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The influence of non-performing loans on environmental innovation: an institutional theory perspective – insights from U.S banks

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ABSTRACT

With the global push for sustainability, banks are turning to environmental innovation to support green projects, offer eco-friendly loans, and align with environmental goals. However, banks burdened by high NPLs may lack the incentive to invest in such initiatives. This study used the institutional theory to probe into the influence of NPLs on environmental innovation. The selection of the banks listed on the New York Stock Exchange was based on inclusion and exclusion criteria, and employing purposive sampling enabled the identification of 70 potential banks without any gaps in the data between 2011 and 2023, and their data were obtained from the Thomson Reuters Eikon. Augmented Mean Group (AMG), Fixed effects with Driscoll-Kraay standard errors and Generalized Methods of Movement were the sophisticated estimation methods used to analyze the relationship between NPLs and environmental innovation. The study discovered a negative and significant relationship between NPLs and environmental innovation. It was further disclosed that the interaction relationship between NPLs and management quality had a negative and significant impact on environmental innovation. To foster environmental innovation, banks should adopt strategies that blend sustainability with long-term growth beyond short-term profits. One effective approach is establishing a dedicated fund solely for financing environmental projects.

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SUBJECTS
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Introduction

An outstanding loan is classified as non-performing when a borrower does not make one or more payments towards the principal or interest for 90 days or longer (Asfaw et al., 2016). Non-repayment of loans substantially impacts a bank's income streams since the bank ceases to receive interest charges from these loans. This leads to a rise in the operational expenses of banks, compelling them to spend extra resources on the administration and retrieval of non-performing financial obligations (Alshebmi et al., 2020). Banks must make significant provisions for any loan losses that affect their income. Elevated non-performing loans (NPLs) gradually undermine investor confidence in the bank, leading to a decline in stock prices and making it difficult for the banks to secure equity capital from the stock market (Ning, 2024). A bank that cannot engage in innovation or development hinders its long-term growth prospects due to diminished profitability caused by NPLs.

With the contemporary global emphasis on sustainability, banks are interested in environmental innovation. Banks that invest in environmentally friendly technology and promote ecologically conscious projects showcase their progressive outlook and actively contribute to worldwide sustainability efforts (Baietti, 2012; Rahman et al., 2023). These enable the banks to create environmental consciousness awareness among consumers, investors, and regulatory bodies. Customers place more

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value on businesses that support sustainability, so banks that refrain from engaging in environmental innovation lose out to their rivals (Weber & Feltmate, 2016). The advent of environmental innovation enabled banks to support sustainable projects, offer green loans, and conform to global environmental goals. When looking for banks to operate with, prospective clients select those that align with their values or integrate environmental innovation into their fundamental strategy (Fasnacht & Fasnacht, 2018).

NPLs weaken bank efforts aimed at promoting environmental innovation. Banks that focus on managing NPLs often lack the means or incentive to allocate resources towards sustainable or ecologically beneficial projects (Cheung et al., 2022; Shirai, 2023). NPLs redirect the focus and resources of the banks from proactive pursuits, such as green innovation, which improve the bank's reputation and create new business prospects. This poses a significant challenge in the market since investors and consumers place more importance on sustainability (Söderholm, 2020). Lack of investment in environmental innovation by a bank may result in missed opportunities to form alliances with environmentally aware businesses and attract an expanding customer base that values green finance (Weber & Feltmate, 2016).

Despite the considerable study undertaken on the influence of NPLs on the operational efficiency and financial solvency of banks (Havidz & Setiawan, 2015; Kashif et al., 2016; Lotto, 2018), there remains a dearth of knowledge concerning the effect of NPLs on environmental innovation. The literature has yet to examine the influence of NPLs on a bank's ability or propensity to participate in environmental innovation. This gap is of utmost importance since the financial difficulties arising from significant NPLs hinder a bank's capacity to actively pursue and progress in green technology, which may ultimately decrease funding for sustainable projects. Also, the literature has not yet examined how management quality mediates the relationship between NPLS and environmental innovation. It is vital to address these gaps to comprehensively grasp the consequences of economic adversity on a bank's dedication to ecological sustainability and its contribution to promoting innovation in environmental practices.

The study addressed these important gaps by looking into how NPLs affect banks' environmental innovations and as well as how management quality mediates this relationship. Addressing these gaps will add to the body of research through empirical evidence. The study addressed the following questions:

First, what is the impact of NPLs on environmental innovation? Second, how does management quality moderate the relationship between NPLs and environmental innovation?

The study contributes to the literature by examining the effect of NPLs on bank's environmental innovations. Addressing this contribution is significant as it provides insight into how financial constraints arising from NPLs impede investments in sustainable technology by the banks. By addressing this knowledge gap, the study will formulate strategies that will enable the achievement of a harmonious equilibrium between financial stability and cutting-edge sustainability initiatives, as well as to understand the influence of economic factors on a bank's environmental obligations.

The study contributes to the literature by probing into the moderating role of management quality in the relationship between NPLs and environmental innovation. This moderating relationship will facilitate an understanding of the influence of financial challenges on sustainability initiatives and the effects of effective leadership. The insight from this moderating role will disclose how effective management strategies can improve a bank's capacity to engage in sustainable innovation despite financial difficulties and reduce the adverse impact of NPLs on environmental initiatives.

This study offers valuable novel perspectives on financial difficulties, such as how NPLs impact a bank's commitment to environmental innovation. The study highlights the significance of management quality in mitigating these impacts, underscoring strategic leadership's need to sustain sustainability efforts under financial constraints. The outcomes will facilitate the integration of sustainability considerations into financial strategic decision-making by providing policymakers and banks with frameworks to address the challenges of balancing financial stability and environmental responsibility.

The remainder of this paper is structured as follows: Section 2 presents the theoretical framework and literature review, Section 3 outlines the methodology and data collection procedures, Section 4 presents the empirical results and analysis, Section 5 discusses the findings and their implications, and Section 6 concludes with limitations and suggestions for future research.

Literature review

Theoretical perspective

The influence of NPLs on a bank's environmental innovation can be examined using three relevant theories: stakeholder, institutional, and resource-based view (RBV). According to the RBV, an institution's internal resources and capabilities determine its capacity for innovation (Maiti et al., 2020). NPLs exhaust financial reserves, diminishing the available funding for ecologically friendly technological advancements. RBV does not consider the broader strategic framework or external influences on NPLs.

According to stakeholder theory, banks should consider the concerns and best interests of many parties, including those who support environmental sustainability (Schaltegger et al., 2019). With higher NPLs, banks may prioritize financial stability over environmental innovation to satisfy pressing stakeholder demands. Nevertheless, this theory does not sufficiently address the financial limitations imposed by NPLs.

Institutional theory examines how external elements, such as industry norms and statutory regulations, impact organizational conduct (Lavandoski et al., 2016). DiMaggio and Powell (1983) assert that institutional theory describes the phenomenon whereby organizations become increasingly homogeneous due to coercive, mimetic, and normative pressures. In organizational contexts, legitimacy supersedes efficiency. Meyer and Rowan (1977) assert that institutional theory posits that formal structures are established based on societal norms. These structures are intended to symbolize legitimacy rather than technological efficiency, frequently resulting in structural decoupling. According to Scott (2013), institutional theory posits that organizations are shaped by regulative, normative, and cultural-cognitive variables that influence behavior and attitudes, embedding them within broader institutional contexts that constrain and enable actions.

Due to the heightened financial strain, NPLs hinder a bank's capacity to adhere to environmental standards and adopt innovative practices. Industry norms and statutory regulations propel innovation amid financial limitations.

Among the theories, institutional theory was the most appropriate. It provides valuable insights into the effects of NPLs on a bank's environmental innovation. It highlights the significance of institutional norms and external factors in contributing to innovation. The theory asserts that banks' conduct and strategic choices are subject to the impact of the industry standards, social expectations, and legal constraints that govern their operations (Barth et al., 2008).

An elevated proportion of NPLs in a bank jeopardizes its financial sustainability, constraining its ability to allocate resources towards environmental innovation (Huang et al., 2023). The institutional theory suggests that banks are shaped by industry norms that encourage sustainability and government requirements to comply with environmental regulations (Brammer et al., 2012). Nevertheless, the burden of NPLs can drive banks to prioritize immediate financial stability above long-term environmental goals, reducing their allocation of resources towards innovative processes.

The institutional theory emphasizes the influence of institutional legitimacy and compliance requirements on a bank's strategic choices (Zhao et al., 2017). Banks face difficulties ensuring their adherence to environmental standards during financial instability, such as significant NPLs. Such a scenario results in a reduced focus on innovation. The institutional theory posits that banks are driven to conform to external norms and regulatory requirements. Nevertheless, their financial limitations and the need to attend to pressing financial concerns limit their capacity to integrate environmental innovation.

Hypothesis development

The influence of NPLs on environmental innovation

Due to the strain on its financial resources and the reorganization of its strategic goals, NPLs can significantly hinder a bank's ability to innovate in climate issues (Cardillo et al., 2021). High NPLs threaten a bank's financial sustainability by raising costs and limiting its capacity to fund environmentally-oriented long-term projects. The escalation of NPLs contributed to financial instability and often compels banks to prefer short-term financial stability to long-term innovation (Jaiwani & Gopalkrishnan, 2024). Empirical

research has shown that banks experiencing financial challenges often redirect resources from discretionary activities, such as environmental programs, to critical financial recovery measures (Hüfner, 2010; Svartzman et al., 2021) This alteration significantly restricts a bank's ability to adopt or maintain new environmental programs.

A study by Muchiri et al. (2025) examines green banking practices and highlights how environmental innovation, including sustainable lending and green financial products, presents both opportunities and risks for banks. Their discussion of operational challenges and credit risk in green finance directly supports this study's interest in how NPLs may emerge or be mitigated through environmentally innovative strategies. The study by Park and Kim (2020) emphasizes the role of financial institutions and regulators in driving green banking transitions. They argue that environmental innovation in financial services—particularly through green credit allocation and sustainability-linked loans—requires sound risk management frameworks. This aligns with how NPLs affect banks' strategic commitment to such innovations.

NPLs can impose a substantial financial strain on a bank, diminishing the capacity to allocate funds towards R&D, especially for projects promoting environmental sustainability (Ding et al., 2022). Financially constrained banks may decrease discretionary spending, reducing investments in environmentally friendly and advanced technologies. For instance, a study by Bassanini and Reviglio (2011) found that companies facing financial challenges prioritize immediate financial stability over long-term strategic goals and dedicate fewer resources to R&D. This assertion is also supported by an empirical study by Kuckertz et al. (2020) that discovered that companies often prioritize immediate recovery strategies over long-term innovation, such as environmental advancements, during periods of financial hardship.

Strict regulatory scrutiny and increased compliance costs resulting from high levels of NPLs hinder a bank's ability to deploy resources towards environmental projects (Salim et al., 2023). Significant expenditures are redirected from R&D projects to minimize financial risks and meet regulatory requirements. Banks with significant NPLs redistribute their resources to meet regulatory requirements instead of investing in sustainable practices and cutting-edge technology (Scardovi, 2024). As banks grapple with reconciling their commitment to sustainable development with regulatory compliance requirements, this focus change hinders the advancement of environmental innovation. The study by Golitsis et al. (2022) identifies the key macroeconomic and institutional factors influencing NPLs. Their insights contribute to understanding how credit quality concerns, shaped by internal and external pressures, may affect banks' decisions on lending strategies, including whether to engage in or avoid innovative environmental financing initiatives.

NPLs influence banks' strategic resource allocation, often constraining their ability to invest in long-term initiatives such as environmental innovation. However, this constraint also presents an opportunity for innovative resource allocation strategies. Hughes and Mester (2013) demonstrate that high levels of credit risk alter the cost structure of large banks, affecting how resources are allocated under risk-return trade-offs. Similarly, Golitsis et al. (2022) demonstrate that elevated NPLs in North Macedonia are linked to macroeconomic instability and internal bank inefficiencies, which can limit the strategic flexibility of financial institutions. These findings suggest that high NPL ratios compel banks to divert resources away from innovative or sustainable projects to focus on risk mitigation and balance sheet repair. In contrast, literature linking environmental strategies to bank performance supports the strategic value of sustainability.

Esteban-Sanchez et al. (2017) find that strong corporate social performance is positively associated with financial outcomes in the banking sector, implying that environmental initiatives can enhance long-term profitability. This emphasis on long-term profitability can inspire a forward-thinking approach to resource allocation. Supporting this, Golitsis et al. (2019) emphasize that effective credit risk management, including responsible lending aligned with sustainability goals, contributes to financial stability. Together, these studies highlight the tension between managing credit risk and pursuing sustainability, framing NPLs as both a constraint and a signal for more prudent, innovative resource deployment. Saliba et al. (2023) found that increased country risk, especially political and financial risk, significantly raises non-performing loans in BRICS banks, highlighting the role of macro-level stability in credit performance. Based on these discussions, this study hypothesized that:

H1: NPLs have a negative and significant impact on NPLs.

The moderating role of management quality in the relationship between NPLs and environmental innovation

The management level plays a crucial role in shaping banks' responses to the growing NPLs within the context of environmental innovation. Typically, rising NPL levels signal poor credit quality, operational inefficiencies, and resource constraints that could hinder a bank's ability and willingness to fund innovative initiatives, particularly those addressing environmental issues (Goyal et al., 2023; Rana et al., 2025). However, banks with high management quality are better equipped to overcome these financial constraints. They are more likely to have the strategic foresight, risk management capabilities, and governance frameworks needed to prioritize long-term sustainability goals, even in the face of short-term financial pressures caused by loan defaults (Anagnostopoulos, 2018).

Furthermore, proactive credit risk evaluation methods, efficient restructuring of defaulted loans, and adequate resource allocation to key innovative sectors empower effective management to mitigate the adverse impacts of NPLs (Addy et al., 2024). In the face of a high NPL ratio, proficient management may opt for innovation-driven solutions such as green financing instruments, enhanced environmental risk evaluations, or partnerships for clean energy initiatives to bolster the bank's brand and regulatory standing. This proactive approach can significantly mitigate the adverse impacts of NPLs, providing a sense of reassurance about the potential solutions. Conversely, poor management may view environmental innovation as an extraneous cost during financial downturns, thus widening the gap between sustainable practices and financial performance (Kim, 2015).

The quality of management significantly influences the cultural orientation and values embedded within the organization. A management team that prioritizes ethical leadership, corporate responsibility, and stakeholder engagement can inspire positive change. Such a team will incorporate environmental innovation as a core element of the bank's strategic framework, regardless of the NPL burden (Al Aina & Faisal, 2024; Barua, 2020). This moderating effect ensures that, despite a rise in NPLs, banks managed by informed and proactive managers are less inclined to abandon their environmental goals. The quality of management acts as a safeguard, ensuring that adverse financial conditions do not undermine a bank's dedication to sustainable innovation (Lumpkin, 2010). Based on these discussions, the study proposes that:

H2: Management quality negatively and significantly moderates the relationship between NPLs and environmental innovation

Methodology

Sample and data

The United States was selected as a country for this study because of its increasing focus on corporate social responsibility (CSR) and environmental sustainability, especially after the implementation of the Paris Agreement (ElAlfy et al., 2020). Given that US banks increasingly incorporate environmental goals into their strategic objectives, the United States was suitable for this study.

The selection of US banks for this study was based on their innovative initiatives in funding ecologically sound projects and sustainable development programs (Weber & Feltmate, 2016). The prevailing expectation for US banks to strike a harmonious equilibrium between environmental responsibility and financial success offers a unique chance to comprehend the possible consequences of NPLs on their sustainability obligations. This paper thoroughly analyses the consequences of financial challenges on the investments made by banks in environmentally innovative projects.

The study obtained the data from Thomson Reuters Eikon DataStream, and the selection of these data repositories was based on its comprehensive financial databases, which offer the precise historical data required for this research. To be eligible for inclusion, the banks had to meet specific requirements: (1) they had to be publicly traded on the New York Stock Exchange, (2) have detailed data from 2011 to 2023 without any gaps, (3) have been consistently operating in the United States for a long time within the specified periods selected for the study, and (4) must not be a financial institution such as venture capital firms, leasing companies, or insurance companies. Using data from the

Eikon, a purposive sampling method was used to identify 70 banks that met the specified inclusion requirements. Unlike imbalanced datasets, balanced data offer a more accurate and transparent basis for evaluating the consequences of NPLs, as they do not add biases caused by missing values. Therefore, the utilization of balanced data was essential for the obtaining of reliable outcomes for this study.

Dependent, independent and moderating variables

Table 1 contains the summary of all the variables utilized in this study.

Dependent variable

Environmental innovation refers to the development and implementation of novel or significantly improved products, processes, practices, services, or business models that facilitate more effective utilization of natural resources or reduce environmental impact (Huber, 2004). A bank's implementation and financial commitment to sustainable practices and technology were evaluated using environmental innovation score, measured on a scale of 0 to 100 (Weber & Feltmate, 2016; Arhinful et al., 2025). It reflects a bank's relative performance in adopting and investing in environmentally sustainable technologies and practices. It is calculated using publicly available data, including sustainability disclosures, green patents, environmental initiatives, and investment in green technologies.

A high score signifies that a bank upholds its commitment to sustainable practices and green technologies, even amid financial difficulties marked by high levels of NPLs, demonstrating robust environmental stewardship. In contrast, a low score suggests insufficient allocation of resources towards environmental innovation. As a result, banks may decrease their focus on sustainability due to financial constraints (Jeucken & Bouma, 2017). Using this metric enables the study to examine the influence of a bank's financial difficulties on its dedication to environmental sustainability and innovation.

Independent variables

Loans for which borrowers have stopped making regular payments for 90 days or more are classified as NPLs (Asfaw et al., 2016), which served as the dependent variable in this study. NPLs adversely affect banks by diminishing profitability, undermining asset quality, and elevating credit risk. Commonly regarded as an indicator of credit portfolio vitality, NPLs were computed in this study as the ratio of NPLs to total loans. NPLs are used as the independent variable in this study because of their capacity to restrict financial resources, hinder green investments, and diminish banks' potential to foster environmental innovation (Ntarmah et al., 2020).

Table 1. Summary of variables, their definition and formulas.

Index	Variable	Abbreviation	Formulae
	Dependent variables:		
1	Environmental innovation	ENVN	Environmental innovation score
	Independent variables:		
1	Non-performing loans	NPLs	$\frac{Non-performing\ loans}{Total\ gross\ loans} * 100$
	Control variables:		
1	Research and development	R&D	$\frac{Research\ and\ devlopment}{\text{Total assets}}$
2	Management quality	MGQT	Management efficiency ratio
3	Capital intensity	CAIY	$\frac{Total\ fixed\ assets}{\text{Total sales}}$
4	Firm size	FMSZ	From the years the firms were incorporated in the stock market to the years in which the data were downloaded (between 2011 and 2023)
5	GDP growth rate	GDPG	$\left(\frac{GDP_{Current\ period} - GDP_{Previous\ period}}{GDP_{Previous\ period}}\right) * 100$

Control variables

This study examined the impact of five control variables (research and development (R&D), management quality, capital intensity, firm size, and GDP growth rate) on environmental innovation.

R&D demonstrates a company's dedication to technical advancement and innovation (Tubbs, 2007). Typically, it is computed as R&D expenditure divided by total assets. R&D is a foundation for creating sustainable technologies and practices within environmental innovation (Weaver et al., 2017). Controlling for R&D ensures that a company's internal innovation skills do not solely drive the observed effects on environmental innovation but rather distinctly isolates the impact of other factors, such as NPLs.

Management quality refers to a company's leaders' strategic capability and effectiveness in resource allocation and decision-making (Litvaj et al., 2022). Management efficiency ratios are commonly employed to assess it. Effective management is likely to implement sustainable, progressive policies. Managing quality as a control variable mitigates internal governance factors that may directly impact environmental innovation performance (Li et al., 2018), ensuring that external influences such as NPLs are not exaggerated.

Capital intensity is the degree to which a corporation utilizes fixed assets in its production process (Pattiasina et al., 2019). Typically, it represents the ratio of total fixed assets to total assets. Firms with elevated capital intensity may incur greater financial obligations, thus hindering their capacity to adopt innovative environmental solutions (Powell et al., 2015). Controlling for capital intensity enables the analysis to differentiate between innovation driven by necessity and innovation facilitated by resource availability.

Firm size affects innovation capacity, resource availability, and environmental responsibility (Elsayed, 2006). It was measured by applying the natural logarithm to total assets. Although smaller enterprises may face constraints, larger corporations typically possess enhanced resources for investment in environmental innovation (Arhinful & Radmehr, 2023; Deakins & Bensemann, 2019). Incorporating firm size as a control variable ensures a more accurate assessment by distinguishing the impact of NPLs from size-related advantages or disadvantages in innovation initiatives.

The gross domestic product (GDP) growth rate indicates the country's overall economic environment and macroeconomic stability (Ali & Rehman, 2015). It is quantified as the annual percentage increase in a country's GDP. Economic growth can enhance corporate confidence, facilitate access to finance, and incentivize investment in long-term sustainable technologies (Zenghelis, 2012). Incorporating GDP growth as a control variable enables the study to exclude broader economic factors that may influence a company's commitment to environmental innovation beyond its financial and operational metrics.

The choice of estimation methods

A cross-sectional test was conducted for the first step to determine the most suitable estimation methods for this study. This was essential to determine if cross-sectional dependence or independence was observed in the panel data. The Pesaran, Friedman, and Frees tests were used to determine the presence of cross-sectional dependence or independence, and the null hypothesis indicates cross-sectional independence, while the alternative posits cross-sectional dependence (Arhinful et al., 2024). The presence of cross-sectional dependence is provided in Table 2. These findings highlight the impact of common traits among banks on efforts to promote environmental innovation.

In the second step, the Pesaran-Yamagata tests were employed to ascertain the homogeneity or heterogeneity of the panel data. In contrast to the null hypothesis, which suggested homogeneity, the alternative hypothesis suggested heterogeneity. The findings of the test shown in Table 2 exhibit heterogeneity, indicating that the degree of dedication to environmental innovation differs among various banks.

Ensuring the selection of the most suitable estimation approach required careful consideration of the heterogeneity and cross-sectional dependence of the panel data. The Augmented Mean Group (AMG) estimator was selected for its remarkable capacity to tackle these issues and provide robust and unbiased estimation results (Eberhardt & Bond, 2009). The preference for AMG over Fixed Effects (FE) stems from the occasional failure of FE to consider intricate cross-sectional interactions, which can result in biased estimation results (Arhinful et al., 2025). Inaccurate results may arise when cross-sectional

Table 2. Cross-sectional, heterogeneity and endogeneity tests.

Types of CD tests	
Pesaran's test	32.724 (0.000)***
Friedman's test	433.485 (0.000)***
Frees' test	3.083 (0.000)***
Heterogeneity test (Peseran-Yamagata test)	
Δ-tilde stat.	34.942 (0.000)***
Δadj-tilde stat.	50.942 (0.000)***
Endogeneity tests	
Durbin-Wu-Hausman (DWH) Test	4.863 (0.000)***
Wu-Hausman test	6.992 (0.000)***

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

dependence is due to the assumption of independence among panels in the Random Effects (RE) model. The Generalized Least Squares (GLS) method is generally inadequate because it cannot adequately handle inter-panel interactions, leading to biased estimates.

Nevertheless, the main advantage of AMG is its ability to make necessary modifications to account for this cross-sectional dependence (Eberhardt & Bond, 2009). Examining the interactions and diverse cross-sectional characteristics among panels provides a more accurate and sophisticated analysis. The AMG method provides dependable insights into the impact of NPLs on environmental innovation by capturing the complexity of the data more correctly than the FE, RE, or OLS estimator. The AMG model is presented as:

$$y_{it} = \alpha_{it} + \beta^{i}_{i\,X_{it}} + \lambda_t + u_{it}$$

Where "y_{it} is the dependent variable for unit i at time t.

X_{it} is the vector of explanatory variables for unit iii at time t.

α_{it} is the individual- specific factors

β_i is the vector of coefficients for the explanatory variables X_{it} specific to each cross-sectional unit i

λ_i is the common dynamic process (common factors) affecting all units.

u_{it} is the error term

Assessing the homogeneity or endogeneity of the independent variables was an important part of this study. The Wu-Hausman and Durbin-Wu-Hausman (DWH) tests were used to evaluate this. The null hypothesis suggested ab exogenous, and the alternative hypothesis suggested the presence of endogeneity. The results displayed in Table 2 provide evidence that the independent factors were endogenous. This suggests they were significantly associated with the error term and could have influenced the estimation results.

Endogeneity in the study revealed that NPLs, R&D, and management quality have a perfect relationship with the error term. GMM was selected as a solution based on its capacity to effectively handle endogeneity by employing lagged measurement variables (Arhinful et al., 2024; Mensah et al., 2024). This method ensures unbiased and uniform calculations, enabling a more accurate evaluation of the influence of NPLs on environmental innovation. The GMM model is presented as:

$$\theta^{GMM} = argmin\theta\left\{\left(\frac{1}{N}\sum_{i-1}^{N} \mathrm{g(yi,xi,Zi)}\right)W\left(\frac{1}{N}\sum_{i-1}^{N} \mathrm{g\,(yi,xi,Zi)}\right)\right\}$$

Where:

- $\hat{\theta}$ GMM is the Two-Step GMM estimator of the parameter vector θ.
- W is a weighting matrix that optimizes the efficiency of the estimator.

Model specification

This study used two models to examine how NPLs impact banks' environmental innovation. Model 1 provides findings relating to the direct impact of NPLs on environmental innovation, while Model 2 provides findings on how quality management moderates the relationship.

Model 1

$$ENVN = \beta 0_{n,B} + \beta 1\text{NPLs}_{n,B} + \beta 2R\,\&\,D_{n,B} + \beta 3MGQT_{n,B} + \beta 4CAIY_{n,B} + \beta 5FMSZ_{n,B} + \beta 6GDPG_{n,B} + u_{n,B}$$

Model 2

$$ENVN = \beta 0_{n,B} + \beta 1\text{NPLs}_{n,B} + \beta 2R\,\&\,D_{n,B} + \beta 3MGQT_{n,B} + \beta 4CAIY_{n,B} + \beta 5FMSZ_{n,B} + \beta 6GDPG_{n,B} + \beta 7NPLs * MGQT_{n,B} + u_{n,B}$$

NB: Table 2 provides details of the abbreviations used in the model presentation. The data's years were designated by "n," the banks by "B," and the error term by "U".

Table 3 shows the descriptive statistics of the variables under investigation in this study. The average for environmental innovation suggests that banks significantly invest in eco-friendly practices and technologies. This can mitigate regulatory risks related to environmental mandates, appeal to environmentally concerned investors, and bolster long-term competitiveness. The average NPL indicates that banks persist in retaining specific problematic loans, which could adversely impact their efficiency and profitability. Addressing NPLs is essential to bolster stakeholder trust and maintain financial stability.

The average expenditure on R&D suggests that banks invest in innovation, resulting in enhanced products and services and greater operating efficiency. Continuous investment in R&D is crucial for sustaining a competitive edge and responding to market fluctuations. The average management quality score indicates the essential function of outstanding leadership in maintaining the bank's operational efficiency and decision-making process. Effective management possesses the capacity to augment overall performance, foster innovation, and refine strategic planning.

The average capital intensity indicates that organizations substantially invest in fixed assets relative to their operations. This suggests that these organizations may own greater financial liabilities, limiting their capacity to allocate resources for environmental innovation initiatives. The average firm size reflects considerable operational scale, implying that these companies have the capacity and resources to implement sustainable practices. The average GDP growth rate suggests a moderately rising economy, which may foster corporate innovations, especially those focused on environmental sustainability.

The Variance Inflation Factor (VIF) was used to identify multicollinearity among NPLs, R&D, management quality, Capital intensity Firm size and GDP growth rate. VIF values below 5 (Arhinful et al., 2024; 2025; Arhinful & Radmehr, 2023; Asare Obeng et al., 2025; Mensah & Bein, 2023) indicate a lack of multicollinearity. These results show that variables are independent and ensure precision in the estimation model.

A matrix correlation study was conducted to evaluate multicollinearity, and the results are presented in Table 4. This aimed to determine whether any independent variables showed multicollinearity, defined as correlations greater than 0.70 (Arhinful et al., 2024; Arhinful & Radmehr, 2023; Mensah et al., 2025). The findings demonstrated that the independent variables had no substantial multicollinearity, as all correlation coefficients remained below the threshold. These findings support the results obtained in Table 3 for the VIF, indicating the absence of significant multicollinearity.

The Cross-sectional Augmented Dickey-Fuller (CADF) and Cross-sectional Augmented IPS (CIPS) tests were employed for unit root analysis, and the results of these tests are presented in Table 5. These tests are appropriate for panel data exhibiting cross-sectional dependence and provide more accurate insights

Table 3. Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max	VIF	1/vIF
Environmental innovation	910	36.317	30.369	0	98.84	–	–
NPLs	910	6.255	0.887	1.612	33.888	1.345	0.743
R&D	910	5.28	1.409	1.231	27.673	1.573	0.636
Management quality	910	22.22	12.063	0	41.67	1.293	0.773
Capital intensity	910	4.234	1.3042	0.232	11.452	1.302	0.768
Firm size	910	7.0834	0.891	1.834	14.982	1.109	0.902
GDP growth rate	910	1.913	1.730	1.610	2.206	1.005	0.995

Table 4. Matrix of correlations.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Environmental innovation	1.000						
(2) NPLs	−0.068	1.000					
(3) R&D	0.133	−0.023	1.000				
(4) Management quality	0.186	−0.024	0.007	1.000			
(5) Capital intensity	0.453	0.492	0.005	0.081	1.000		
(6) Firm size	0.003	0.008	0.072	0.221	0.042	1.000	
(7) GDP growth rate	0.010	0.032	0.046	0.491	0.002	0.091	1.000

Table 5. Panel unit root tests.

	Cross sectional augmented Dickey-Fuller (CADF) test		Cross-sectional augmented IPS (CIPS)	
Variable	Levels	1st difference	Levels	1st difference
Environmental innovation	−22.709 (0.000)***	−39.747 (0.000)***	−16.538 (0.000)***	−34.173 (0.000)***
NPLs	−20.469 (0.000)***	−38.126 (0.000)***	−15.025 (0.000)***	−32.669 (0.000)***
R&D	−22.597 (0.000)***	−22.597 (0.000)***	−17.385 (0.000)***	−17.385 (0.000)***
Management quality	−19.951 (0.000)***	−34.404 (0.000)***	−14.065 (0.000)***	−26.909 (0.000)***
Capital intensity	−4.034 (0.000)***	−12.974 (0.000)***	−4.903 (0.000)***	−16.873 (0.000)***
Firm size	−11.934 (0.000)***	−34.234 (0.000)***	−10.473 (0.000)***	−35.842 (0.000)***
GDP growth rate	−8.084 (0.000)***	−15.024 (0.000)***	−9.001 (0.000)***	−16.074 (0.000)***

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

Table 6. Augmented mean group estimator results.

Variables	Model 1	Model 2
NPLs	−0.399***	−0.574***
	(0.099)	(0.098)
R&D	0.455***	0.446***
	(0.037)	(0.035)
Management quality	0.502***	0.207***
	(0.046)	(0.071)
Capital intensity	0.473***	0.584***
	(0.053)	(0.067)
Firm size	0.078***	0.083***
	(0.012)	(0.016)
GDP growth rate	0.006***	0.009***
	(0.001)	(0.001)
NPLs * Management quality		−0.813***
		(0.111)
Constant	12.329***	13.537***
	(5.622)	(5.773)
Number of observations	910	910
Wald tests	239.24 (0.000)	350.23 (0.000)
CD-statistic	1.001***	1.002***
	(0.038)	(0.041)
RMSE	20.4686	20.2788

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

than traditional tests (ADF, DF). The alternative hypothesis asserts that the variables are stationary, and the null hypothesis indicates unit roots in the panel data. All variables were found to be stationary by unit root tests at both levels, as well as the first differences. This means the data is strong enough to continue being analyzed without needing more differencing.

Table 6 presents the results of the AMG estimator, which show the influence of NPLs, R&D, management quality, capital intensity, and firm size GDP growth rate on environmental innovation.

The study found that NPLs had a negative and significant impact on environmental innovation. The significant impact supports the study's hypothesis. Elevated NPLs signify inefficiencies or deficiencies in risk management within a bank, potentially resulting in a focus on short-term financial stability at the expense of long-term projects such as environmental innovation (Kazbekova et al., 2020). This shift in focus indicates that banks dedicate fewer resources to sustainability projects when institutional pressures to ensure regulatory compliance or avert financial instability intensify. These findings corroborate institutional theory, as external influences affect strategic decision-making and diminish investments in innovation (Kang & He, 2018).

Due to the rising numbers of NPLs, banks may need substantial financial resources to provision and manage these loans, which was the principal cause for these results (Miglionico, 2019). This reduces the funds available for sponsoring environmental innovation and green initiatives. Consequently, the bank's ability to fund ecologically beneficial projects declines. Heightened regulatory scrutiny, often accompanying increased NPL levels, may also contribute to the cause. The examination requires managers to reallocate their focus and resources to enhance compliance and credit risk management (Skoglund & Chen, 2015). This leads to decreased time and resources allocated to fostering environmental innovation and sustainability activities within the organization.

The economic implication for investors is that banks with significant NPLs may face obstacles in achieving sustainable growth, undermining their long-term profitability and appeal to ESG-conscious investors (Minocha, 2022). Decreasing NPLs and allocating funding for environmental projects can improve the bank's competitiveness and market position, which is increasingly oriented towards sustainability.

The study discovered a positive and significant relationship between R&D and environmental innovation, which supports the study's hypothesis. The institutional theory asserts that organizations must adopt sustainable practices due to external pressures, including legislative mandates and societal expectations (Colwell & Joshi, 2013). Banks are likely engaging in R&D due to institutional pressure to enhance their environmental performance and foster innovation. These findings support the institutional theory since banks implement R&D projects to devise sustainable technology or environmentally friendly financial solutions that align with public expectations and regulatory mandates (Aghion et al., 2022).

A potential rationale for this result is that heightened R&D investment may allow banks to explore and adopt more ecologically sustainable and efficient practices, thus enhancing their operational sustainability (Agrawal et al., 2024). By investing in R&D, banks can create new solutions to reduce their environmental footprint, such as energy-efficient technologies and sustainable financial products. Another reason is that R&D projects allow banks to swiftly adjust to changing environmental legislation, assuring compliance and reducing potential risks (Kedward et al., 2020). The adaptability of banks not only allows them to meet institutional requirements but grants them a competitive advantage in the market by leveraging sustainability and innovation trends.

Increased R&D expenditures by banks lead to greater environmental innovation, which economically influences investors by attracting ESG-focused individuals and enhancing the bank's market reputation (Cabaleiro-Cerviño & Mendi, 2024). The bank's focus on R&D allows management to foresee regulatory changes, offering market distinction and enduring growth opportunities.

Management quality was observed to have a positive and significant impact on environmental innovation. The significant impact aligned well with the study's hypothesis. The institutional theory emphasizes how organizations adjust to external influences, including legal frameworks and societal expectations (Delmas & Toffel, 2004). Effective management teams may identify these demands, integrate their plans with ecologically sustainable practices, and cultivate an atmosphere of ecological innovation. These findings corroborate the institutional theory by illustrating that innovative solutions to environmental challenges are more readily embraced when management quality is superior (Shrivastava, 2018).

A plausible explanation for this result is that proficient management fosters the bank's progressive culture, encouraging sustainable practices and green technologies (Lin et al., 2024). Due to this proactive mentality, the organization may promote environmental innovation as a strategic goal and align it with overarching sustainability objectives. Another reason for such results is that high-quality management teams possess the skills to negotiate intricate regulatory landscapes, enabling banks to foresee and respond to environmental requirements more effectively (Barac et al., 2016). This ensures adherence and affords the bank a competitive edge in markets emphasizing sustainability, allowing for proactive development.

These findings indicate that banks with effective management are more likely to improve their reputation, attract socially responsible financing, and implement sustainable innovations to enhance their long-term value (Aramburu & Pescador, 2019). This result highlights the significance of leadership in fostering innovation, enabling the bank to seize possibilities for sustained growth and secure a competitive advantage in areas where environmental issues are paramount.

Table 7. Fixed effects with Driscoll-Kraay standard errors.

Variables	Model 1	Model 2
NPLs	−0.839***	−0.74***
	(0.092)	(0.098)
R&D	0.215***	0.203***
	(0.045)	(0.043)
Management quality	0.187***	0.174***
	(0.041)	(0.039)
Capital intensity	0.161***	0.149***
	(0.036)	(0.035)
Firm size	0.228***	0.213***
	(0.048)	(0.046)
GDP growth rate	0.132***	0.126***
	(0.030)	(0.029)
NPLs * Management quality		−0.311***
		(0.062)
Constant	0.412***	0.384***
	(0.092)	(0.089)
Number of observations	910	910
R-square	0.476	0.528

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

The study revealed that the moderating relationship between NPLs and management quality exhibited a negative and significant impact on environmental innovation. While quality management generally promotes innovation, the financial strain and operational challenges arising from elevated NPLs may lead management to redirect its focus towards environmental issues. The institutional theory posits that competent management may favour short-term financial stability over long-term environmental initiatives, leading to total innovation rates declining (Ornston, 2012). This discovery corroborates institutional theory by illustrating those external forces, such as financial instability resulting from NPLs, can override institutional sustainability objectives.

These findings result from management's inclination to favour short-term financial stability over long-term goals when handling significant NPLs, diverting resources and focus from environmental innovation (Kokkinis & Miglionico, 2020). This change in focus may decrease funding for sustainable programs, as priority is assigned to resolving problematic loans. A potential contributing factor is the uncertainty created by financial instability linked to elevated NPLs, which diminishes management's inclination to engage in long-term sustainability activities (Naili & Lahrichi, 2022). This reluctance may further reduce the bank's capacity for green progress by obstructing innovative efforts to improve environmental performance.

These findings indicate that even well-managed banks may have difficulties in ecological innovation if they possess a significant NPL burden (Atichasari et al., 2023). This may impact the banks' long-term sustainability and attractiveness to ESG-oriented investors. These findings highlight managers' need to balance long-term environmental goals and short-term financial recovery to prevent the neglect of sustainability innovation, especially amid financial difficulties (Zhang et al., 2020).

Robustness testing

Robustness testing was conducted to assess the AMG estimator utilizing fixed effects with Driscoll-Kraay standard errors. This model is appropriate since it tackles heteroskedasticity, autocorrelation, and cross-sectional dependence, resulting in consistent standard errors (Arhinful et al., 2025). Utilizing fixed effects reduces unobserved variability among cross-sectional units, resulting in more accurate estimations of variable relationships and improving resilience against possible violation of the AMG model's assumptions.

Table 7 presents the outcomes of the fixed effects study utilizing Driscoll-Kraay standard errors for robustness verification, intended to validate the results in Table 6. The most notable difference was identified in the coefficient estimation values. Nevertheless, significant positive or negative outcomes consistently remained congruent. This consistency enhances the reliability of the results drawn from the study, as demonstrated in Table 6.

Table 8. Two-step difference GMM.

Variables	Model 1	Model 2
Environmental innovation (−1)	−0.122***	−0.073***
	(0.034)	(0.022
NPLs	−0.256***	−0.587***
	(0.021)	(0.222)
R&D	0.300***	0.343***
	(0.069)	(0.112)
Management quality	0.419***	0.161***
	(0.054)	(0.048)
Capital intensity	0.073***	0.084***
	(0.005)	(0.006)
Firm size	0.631***	0.683***
	(0.055)	(0.058)
GDP growth rate	0.198***	0.201***
	(0.008)	(0.007)
NPLs * Management quality		−0.140***
		(0.051)
Number of observations	884	884
AR (1)	0.021	0.032
AR (2)	0.782	0.888
Sargan tests	0.382	0.493
Hansen tests	0.201	0.233

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

Dealing with endogeneity

The endogeneity tests revealed a significant association between the error term and NPLs, R&D, management quality, capital intensity, firm size and GDP growth rate, leading to endogeneity issues. If left unaddressed, these issues could distort the influence of NPLs on environmental innovation. We developed an extended regression model incorporating environmental innovation as a dynamic panel variable to tackle this. This innovative approach provides a more accurate assessment of historical relationships and eliminates endogeneity from the datasets, a crucial step in our research.

We effectively mitigate endogeneity issues by using internal instrumental factors to address endogeneity by lagging all independent variables. Ensuring that the relationships among the variables are accurately represented and understood is crucial, and endogeneity problems are eliminated. In addition, our model incorporates external instrumental variables, such as Tobin's Q, return on invested capital, and return on assets. This inclusion significantly enhances the robustness of our findings by eliminating endogeneity from the datasets, providing a solid foundation for our research.

Arellano-Bond (AR) tests were employed to establish the validity of the GMM model. The AR results demonstrated that endogeneity was effectively managed and that auto-serial correlation was absent, as evidenced by the significant AR (1) and insignificant AR (2) findings (Arhinful et al., 2024; Arhinful & Radmehr, 2023). The Sargan test confirmed the exogeneity of the instrumental variables as statistically insignificant results, thus ensuring unbiased estimations. The Hansen tests produced results between 0.10 and 0.30, indicating that the instrumental variables have no perfect relationship with the error term. A fall below 0.10 or a rise above 0.30 suggests possible instrument deficiencies or persistent endogeneity concerns.

The GMM results for this study validated the model outcomes shown in Table 8 since they satisfied the necessary GMM index requirements: AR(1), AR(2), and Hansen and Sargan tests. The findings of Table 8 are consistent with those of Table 6 regarding the positive or negative significant relationship between NPLs, R&D, management quality and environmental innovation. The significant difference between Tables 6 and 8 findings is the significant coefficient estimations and standard error changes. Despite this significant difference, while the directional relationship remains the same, the study concluded that the GMM findings are robust to the AMG findings.

Conclusion

This study examines how NPLs of banks contribute to environmental innovation. Banks that make significant environmental innovations always have competitive advantages over their rivals in the competitive business landscape. The selection of the banks listed on the New York Stock Exchange was based on

inclusion and exclusion criteria. The employing of purposive sampling enabled the identification of 70 potential banks without any gaps in the data between 2011 and 2023, and their data were obtained from the Thomson Reuters Eikon.

The study found that NPLs have a negative and significant effect on environmental innovation, indicating that higher credit risk constrains banks' capacity to support innovative environmental initiatives. In contrast, investment in R&D and strong management quality both positively and significantly influence environmental innovation, highlighting their critical role in driving sustainable transformation. However, the interaction between NPLs and management quality revealed a negative and significant impact, suggesting that even effective management may not fully offset the adverse effects of high NPLs on banks' environmental innovation efforts.

Managerial implications

To effectively promote environmental innovation, banks listed on the New York Stock Exchange must adopt integrated, long-term strategies that align sustainability with financial performance. A critical step is the establishment of a dedicated environmental fund to support green projects and technologies, protected from reallocation during financial downturns. A robust governance framework should guide the fund's usage, ensuring investments prioritize high-impact environmental solutions and enhance ESG ratings.

Banks should form interdisciplinary teams—comprising sustainability officers, innovation experts, and risk managers—to align environmental goals with financial strategy. These teams can identify opportunities where green innovation mitigates credit risk and enhances value. Continuous training is essential to keep these teams updated on sustainability trends and reporting standards.

Strategic partnerships with fintech and green enterprises can accelerate environmental R&D and reduce development costs. Collaborations can yield tools like carbon-tracking systems or sustainable finance products, while bank-led incubators can nurture environmental startups, driving innovation and reinforcing the bank's environmental leadership.

Embedding sustainability into executive performance evaluations—linking compensation to KPIs such as emissions reduction or green loan growth—ensures leadership accountability. Transparent reporting systems can further build stakeholder trust by tracking progress against environmental targets.

To guide long-term strategy, banks should establish sustainability advisory councils with internal and external experts. These bodies ensure alignment with global trends, advise on innovation, and strengthen stakeholder confidence in the bank's environmental direction.

Recognizing the constraint that NPLs place on innovation, banks must enhance asset recovery using AI and data analytics to reduce default risk. Improved NPL management frees up capital for green initiatives and reinforces sound risk practices. Finally, investing in digital infrastructure expands the bank's capacity to deliver sustainable products and transparent reporting, supporting both innovation and stakeholder engagement.

Limitation of the study

The first limitation of this study was that the selection of the banks using inclusion and exclusion criteria did not qualify most of the identified banks in the Thomson Eikon listed in the New York Stock Exchange, reducing the final sample to 70 instead of the larger number of banks identified in the Eikon.

The second limitation was that this study did not compare the findings obtained from the regression analysis to past studies' results to determine whether the study findings were consistent with prior studies or showed a contradiction in the discussion. This was because no studies have examined the impact of NPLs on environmental innovation, making this study a novel contribution to the literature.

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Authors contributions

CRediT: **Richard Arhinful**: Conceptualization, Formal analysis, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing; **Leviticus Mensah**: Conceptualization, Data curation, Methodology, Software, Writing – original draft, Writing – review & editing; **Bright Akwesi Gyamfi**: Conceptualization, Investigation, Methodology, Software, Supervision, Writing – original draft, Writing – review & editing; **Hayford Asare Obeng**: Formal analysis, Methodology, Software, Writing – original draft, Writing – review & editing.

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Data availability statement

The data associated with the study will be made available upon reasonable request from the corresponding author.

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