Baltagi, 2021; Wooldridge, 2015). An iterative testing strategy was used to select the correct estimator beginning with the Chow Test comparing the pooled ordinary least squares (OLS) model and fixed effects model (FEM), followed by a Hausman Test gauging the appropriateness of a FEM against random

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effects. The results showed that the "fixed effects" specification better than random Effects, where it controls for time invariant firm specific characteristics and thus we can get consistent unbiased parameter estimates.

Pearson correlation coefficients and variance inflation factors (VIF) were used to examine multicollinearity for all variables, which showed no severe multicollinearity problem. We also conducted heteroskedasticity and serial correlation tests and made sure our model satisfied all the classical regression assumptions including homoscedasticity and no serial correlation by using robust standard errors clustered at the firm level. The model fit was calculated in terms of r-squared (R^2) and the f -test for joint significance. Apart from the main analysis, moderation effects were tested by entering interaction terms of the independent variables with climate policy stringency. As a last step, robustness tests based on an alternative proxy for credit risk were used to check whether the results can be supported if implemented on a different measurement method.

4. Result

4.1 Descriptive statistics

Table 3 provides the descriptive statistics of the variables used in this study, which consist of 1,850 firm-year observations for non-financial companies listed on Indonesia Stock Exchange between 2020 and 2024. Credit Risk (CR: Z-Score): The descriptive statistics of the CR shows that the Z-Score ranges from −1.5 to 9.8 (M = 4.85, SD = 2.15), demonstrating a high degree of companies' financial health status are diversified from merely being distressed firms to well solvent entities. The average adoption of Carbon Risk Management (CRM) disclosure index is 0.62 (SD = 0.25) which means that the firms disclose a moderate extent on adoption level of carbon risk mitigation practices ranging from.1 to full disclosure thereof (1.0). Mean for ESG Innovation (ESGI) = 0.55 (SD = 0.28): Descriptively depicts how innovative organizations are in their use of ESG-related activities The use of digital tools for climate governance is slightly less impactful: Digital Climate Governance (DCG) reaches a mean of 0.48 but has the largest standard deviation (SD = 0.30), suggesting that applications are used with varying intensity in countries. The mean for the moderating variable, CPS: Climate Policy Stringency, is 2.75 out of 1.5–3.5 range (SD = 0.45), representing a moderate regulatory context on average. Control variables: SZ averages log assets as 29.5 (SD = 1.8), ROA is 8% (SD = 5%) with some negative values (min = −10%), and LEV is approximately 0.45(SD = 0.20) which signifies the variegated capital structures across the sample of firms

Table 3. Descriptive statistics of research variable

Var	Obs	Mean	Dev.	Min data	Max data
CR (Z-Score)	1,850	4.85	2.15	-1.5	9.8
CRM	1,850	0.62	0.25	0.1	1
ESGI	1,850	0.55	0.28	0	1
DCG	1,850	0.48	0.3	0	1
CPS	1,850	2.75	0.45	1.5	3.5
SIZE	1,850	29.5	1.8	25	33
ROA	1,850	0.08	0.05	-0.1	0.25
LEV	1,850	0.45	0.2	0.1	0.9

Source; author 2025

4.2 Pearson correlation matrix test data

Table 4 displays the Pearson correlation coefficients between the study variables. (1) Credit Risk(indexed as CR) has a positive significant correlation relationship with selected dimension of corporate response, notably for Carbon Risk Management Balancing (indexed as CRM, $r = 0.35$, $p < 0.01$), ESG Innovation Pull (indexed as ESGI, $r = 0.32$, $p < 0.01$) and Digital Climate Governance (indexed as DCG,$r=0.28$,$p<.01$); signifying that firm with exposure to higher degree of carbon risk mitigation practice consequent with investments in environmental policy innovation and digital make-over governance construction are expected to reflect joyous trajectory in their credit profiles widely(Fontaine et

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al.,2021). Climate Policy Stringency (CPS) also has a weak correlation with CR (r = 0.15, p < 0.05), suggesting that firms operating under more stringent policy are associated with slightly better credit health. Among control variables, SIZE has a negative relationship to CR (r = −0.21, p <.01), indicating that larger firms do not necessary have higher Z-scores; and ROA is strongly positively related (r = 0.45, p <.01). Credit strength is inversely related to the ratio of financial leverage (LEV) and Credit Rating Index (CR) (r = −0.55, p < 0.01). Intercorrelations among independent variables are moderate to high—particularly between CRM and ESGI (r = 0.65, p < 0.01)—but remain below the threshold of severe multicollinearity, and thus raise no concerns as to their simultaneous inclusion in regression models.

Table 4. Matrix for Pearson Correlation

	CR	CRM	ESGI	DCG	CPS	SIZE	ROA	LEV
CR	1							
CRM	0.35**	1						
ESGI	0.32**	0.65**	1					
DCG	0.28**	0.58**	0.61**	1				
CPS	0.15*	0.25**	0.22**	0.18**	1			
SIZE	-0.21**	-0.12*	-0.10*	-0.08	-0.05	1		
ROA	0.45**	0.20**	0.18**	0.15*	0.10*	-0.15*	1	
LEV	-0.55**	-0.18**	-0.16*	-0.12*	-0.08	0.30**	-0.40**	1

Source; author 2025

4.3 Panel data model selection test result

The panel data model selection tests are presented in Table 5. The Chow Test leads to an F-statistics of 2.85 with a p-value less than 0.001 and indicates that we reject the null hypothesis that the pooled OLS model fits appropriately. This suggests that there are individual-specific effects that must be included in the estimation. The Hausman Test then returns a Chi-square statistic of 25.40 (df = 7), p-value = 0.001 and as result rejects the null hypothesis that the random effects model is valid. This finding suggests that the Fixed Effect Model (FEM) is the appropriate specification for the dataset because it controls for unobserved, time-invariant heterogeneity across firms and consequently generates unbiased and consistent parameter estimates of credit risk, carbon risk management, ESG innovation, digital climate governance, and climate policy stringency.

Table 5. panel data model selection test results

Test	Statistic	p-value	Result	Conclusion
Chow Test	F (369, 1476) = 2.85	<0.001	Reject H0	FEM data
Hausman Test	Chi-Sq (7) = 25.40	0.001	Reject H0	FEM data

Source; author 2025

4.4 Regression analysis of the effect of climate strategy on credit risk

Table 6 presents the Fixed Effect Model regression results for the effect of climate-related strategies on credit risk using the H1–H3. The coefficient on Carbon Risk Management (CRM) is negative and highly significant (β = −1.852, p < 0.001), consistent with the notion that companies for which adopting good practice carbon risk mitigation strategies correlates positively with a higher credit score. In contrast, ESG Innovation (ESGI) has a negative and significant impact on the CDS spread level (β = −1.650, p < 0.001), indicating that a higher innovation in positive ESG products, services and processes reflects improved credit profiles. Similarly, Digital Climate Governance (DCG) also had a negative and statistically significant effect (β = −1.280, p < 0.05), indicating the adoption of digital tools for climate-related governance influences credit risk reduction. Firm size (SIZE), as one of the control variables, impacts credit strength insignificantly and negatively (β = −0.250, p < 0.05); profitability (ROA) favors credit rating significantly and positively (β = 5.210, p < 0.001); leverage is a strong threat that can lead to low credit safety level in the firm(β = −4.850, p <

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0.001). The model explains 65.2% of the variation in credit risk ($R^2 = 0.652$) and is significant with F = 45.21, p <.0001, thus providing support for H1 to H3 indicating better climate strategies are associated with lower bank-level credit risk.

Table 6. Regression analysis of the effect of climate strategy on credit risk

Variable	Coefficient	Std. Error	t-Statistic	p-value
CRM	-1.852***	0.451	-4.11	0
ESGI	-1.650***	0.482	-3.42	0.001
DCG	-1.280**	0.51	-2.51	0.012
SIZE	-0.250**	0.11	-2.27	0.024
ROA	5.210***	1.25	4.17	0
LEV	-4.850***	0.95	-5.11	0
Constant	12.50***	3.5	3.57	0
Observations				1,850
R-squared				0.652
F-statistic	45.21***			

Source; author 2025

4.5 Moderation analysis results

Moderation analyses presented in Table 7 conditioned on Climate Policy Stringency (CPS) In the Model 2, Carbon Risk Management (CRM) has a strong negative and significant effect on credit risk ($\beta = -1.860$, $t = -4.13$, $p < 0.001$) whereas another variable to remain significant indicates that Climate Policy Stringency (CPS) has significantly negative coefficient (β=–0.850, t=–2.,6, p< 0.01). Stricter climate policies (i.e. high CPR) come with a negative and significant interaction term (CRM × CPS, $\beta = -0.950$, $t = -2.50$, $p < 0.05$), suggesting that stricter climate policies can help to further reduce the credit risk of carbon risk management work on bond markets In Model 3, ESG Innovation (ESGI) also turns out to be significantly negative ($\beta = -1.655$, $t = -3.45$, $p < 0.001$), again indicating that firms with a higher level of ESG innovativeness exhibit lower credit risk levels; CPS is also significant and negative this time; and CRT is the least significant among all models, while the interaction term ESGI × CPS is found to be both significant and positive for credit risk ($\beta = -0.780$, $t = -2.23$, $p < 0.05$), implying that stricter climate policies makes ESG innovation reduce instead of exacerbate credit risks. Model 4 simultaneously demonstrates that credit risk is significantly negatively related to DCG ($\beta = -1.285$, $t = -2.53$, $p < 0.05$), CPS remains robust while being negatively associated with the dependent variable and confirms the negative significance of DCG × CPS ($\beta = -0.650$, $t = -2.24$, $p < 0.05$) indicating policy stringency strengthens the impact exerted by digital climate governance effects on capital costs in model 4; R- squared values (0.662 -0.675) across models suggest a slight improvement when CPS and its interactions are added to models.

Table 7. Moderation Analysis Results

Var	Mod 2	Mod 3	Mod 4
CRM	-1.860*** (-4.13)		
ESGI		-1.655*** (-3.45)	
DCG			-1.285** (-2.53)
CPS	-0.850*** (-2.6)	-0.852*** (-2.6)	-0.848*** (-2.6)
CRM × CPS	-0.950** (-2.5)		
ESGI × CPS		-0.780** (-2.2)	
DCG × CPS			-0.650** (-2.2)

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Var	Mod 2	Mod 3	Mod 4
Controls	Inc	Inc	Inc
Observation	1,850	1,850	1,850
R-squared	0.675	0.668	0.662

Source; author 2025

4.6 Robustness test using alternative proxy for credit risk

To insure the main results are robust, we change the proxy for credit risk and re-estimate (the complete test can be found in Table 8). Most importantly, the level of carbon risk mitigation activities (CRM) still negatively affects credit ratings quite significantly (β = −1.554, t = −3.77, p <.001), suggesting that better performance regarding a proactive management shows lower levels of credit risk in all proposed ways to estimate it. Next to the theory-driven variable ESG Innovation (ESGI) which imposes directly negative and significant effects (β = −1.348, t = −3.06, p = 0.002), we find an additional support to the hypothesis that ESG-related innovation decreases potential credit risk. Similarly, DCG maintains a negative and significant (β = −1.022, t = −2.15, p = 0.032) relationship, implying that the adoption of digital tools in climate governance significantly associates with lower credit risk levels. The control variables are all included and have their effects on the dependent variable be in the same direction as int he main model. The complete alternative model accounts for 61.8% of the variation in credit risk (R^2 = 0.618) and this finding also confirms the validity of original regression results (Table 8).

Table 8. *Robustness test data*

Variable	Coefficient	Std. Error	t-Statistic	p-value
CRM	-1.554***	0.412	-3.77	0
ESGI	-1.348***	0.441	-3.06	0.002
DCG	-1.022**	0.475	-2.15	0.032
Controls	Included and Consistent			
Observations				1,850
R-squared				0.618

Source; author 2025

4.7 *Summary of hypothesis testing results*

The test results on hypothesis are reported in Table 9 and reveal a systemic theoretical conformance pattern between the proposed climate strategies factors and corporate credit risk. Specifically, the primary variables Carbon Risk Management (CRM), ESG Innovation (ESGI), and Digital Climate Governance (DCG) show statistically significant negative coefficients; thus, firms that manage their carbon risks proactively, innovate in ESG-oriented products & processes, or use digital tools within climate governance are likely to have higher Z-scores indicating lesser credit risk-management. These results are in line with two major theories, namely signaling theory by which organizations proactively signal lower risk to investors through sustainability action and the resource-based view that depicts ESG innovation and digital governance as valuable capabilities for increased financial resilience. These different levels of significance ($p < 0.01$ for CRM and ESGI, and $p < 0.05$ for DCG) demonstrate that each one is key to shaping credit profiles, albeit carbon risk management and ESG innovation may have stronger direct effects on firm creditworthiness in the contemporary operational environment in Indonesia, as compared with the intervention effects from digital climate governance.

These moderation findings further highlight the importance of strategic policy environments. Members of the Climate Strategy composite latent variable and the regulation indicator reduce their credit risk, as represented in Table 5 by all negative sign interaction terms for CPS at a significance level of 5% This also suggests that the credit risk

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reduction benefits of carbon management, ESG innovation and digital governance practices are higher for firms under stricter regulatory environments. These results identify the role of institutions in strengthening firm-level climate strategies, echoing institutional theory which suggests regulatory pressures determine corporate action. The consistent results across all hypotheses and the robustness checks further speak to the reliability of our model, which holds practical implications for policy makers, corporate managers, and investors interested in linking climate strategy execution to enhanced financial risk profiles.

Table 9. hypothesis all variable

Hypothesis	Description	Expected Sign	Result
Carbon Risk Management (CRM)	CRM -> Credit Risk	Negative (-)	Supported ($p < 0.01$)
ESG Innovation (ESGI)	ESGI -> Credit Risk	Negative (-)	Supported ($p < 0.01$)
Digital Climate Governance (DCG)	DCG -> Credit Risk	Negative (-)	Supported ($p < 0.05$)
Climate Policy Stringency (CPS)	CPS moderat CRM -> Credit Risk	Negative (-)	Supported ($p < 0.05$)
Climate Policy Stringency (CPS)	CPS moderat ESGI -> Credit Risk	Negative (-)	Supported ($p < 0.05$)
Climate Policy Stringency (CPS)	CPS moderat DCG -> Credit Risk	Negative (-)	Supported ($p < 0.05$)

Source; author 2025

4.7 Discussion

Based on the presented results, this study provides evidence of the importance of climate-related strategies in determining firms′ credit risk profiles, at least with respect to the finance sample of non-financial publicly listed companies operating in Indonesia. Since the coefficients of carbon risk management, ESG innovation, and digital climate governance are consistently in a negative association with credit risk, this implies that more active and proactive sustainability strategies have the power to significantly improve firms′ financial stability. This corroborates previous findings showing that strong environmental performance reduces the likelihood of financial distress by reducing regulatory, reputational and operational costs stemming from carbon exposure. In particular, the estimates for carbon risk management and ESG innovation are more substantial, suggesting that these initiatives can have more direct and immediate impacts on creditworthiness due to origins from performance-based interventions, as opposed to "soft" digital interventions that are likely to deliver results only in the long term.

The results further indicate that policy stringency enhances the effectiveness of each climate strategy in reducing credit risk. These results align with institutional theory, which argues that regulatory frameworks create external pressures pushing firms toward more effective environmental strategies. Hence, in strict policy environments, firms are better placed – or forced – to develop sustainability initiatives that align better with regulatory expectations, gaining more acknowledgment from credit market actors. The evidence is consistent with the existing literature that shows how environmental regulatory risk interacts with firm sustainability profiles to impact financing costs. Therefore, corporate-level climate strategies interact with policy-level interventions to mutually reinforce each other. Without the latter, the former is likely to have muted credit market impacts.

Theoretically, findings confirm the synthesis of signaling theory and RBV to explain climate strategy–credit risk linkage. This underscores the importance of visible and credible sustainability practices in terms signaling value to investors and creditors and hence reduce risk (Flammer, 2021). In contrast, the resource-based view positions ESG innovation and digital climate governance as strategic resources that are valuable scarce and difficult to imitate, making firms more competitive and financially stronger (Hart & Dowell, 2011). Together, these frameworks illuminate the reasons why firms excelling in carbon management, ESG innovation and digital tools have better credit outcomes.

Additionally, the more flexible nature of results for alternative credit risk proxies implies that findings were not an artifact of measurement decision yet instead reflect strengthen primary powers. This generality is in line with recent multi-proxy financial risk papers, who argue that it is critical to validate environmental-financial connections using many different measurement approaches (Ehlers et al 2022; Engle et al. 2020). And the durability of these affects indicate that sustainability oriented strategies are entering the risk assessment frameworks for lenders and investors, as global adoption of ESG disclosure standards, as well as climate-related financial reporting more broadly tracked.

At a practical level, these results have large implications for multiple or service users. For corporate managers, the evidence accentuates the strategic power of making climate risk management, ESG-led innovation and digital governance part of standard operating procedures not only as compliance requirements but as means to lower financing costs and augment bottom line strength over time. This reinforces the point that policy makers need to scale up climate policies in order to boost the financial gains associated with corporate sustainability initiatives. The study provides real world evidence that when companies take sustainability and ESG seriously, it is not just a matter of enhancing their reputation; but that there are material benefits from both a lower cost of capital perspective and the likelihood of default.

In sum, the study contributes to a richer understanding of how multifaceted climate strategies, within different regulatory settings, influence financial resilience among corporations. Through this, it provides a nuanced viewpoint which illustrates the need for both firm-level action and policy context, something that is relevant to strategic corporate decisions and climate policy. Takeaways An integrated approach is vital for developing markets such as Indonesia, with the alignment of environmental imperatives and financial risk management increasingly being a focal point for sustainable economic growth.

5. Conclusion

Proactive climate strategies—especially carbon risk management, ESG innovation, and digital climate governance—will reduce credit risk for non-financial companies listed on Indonesia Stock Exchange. The results suggest that more sustainable firms benefit from lower credit score – a sign of less financial stress, with carbon risk mitigation and ESG innovation being the largest drivers. I also find that the effects of corporate sustainability on financial performance are increased when stringent climate policies are in place, illustrating the important synergizing function of regulatory environments in strengthening sustainable development. The findings are in line with signaling theory and the resource-based view, which consider credible sustainability actions to be strategic resources that imply lower perceived risk to investors as well as higher competitive advantage(invited). Additional robustness tests show that these results are intact across different credit risk measures. The evidence leads to one conclusion: that incorporating climate strategy as part of corporate governance, innovation and policy alignment is a sustainability necessity that makes financial risk management sense.

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Declaration of Competing Interest

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

Appendix A. Cross-cutting Issues

This study straddles the area between corporate finance, environmental economics and sustainability governance. This has manifested in the increasing convergence of financial stability and environmental responsibility through climate risk management, ESG innovation and digital governance integration. Results substantiate the overlapping items of sustainable development, climate policy compliance and responsible investment agendas, with practical impact for corporate managers, regulators and investors pertaining to emerging markets.

Appendix B. Definition of variables

Variable Category	Variable / Symbol	Definition	Measurement	Scale	Source
Dependent Variable	Credit Risk (CR)	The likelihood of a company failing to meet its debt obligations.	Altman Z-Score for non-manufacturing: Z = 6.56(X1) + 3.26(X2) + 6.72(X3) + 1.05(X4); lower Z-Score = higher credit risk.	Ratio	Refinitiv Eikon
Independent Variable	Carbon Risk Management (CRM)	The extent of a company's efforts to manage and mitigate carbon-related risks.	Disclosure index (1 = disclosed, 0 = not disclosed) based on sustainability reports: policies, targets, performance related to carbon reduction.	Ratio	Annual / Sustainability Reports
	ESG Innovation (ESGI)	The extent of a company's innovation in ESG-positive products/processes.	Disclosure index (1 = disclosed, 0 = not disclosed): R&D for green products, sustainable supply-chain initiatives, etc.	Ratio	Annual / Sustainability Reports
	Digital Climate Governance (DCG)	Use of digital technology in governance of climate issues.	Disclosure index (1 = disclosed, 0 = not disclosed): use of data analytics, IoT for emissions monitoring, etc.	Ratio	Annual / Sustainability Reports
Moderating Variable	Climate Policy Stringency (CPS)	Degree of stringency of a country's climate-related environmental policies.	OECD Environmental Policy Stringency (EPS) Index: higher score = more stringent policies.	Interval	OECD Database
Control Variables	Firm Size (SIZE)	Scale of a company's assets.	Natural logarithm of total assets.	Ratio	Refinitiv Eikon
	Profitability (ROA)	Company's ability to generate profit from its assets.	ROA = Net Income / Total Assets.	Ratio	Refinitiv Eikon
	Leverage (LEV)	Extent to which a company is financed by debt.	Debt-to-Asset Ratio = Total Debt / Total Assets.	Ratio	Refinitiv Eikon

Appendix C. Supplementary material

Supplementary data associated with this article, including the detailed coding scheme for content analysis, robustness checks with alternative econometric specifications, and additional regression diagnostics, can be found in the online version at.

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