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Green Banking, ESG Performance, and Profitability on Bank Credit Risk: The Moderating Role of Asset Quality Using a Fuzzy Structural Risk Approach

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Abstract: This study examines the effect of green banking, environmental social governance performance, and profitability on bank credit risk, with asset quality acting as a moderating variable. The research object consists of Indonesian conventional commercial banks classified as KBMI 3 and KBMI 4 during 2020–2024. The objective is to analyze whether sustainability integration reduces structural default vulnerability and how credit discipline conditions this relationship. The study applies panel data regression and moderated regression analysis using the Fuzzy Structural Risk of Default as a structural credit risk proxy. The results show that green banking is associated with higher short-term credit risk due to transition-related frictions. Environmental social governance performance significantly reduces credit risk, while profitability does not directly influence risk but strengthens stability when asset quality is strong. Asset quality functions both as a determinant and as a conditioning mechanism in sustainability–risk dynamics. The findings indicate that sustainable banking resilience depends on disciplined credit portfolio management during sustainability transition phases in emerging financial systems.

Keyword: Green Banking, ESG Performance, Asset Quality, Credit Risk, Fuzzy Structural Risk.

INTRODUCTION

Banks play a fundamental role in allocating capital, managing liquidity, and maintaining financial system stability. Among various risk categories, credit risk remains the most critical determinant of banking resilience, particularly in emerging markets characterized by structural transformation and macroeconomic volatility. The stability of the banking system is closely related to asset quality, default probability, and the management of non-performing loans (Arhinful, Gyamfi, et al., 2025; Arhinful, Mensah, et al., 2025).

In recent years, the global shift toward sustainable finance has encouraged banks to integrate green lending practices and environmental, social, and governance (ESG) considerations into strategic decision-making processes. Green banking initiatives aim to align financial intermediation with environmental sustainability objectives while maintaining financial performance (Bang et al., 2023; Lalon et al., 2025). However, empirical findings regarding the relationship between green banking and credit risk remain inconclusive. While sustainable lending is expected to reduce long-term risk exposure, transition-related adjustments may introduce temporary vulnerabilities (Palmieri et al., 2024; M. Zhou, 2022).

Profitability also presents an ambiguous relationship with credit risk. Higher return on equity may provide capital buffers against potential loan losses. Conversely, higher profitability may be associated with aggressive lending strategies that increase future credit risk exposure (Naili & Lahrichi, 2022; M. Zhou, 2022). Therefore, profitability alone may not fully explain structural credit vulnerability in large banking institutions.

ESG performance reflects governance quality, transparency, and sustainability integration. Strong ESG practices are associated with improved monitoring mechanisms and enhanced institutional stability (Chodnicka-Jaworska, 2021; Korzeb et al., 2025; Vivel-Búa et al., 2024). In the banking context, governance structures and ESG integration may influence risk management effectiveness and reduce default risk exposure.

Another critical factor shaping sustainability–risk dynamics is asset quality. Asset quality, commonly proxied by non-performing loans, reflects the effectiveness of underwriting standards and credit monitoring systems (Matanda et al., 2022; Milenković et al., 2024). Strong asset quality may serve not only as a direct determinant of credit risk but also as a conditioning mechanism that strengthens or weakens the impact of sustainability practices and profitability on structural stability. This perspective is consistent with prudential banking supervision emphasizing risk discipline (Bank for International Settlements, 2021; Otoritas Jasa Keuangan, 2023).

Despite growing research on ESG and green finance, limited empirical studies integrate sustainability variables, profitability, and asset quality within a structural credit risk framework using fuzzy-based risk measurement approaches. Fuzzy modeling enables the capture of gradual risk transitions and uncertainty in default probability estimation (Matanda et al., 2022; Reyes et al., 2023; Wójcicka-Wójtowicz & Piasecki, 2021).

This study addresses the following research questions: 1.Does green banking influence bank credit risk? 2.Does profitability affect structural default vulnerability? 3.Does ESG performance reduce credit risk? 4.Does asset quality directly affect credit risk? 5.Does asset quality moderate the relationships between sustainability, profitability, and credit risk?

By integrating panel data regression and moderated regression analysis, this research clarifies the conditional mechanisms linking green banking, ESG performance, profitability, asset quality, and structural credit risk. The findings are expected to contribute to the sustainability–risk literature by demonstrating that banking resilience during transition phases depends not solely on sustainability expansion but on alignment between governance integration and disciplined credit portfolio management.

METHOD

This study applies a quantitative explanatory research design to examine the structural relationships between green banking, profitability, ESG performance, asset quality, and bank credit risk. Quantitative explanatory research is appropriate for testing causal relationships among variables using statistical modeling approaches (Priadana & Sunarsi, 2021). The analysis employs panel data regression combined with Moderated Regression Analysis (MRA) to capture both direct and conditional effects among variables. Panel data methodology integrates cross-sectional and time-series dimensions, allowing improved estimation efficiency and control of unobserved heterogeneity (Basuki, 2021; Madany & Rais, 2022).

The research focuses on Indonesian conventional commercial banks classified as KBMI 3 and KBMI 4 and listed on the Indonesia Stock Exchange during the period 2020–2024. These banks represent large-scale institutions with systemic importance and active participation in sustainability integration initiatives, consistent with regulatory monitoring of banking risk profiles (Bank for International Settlements, 2021; Otoritas Jasa Keuangan, 2023).

The population consists of all KBMI 3 and KBMI 4 conventional banks operating during the observation period. The sample is determined using purposive sampling based on the following criteria: (1) banks are continuously listed throughout 2020–2024, (2) publish complete and audited annual financial statements, (3) disclose sustainability or ESG-related information consistently, and (4) provide sufficient financial data to construct the structural credit risk proxy. The use of purposive sampling ensures data completeness and comparability in panel regression analysis (Indartini & Mutmainah, 2024; Mubarak, 2021). The final dataset is structured as a balanced annual panel covering five consecutive years, allowing analysis of both cross-sectional heterogeneity and intertemporal dynamics (Basuki, 2021).

The dependent variable, credit risk, is proxied by the Fuzzy Structural Risk of Default (FSRD). FSRD integrates structural credit risk theory with fuzzy logic modeling to capture uncertainty, gradual risk transitions, and non-linear vulnerability patterns (Matanda et al., 2022; Reyes et al., 2023). Fuzzy-based credit risk assessment allows default probability to be expressed in degrees rather than binary classifications, enhancing the representation of structural vulnerability under uncertainty (Wójcicka-Wójtowicz & Piasecki, 2021; M. Zhou, 2022).

Green banking (GREEN) is measured using the proportion of green financing to total loans, reflecting the extent of sustainability-oriented lending exposure (Bang et al., 2023; Riananda & Fasa, 2025). Profitability (ROE) is calculated as net income divided by total equity, representing earnings efficiency and capital utilization performance (Prihadi, 2021). ESG performance (ESG) is measured using standardized ESG scores obtained from publicly disclosed sustainability information (Chodnicka-Jaworska, 2021; Korzeb et al., 2025). Asset quality (Z) is proxied by one minus non-performing loans ($1 - NPL$), consistent with banking stability literature emphasizing loan portfolio health as a determinant of default risk (Arhinful, Mensah, et al., 2025; Milenković et al., 2024).

To examine moderation effects, interaction terms are constructed between asset quality and each independent variable, namely GREEN × Z, ROE × Z, and ESG × Z. Moderated Regression Analysis (MRA) is used to evaluate conditional relationships where the effect of independent variables depends on the level of a moderating variable (Asmaranti & Sihombing, 2025; Rahadi & Farid, 2021). The inclusion of interaction terms enables identification of whether asset quality strengthens or weakens sustainability–risk relationships.

The baseline panel regression model is specified as:

$Y_{it} = \alpha + \beta_1 GREEN_{it} + \beta_2 ROE_{it} + \beta_3 ESG_{it} + \beta_4 Z_{it} + \mu_i + \lambda_t + \varepsilon_{it}$ where Y_{it} represents FSRD-based credit risk for bank i in year t, μ_i captures unobserved bank-specific effects, λ_t represents time effects, and ε_{it} denotes the error term. The extended moderated regression model is specified as:

$$Y_{it} = \alpha + \beta_1 GREEN_{it} + \beta_2 ROE_{it} + \beta_3 ESG_{it} + \beta_4 Z_{it} + \beta_5 (GREEN_{it} \times Z_{it}) + \beta_6 (ROE_{it} \times Z_{it}) + \beta_7 (ESG_{it} \times Z_{it}) + \mu_i + \lambda_t + \varepsilon_{it}$$

Panel model selection is conducted using the Chow test to compare pooled ordinary least squares and fixed-effects models, followed by the Hausman test to determine the suitability of fixed versus random effects estimators (Basuki, 2021; Septianingsih, 2022). The fixed-effects specification is selected to control for unobserved heterogeneity across banks that may correlate with explanatory variables.

Robust standard errors are applied to address potential heteroskedasticity and serial correlation within the panel structure to ensure consistent statistical inference (Madany & Rais, 2022). Hypothesis testing is conducted based on the statistical significance and direction of regression coefficients at conventional levels (1%, 5%, and 10%). A statistically significant interaction term indicates the presence of moderation effects, while the sign of the coefficient reflects whether asset quality strengthens or weakens the relationship between independent variables and structural credit risk. The interpretation of empirical results aligns with sustainability–risk integration frameworks in banking (Palmieri et al., 2024; Sutrisno et al., 2024).

RESULTS AND DISCUSSION

Descriptive Statistics

Based on Table 1, the mean FSRD value is 0.638094, with a minimum of 0.226964 and a maximum of 0.834958. The relatively wide range indicates substantial heterogeneity in structural default vulnerability among KBMI 3–4 banks. The standard deviation of 0.134796 further confirms moderate dispersion in structural credit risk. Variability in fuzzy-based structural risk measures is consistent with prior fuzzy credit modeling studies (Matanda et al., 2022; Reyes et al., 2023).

Green banking (GREEN) shows a mean of 0.175619 with a maximum value of 0.613744 and a minimum of 0.000381, indicating significant variation in sustainability-oriented lending intensity across banks. The standard deviation of 0.156284 suggests relatively high dispersion compared to its mean, reflecting differing levels of green portfolio commitment (Bang et al., 2023; Riananda & Fasa, 2025). Profitability (ROE) has a mean of 0.119370 and a standard deviation of 0.063668, indicating moderate cross-sectional variation in earnings performance. ESG performance exhibits a mean of 0.637674 and a maximum of 0.991150, suggesting variation in governance and sustainability integration practices (Chodnicka-Jaworska, 2021; Korzeb et al., 2025).

Asset quality (Z) shows a high mean of 0.974676 and low standard deviation of 0.008800, indicating generally sound credit portfolios across sampled banks, consistent with NPL-based risk assessments (Arhinful, Mensah, et al., 2025; Milenković et al., 2024).

Overall, these descriptive statistics provide preliminary evidence that sustainability integration, profitability, and credit discipline vary across banks and may interact in shaping structural credit risk dynamics rather than operating independently.

Table 1. Descriptive Statistics of Research Variables

Statistic	FSRD	GREEN	ROE	ESG	Z (1-NPL)
Mean	0.638094	0.175619	0.119370	0.637674	0.974676
Median	0.667123	0.174780	0.106350	0.610619	0.972500
Maximum	0.834958	0.613744	0.273100	0.991150	0.990300
Minimum	0.226964	0.000381	0.026000	0.309735	0.955200
Std. Dev	0.134796	0.156284	0.063668	0.147789	0.008800
Observations	70	70	70	70	70

Source: Processed research data

Panel Model Selection

Panel model selection tests were conducted to determine the most appropriate estimation framework for the regression model. As presented in Table 2, the Chow test produces a Cross-section F statistic of 78.568985 with degrees of freedom (13, 49) and a probability value of 0.0000. Since the probability is below the 5% significance level, the pooled ordinary least squares (POLS) model is rejected. This result confirms the presence of significant bank-specific heterogeneity across KBMI 3–4 institutions during 2020–2024. The existence of cross-sectional heterogeneity justifies the use of panel data techniques to control for unobserved institutional characteristics (Basuki, 2021; Madany & Rais, 2022).

Furthermore, the Cross-section Chi-square statistic is 215.877508 (Prob. = 0.0000), reinforcing the rejection of the pooled model. These findings indicate that ignoring cross-sectional effects would produce biased and inconsistent estimates.

To determine whether the fixed-effects or random-effects specification is more appropriate, the Hausman test was performed. The test yields a Cross-section Random (Hausman) statistic of 80.841459 with 7 degrees of freedom and a probability value of 0.0000. The statistically significant result indicates that unobserved bank-specific effects are correlated with the explanatory variables. Therefore, the random-effects model is rejected in favor of the fixed-effects specification. The adoption of fixed effects is consistent with panel data modeling guidelines emphasizing the importance of controlling for time-invariant institutional differences in financial research (Basuki, 2021; Septianingsih, 2022).

Overall, the empirical evidence strongly supports the use of the fixed-effects model to ensure robust estimation and mitigate omitted-variable bias arising from structural differences among banks.

Table 2. Panel Model Selection Tests

Test Type	Statistic	d.f.	Prob
Cross-section F	78.568985	(13, 49)	0.0000
Cross-section Chi-square	215.877508	13	0.0000
Cross-section Random (Hausman)	80.841459	7	0.0000

Source: EViews output (2020–2024)

Direct Effects Estimation

The fixed-effects regression results are presented in Table 3. Green banking (GREEN) exhibits a positive and statistically significant coefficient (β = 0.065555; t = 3.166522; p = 0.0027). This indicates that a one-unit increase in the proportion of green financing increases the Fuzzy Structural Risk of Default (FSRD) by approximately 0.0656 units, holding other variables constant. The positive sign suggests that sustainability-oriented lending expansion is associated with higher short-term structural vulnerability. This finding is consistent with transition-risk arguments indicating that green portfolio reallocation may involve sectoral concentration, regulatory adaptation, and borrower performance uncertainty during early implementation phases (Palmieri et al., 2024; X. Y. Zhou et al., 2022).

Profitability (ROE) shows a positive but statistically insignificant coefficient (β = 0.020839; t = 0.931806; p = 0.3560). Since the probability value exceeds the 5% significance level, ROE does not exert a direct influence on structural credit risk. This implies that earnings performance alone does not automatically translate into lower default exposure, supporting findings that profitability effects depend on underlying credit discipline (Arhinful, Gyamfi, et al., 2025; Naili & Lahrichi, 2022).

In contrast, ESG performance demonstrates a negative and statistically significant coefficient (β = −0.064372; t = −2.947561; p = 0.0049). The negative sign indicates that improved governance quality and sustainability integration reduce structural credit risk. A one-unit increase in ESG score decreases FSRD by approximately 0.0644 units. This result aligns with evidence that ESG integration enhances monitoring effectiveness and reduces institutional default exposure (Korzeb et al., 2024; Vivel-Búa et al., 2024).

Asset quality (Z), measured as one minus non-performing loans, also exhibits a negative and statistically significant direct effect (β = −0.076368; t = −3.168198; p = 0.0026). This implies that improved loan portfolio health directly reduces structural default vulnerability. The magnitude of the coefficient indicates that asset quality plays a stronger stabilizing role than ESG performance in the direct-effects specification. This finding is consistent with NPL-based risk literature emphasizing credit discipline as the core determinant of banking stability (Arhinful, Mensah, et al., 2025; Milenković et al., 2024).

Overall, the model explains 95.68% of the variation in structural credit risk (R^2 = 0.956816). The regression is jointly significant (F-statistic = 54.28332; Prob(F) = 0.000000), confirming strong explanatory power under the fixed-effects specification. The high R^2 reflects the inclusion of cross-sectional fixed effects capturing institutional heterogeneity across banks rather than model overfitting.

Table 3. Fixed-Effects Regression Results

Variable	Coefficient	STD.Error	T-Statistic	Prob
GREEN	0.065555	0.020702	3.166522	0.0027
ROE	0.020839	0.022364	0.931806	0.3560
ESG	-0.064372	0.021839	-2.947561	0.0049
ASSET QUALITY (Z)	-0.076368	0.024105	-3.168198	0.0026
GREEN × Z	0.014245	0.028066	0.507558	0.6140
ROE × Z	-0.062803	0.026561	-2.364481	0.0221
ESG × Z	-0.089420	0.025733	-3.474956	0.0011

Source: Processed research data (2020–2024)

Moderation Effects

The moderation analysis evaluates whether asset quality (Z) conditions the relationships between sustainability variables, profitability, and structural credit risk. As reported in Table 3, the interaction term between green banking and asset quality (GREEN × Z) yields a coefficient of 0.014245 with a t-statistic of 0.507558 and a probability value of 0.6140. Since the p-value exceeds the 5% significance level, the interaction effect is statistically insignificant. This indicates that asset quality does not significantly moderate the short-term relationship between green lending exposure and structural default risk. In practical terms, even banks with strong credit discipline may still experience transitional risk during early-stage green portfolio reallocation. This finding is consistent with sustainability transition literature suggesting that green finance implementation may involve sectoral concentration and regulatory adaptation risks beyond traditional prudential buffers (Palmieri et al., 2024).

In contrast, the interaction between profitability and asset quality (ROE × Z) shows a negative and statistically significant coefficient ($\beta = -0.062803$; $t = -2.364481$; $p = 0.0221$). The negative sign indicates that the stabilizing effect of profitability on structural credit risk strengthens when asset quality is high. Specifically, profitability contributes to lower FSRD only under conditions of disciplined underwriting and effective credit monitoring. Without strong asset quality, higher profitability may reflect increased risk-taking behavior rather than enhanced resilience. This conditional mechanism aligns with moderation-based financial performance models (Asmaranti & Sihombing, 2025; Rahadi & Farid, 2021).

Similarly, the interaction between ESG performance and asset quality (ESG × Z) is negative and highly significant ($\beta = -0.089420$; $t = -3.474956$; $p = 0.0011$). The magnitude of this coefficient is larger than that of the ROE interaction, indicating that asset quality strengthens the risk-reducing impact of ESG more than it strengthens profitability effects. This suggests that governance quality and sustainability integration become substantially more effective in mitigating structural default vulnerability when supported by healthy loan portfolios. Empirical evidence in global banking research similarly emphasizes that ESG effectiveness depends on institutional risk management capacity (Korzeb et al., 2025; Vivel-Búa et al., 2024).

Overall, the moderation results confirm that sustainability integration does not operate independently of core prudential mechanisms. Asset quality functions as a conditioning variable that amplifies the stabilizing roles of profitability and ESG governance in reducing structural default exposure. Therefore, sustainable banking resilience in emerging markets depends not only on sustainability expansion but also on disciplined credit portfolio management as the structural anchor of financial stability (Arhinful, Gyamfi, et al., 2025; Milenković et al., 2024).

The empirical results demonstrate that sustainability–risk dynamics in large Indonesian banks are conditional rather than uniformly linear. The positive and statistically significant coefficient of green banking ($\beta = 0.065555$; $p = 0.0027$) indicates that greater green lending exposure is associated with higher short-term structural credit risk. This finding suggests the presence of transitional frictions during sustainability implementation. In emerging financial systems, green portfolio reallocation often involves limited borrower track records, sectoral concentration, and regulatory adaptation costs, which may temporarily elevate structural vulnerability before long-term stability benefits materialize. This transitional-risk argument is consistent with empirical evidence documenting short-term risk adjustments during green finance implementation (Palmieri et al., 2024; Zhou et al., 2022; Fan & Xu, 2025).

In contrast, ESG performance exhibits a negative and statistically significant direct effect ($\beta = -0.064372$; $p = 0.0049$), confirming its stabilizing role in structural credit risk mitigation. Strong ESG performance reflects enhanced governance quality, transparency, accountability, and monitoring intensity, which improve institutional risk management systems and reduce information asymmetry. This finding aligns with global banking evidence suggesting that ESG integration strengthens default risk control mechanisms (Korzeb et al., 2025; Vivel-Búa et al., 2024; Neitzert & Petras, 2022). The result reinforces the view that governance integration operates as a structural resilience enhancer rather than merely a reputational or compliance mechanism.

Profitability, however, does not exert a statistically significant direct effect on structural credit risk ($\beta = 0.020839$; $p = 0.3560$). This implies that earnings performance alone does not guarantee structural resilience. Higher profitability may coexist with heterogeneous lending strategies or elevated risk-taking incentives, particularly in competitive emerging markets. This ambiguous profitability–risk relationship is consistent with prior findings suggesting that earnings buffers do not automatically translate into lower default exposure without complementary prudential mechanisms (Arhinful et al., 2025a; Zhou, 2022).

Asset quality emerges as the central structural anchor. Its direct negative and significant coefficient ($\beta = -0.076368$; $p = 0.0026$) confirms that disciplined underwriting and low non-performing loan ratios directly reduce structural default exposure. More importantly, moderation results reveal that asset quality strengthens the risk-reducing effects of profitability

($\beta\_ROE \times Z = -0.062803$; $p = 0.0221$) and ESG performance ($\beta\_ESG \times Z = -0.089420$; $p = 0.0011$). These interaction effects demonstrate that sustainability and earnings effectiveness are conditional upon core credit discipline. Without strong asset quality, sustainability initiatives and profitability improvements may not fully translate into structural stability. This moderation pattern aligns with conditional financial performance frameworks and moderation theory applications in corporate finance research (Rahadi & Farid, 2021; Asmaranti & Sihombing, 2025).

Collectively, the findings indicate that sustainability-driven resilience in emerging markets requires alignment between green finance expansion, governance integration, profitability strategies, and prudential credit discipline. Sustainability transformation is therefore not a linear risk-reduction mechanism but a structural process dependent on institutional risk management capacity. This conditional mechanism contributes to the sustainability–risk literature by demonstrating that governance and profitability operate within a broader structural credit quality framework, rather than independently determining banking stability.

CONCLUSION

This study investigates the effects of green banking, profitability, and ESG performance on structural bank credit risk, with asset quality functioning both as a direct determinant and as a moderating mechanism. Using panel data from Indonesian KBMI 3–4 conventional commercial banks during 2020–2024 and applying the Fuzzy Structural Risk of Default as a structural risk proxy, the findings demonstrate that sustainability–risk dynamics are conditional rather than uniformly linear.

The empirical evidence reveals that green banking expansion increases short-term structural credit risk, indicating the presence of transitional frictions during early-stage sustainability implementation. Conversely, ESG performance consistently reduces structural default vulnerability, confirming the stabilizing role of governance quality and transparency. Profitability does not exert a direct effect on structural risk, suggesting that earnings performance alone is insufficient to ensure banking stability.

Asset quality emerges as the core stabilizing mechanism. It not only directly reduces structural credit risk but also strengthens the risk-mitigating effects of profitability and ESG performance. These results confirm that sustainability-driven resilience depends critically on disciplined credit portfolio management. Without strong asset quality, sustainability integration and profitability improvements may not effectively translate into structural risk reduction.

Theoretically, this study contributes to the sustainability–risk literature by demonstrating that governance integration influences banking stability through conditional mechanisms anchored in asset quality. Sustainability practices, profitability, and governance quality do not operate independently but interact within a structural credit discipline framework. Methodologically, the application of the Fuzzy Structural Risk of Default extends conventional risk measurement by incorporating uncertainty and non-linear vulnerability patterns in emerging financial systems.

From a policy perspective, sustainability mandates and green finance initiatives should be aligned with strict asset quality supervision to safeguard systemic resilience. For bank management, green portfolio expansion must be accompanied by strengthened underwriting standards and enhanced credit monitoring frameworks. Future research may extend the observation horizon, incorporate cross-country comparisons, or apply alternative structural risk modeling approaches to further examine sustainability–risk interactions in banking sectors.

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