

AN ANALYSIS OF GREEN LENDING INTENSITY OF INDIAN BANKS USING MACHINE LEARNING TOOLS

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ABSTRACT

Green lending is a vital mechanism for aligning financial systems with sustainability goals, yet its execution varies across institutional and regulatory contexts. This study investigates green lending practices through case studies of China's Green Credit Policy (GCP), the European Central Bank's Green TLTROs, and India's banking sector initiatives, supplemented by empirical data on credit trends, ESG performance, and financial stability indicators in India. Findings reveal that China's GCP reduces credit risk and enhances financial stability, while India's green lending remains constrained by weak enforcement, low public awareness, and sectoral imbalances favoring personal loans over sustainable investments. Private banks leverage fintech and AI for green products, whereas public banks focus on large-scale renewable projects hindered by bureaucratic inefficiencies. Key challenges include greenwashing risks, inconsistent ESG reporting, and a weak correlation ($r = 0.099$) between green lending intensity and ESG scores, signaling a disconnect between policy commitments and financial flows. The study recommends AI and blockchain for transparency, alongside policy measures like standardized blended finance models and green taxonomies to accelerate sustainable finance adoption. The paper suggests the use of AI and blockchain technologies for improvement in transparency for risk assessments, data gaps, and persisting ethical concerns. Policy recommendations such as standardized blended finance models, green taxonomies, and integrated regulatory frameworks have been made to quicken sustainable finance adoption. This research contributes to the knowledge bank on scaling green finance while balancing financial stability and environmental objectives.

Keywords: Banking sector, credit risk, ESG, fintech, green lending, regulatory policy, sustainable finance.

INTRODUCTION

The conjunction of green lending with financial stability has been deeply explored in literature and empirical studies, exploring benefits and challenges for sustainable finance. A

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study by Cui *et al.* (2018) reveals reduced credit risk and improved financial stability owing to higher indulgence in green lending activities. Relatedly, the relation between China's Green Credit Policy (GCP) based regulations and lower credit risks highlights the alignment of financial and environmental goals (Zhou *et al.*, 2022). Del Gaudio *et al.* (2022) emphasized the benefits of adhering to credible sustainability standards as instanced by lead banks in syndicated green loans. Results from studies of BRIC countries further reveal improvement in bank profitability and asset quality as an enhanced benefit of green SME lending. These studies support green lending as a strategic priority for the mitigation of financial risks and long-term performance improvement.

On the other hand, literature studies discover significant barriers to effective green finance implementation. While Gilchrist *et al.* (2021) focused on inconsistencies in green bonds with associated green risks needing verification, Bose *et al.* (2018) underlined the necessity of strong corporate governance and regulatory pressure for transparent green banking disclosure from the South Asian context. The DSGE model by Punzi (2018) illustrated the aspects of stabilization of economies through green lending initiatives, with dependency on policy incentives by banks. From the Indian context, Bihari and Pandey (2015) discussed low awareness and weak regulatory enforcement as the major challenges for Indian banks, limiting the impact of green initiatives. Sharma and Choubey (2022) confirmed the need for standardized frameworks and stakeholder engagement for the expansion of green banking initiatives in India. These findings emphasize the need for harmonized regulations, transparency, and institutional capacity as the building blocks of a green financial framework.

Studies related to the vision of green financing also signify dependency on coordinated policy action and institutional innovation. Volz (2018) supported the role of integrated tools like green bonds and sustainable banking regulations for Asia's climate goals, while Setyowati (2023) figured policy fragmentation and enforcement as the main struggles for the green financing initiative for Indonesia. The role of entrepreneurs as the prime green initiative driver for mission-oriented public investments to de-risk private participation was discussed by Mazzucato (2015). Further study by Maltais and Nykvist (2020) affirmed the need for stringent green bond certification to confirm real environmental impact, to face legal risks using clearer contractual safeguards (Prum and Del Percio, 2009). Pulgam and Charkha (n.d.) stated the role of policy alignment and disclosure requirements for driving corporate environmental responsibility. Similarly, Ozili (2022) and Bahl (2012) underscored the strategic imperative of green banking for ensuring both competitiveness and regulatory compliance. All these studies point to the necessity of global standardization, stronger oversight, and multi-stakeholder collaboration for alignment with existing financial systems, sustainability goals, and making sure that green finance delivers both ecological and economic benefits.

RESEARCH OBJECTIVES

This study aims to achieve the following research objectives: (1) To examine the impacts of financial regulations on credit risk mitigation and bank stability in emerging versus developed

markets; (2) To investigate the institutional contrasts between private and public sector banks in green lending adoption, depending on innovation versus scale trade-offs; (3) To evaluate the efficacy of the current ESG framework (India) for scaling green finance activities concerning sectoral credit allocation imbalances and SME participation barriers; (4) To assess the role of AI and fintech solutions in handling different challenges of greenwashing, for encouraging sustainable lending practices;(5) To analyze the relationship between ESG performance and financial indicators (NPAs, ROA) for the development of integrated risk assessment models; (6) To identify policy interventions for strengthening green taxonomies, disclosure standards, and incentive structures for banks;(7) To propose a harmonized framework using cross-country case studies and banking performance metrics to support alignment of financial practices with SDGs. These objectives jointly address critical gaps in recognizing how regulatory, technological, and institutional factors can work together to re-engineer effective green finance ecosystems.

RESEARCH METHODS

The study employs a mixed-methods approach, combining qualitative case studies, empirical data analysis, and machine learning techniques to assess green lending trends in Indian banks. Below is a structured breakdown of the methodology:

- The study uses an exploratory and analytical research strategy that utilizes qualitative and quantitative methods.
- It contrasts China’s GCP, the ECB’s Green TLTROs, and India’s initiatives regarding regulatory consequences. The RBI and CRISIL offer empirical data (2020-2025) to assess green loan trends, NPAs, and ESG performance.
- Machine learning technologies (Python-based modeling) explore the relationships between green finance and financial stability.

This mixed-method approach provides a thorough overview of India’s green lending landscape, integrating policy insights with data-driven analysis to determine gaps and possibilities in sustainable banking practices.

Table 1: Variables with sources

Variable	Measurement	Source
Green Lending Intensity (%)	Proportion of green loans to total loans	RBI DBIE
ESG Scores	CRISIL sustainability metrics	CRISIL Reports
NPAs (%)	Gross non-performing assets	Bank annual reports
ROA (%)	Return on assets	RBI database

DISCUSSIONS

Case studies on Green Lending

Case Study 1: China’s Green Credit Policy (GCP)

China's Green Credit Policy (GCP) was launched in 2012, which enabled banks to integrate environmental criteria into lending decisions, limiting financing for high-pollution industries while advocating green projects. Research by Zhou *et al.* (2022) and Cui *et al.* (2018) discussed how the banks adhering to GCP experienced were able to reduce credit risk and improve financial stability, exhibiting the policy's effectiveness in aligning finance with sustainability. Although China's GCP functions as a critical model for emerging economies on a quest to integrate environmental regulation into banking systems, challenges such as unpredictable enforcement and greenwashing continue to impact its economy.

Case Study 2: European Central Bank's Green TLTROs

Green Targeted Longer-Term Refinancing Operations (TLTROs) was established by the European Central Bank (ECB) to intensify green lending with low-interest loan offerings coupled with sustainable investments. Van Tilburg (2020) merged monetary strategy with climate action for boosting funds for renewables and energy efficiency. On the contrary, other critics were wary of the risks associated with fewer eligibility criteria. This approach implicates the relevance of the green transition using innovative monetary policy.

Case Study 3: India's Green Banking Initiatives

Many Indian banks have adopted *green banking* through digitalization, solar-powered branches, and privileged loans for renewable energy projects. Although studies by Bihari & Pandey (2015) and Sharma & Choubey (2022) emphasized the progressions to eliminate carbon footprints during dispersal of green lending funds for SME's, weaker enforcement and low public awareness have slowed scalability. RBI has made considerable efforts for mandatory ESG disclosures, indicating movement towards stronger green finance regulation. India's experience has highlighted the potential for growth and the challenges of green banking in emerging markets.

Green Lending by Banks

Table 2: Green lending in Private Sector Banks vs. Public Sector Banks

Aspect	Private Sector Banks	Public Sector Banks	Key References
Regulatory Pressure	Mostly driven by market demand, investor expectations, and voluntary ESG commitments.	Stronger influence from government policies and Central Bank mandates (e.g., priority sector lending).	Bihari & Pandey, 2015; Zhou <i>et al.</i> , 2022
Risk Appetite	More flexible in financing innovative green projects (e.g., green bonds, fintech-driven solutions).	More cautious due to bureaucratic processes but support large-scale renewable energy and infrastructure projects.	Mirza <i>et al.</i> , 2023; Sharma & Choubey, 2022

Green Loan Portfolio	Faster adoption of niche green products (e.g., EV loans, green mortgages).	Higher volume of green loans due to State-backed initiatives (e.g. India’s GBI, China’s GCP).	Cui <i>et al.</i> , 2018; Bose <i>et al.</i> , 2018
Transparency & Reporting	More advanced ESG disclosures due to stakeholder pressure (e.g., TCFD, SASB compliance).	Lag in reporting quality but improvement due to regulatory mandates (e.g., RBI’s ESG guidelines).	Gilchrist <i>et al.</i> , 2021; Ozili, 2022
Challenges	Greenwashing risks, lack of standardized metrics.	Slower innovation, political interference in lending decisions.	Punzi, 2018; Setyowati, 2023

(Source: Author’s analysis)

The comparative table highlights the pertinent differences between private and public sector banks based on the parameters of regulatory pressure, risk appetite, green loan portfolio, transparency-reporting, and challenges faced by banks. Innovative green financial products such as green bonds and fintech-driven solutions have been rapidly adopted by private banks. Results from studies (Bihari & Pandey, 2015; Zhou *et al.*, 2022) confirm that these are mostly driven by market forces and investor expectations, with challenges related to weaker standardization (Gilchrist *et al.*, 2021). In comparison, public sector banks are prioritizing large-scale renewable energy and infrastructure (Sharma & Choubey, 2022) projects with slower innovations prompted by government mandates and central bank policies (Cui *et al.*, 2018; Bose *et al.*, 2018). While private banks show more transparency and ESG reporting to fulfill stakeholder demands (Ozili, 2022), public sector banks often face quality concerns despite efforts made by RBI for regulatory interventions (Mirza *et al.*, 2023). Also, contradictions underscore the role of private banks in leveraging market mechanisms to advance niche green financing, and public banks fulfilling the national sustainability agendas, with relative constraints owing to political and structural limitations (Punzi, 2018; Setyowati, 2023). Together, these findings emphasize the different roles of both sectors in scaling green finance initiatives, and their dependency on intense policy alignment and standardized metrics to manage innate tradeoffs (See Table 2).

Use of Artificial Intelligence as a Green Lending Enabler

The use of intelligence techniques has transformed the advancement of green finance and sustainable development. Research studies indicate the existing and potential of artificial intelligence and machine learning in augmenting financial performance and decision making, particularly risk assessments and impact measurements (Hemanand *et al.*, 2022; Kumar *et al.*, 2025). Recent studies have witnessed fintech innovations like digital lending platforms

and blockchain being dominant in the reduction of transaction costs are showing signs of further growth with robust regulatory frameworks (Liu *et al.*, 2022; Udeagha & Ngepah, 2023) in both developing and emerging economies (Nassiry, 2018; Hasan *et al.*, 2024). Technology-aided green lending often suffers from challenges that include data quality, ethical AI use, and institutional barriers that persist (Yigitcanlar *et al.*, 2021; Tamasiga *et al.*, 2022). This is further supported by the integration of IoT and automated machine learning (AutoML) that optimizes resource efficiency and supports scalable green financial solutions (Bhat *et al.*, 2023; Castellanos-Nieves & García-Forte, 2024). The role of multi-stakeholder collaboration and adaptive policies is deemed crucial for utilizing these techniques for inclusive and climate-resilient growth (Thomas, 2023). Collectively, these studies underline the necessity for interdisciplinary approaches, standardized metrics, and policy innovation to align financial systems with global sustainability goals.

Challenges of Green Lending in India

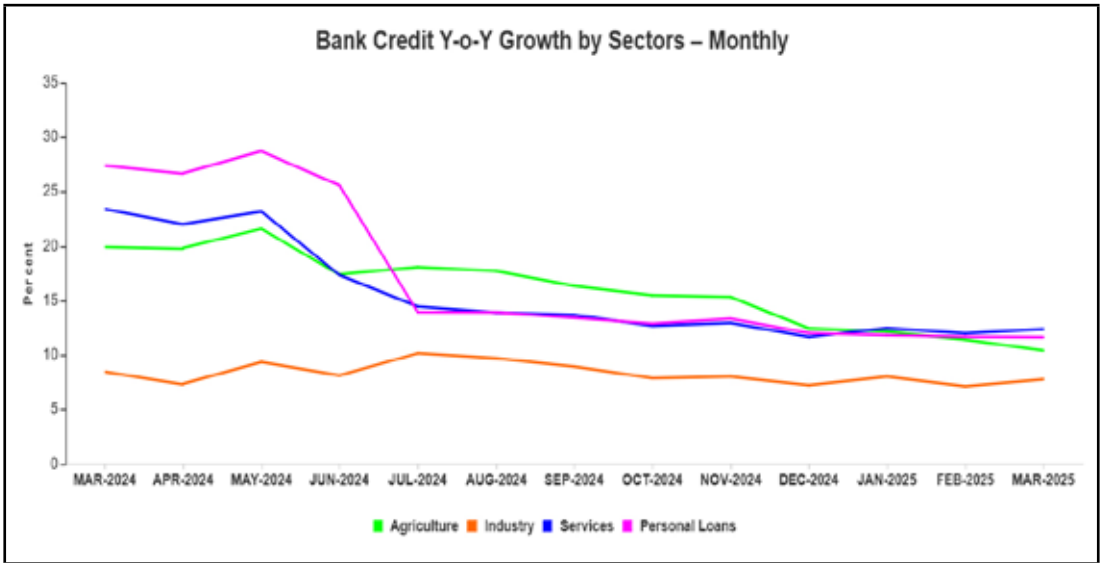
Scalability and effectiveness are the two major challenges of Green Lending in India. Firstly, a lack of a transparent regulatory framework and inconsistent policy frameworks leads to uncertainty for banks and borrowers (Bihari & Pandey, 2015; Sharma & Choubey, 2022). The concept of sustainable finance has been encouraged by the Reserve Bank of India (RBI), although the lack of minimum Green Lending targets signals fragmented adoption. Secondly, market growth of small and medium enterprises (SMEs) for Green Lending has been restricted due to the limited awareness among targets (Mirza *et al.*, 2023). Most businesses normally prioritize short-term impacts over long-term sustainability due to higher initial costs. Thirdly, verification of the environmental benefits of green projects seems difficult due to existing data gaps and inefficient risk assessments, further expanding chances of an increase in risks (Gilchrist *et al.*, 2021). Fourthly, persistent bureaucratic delays and the tendency of risk aversion shadow the green lending activities of public sector banks, slowing lending disbursement rates (Sharma & Choubey, 2022). Reporting of 'green projects' is further complicated by the lack of standardized definitions and taxonomies of green terminologies (Ozili, 2022). Therefore, to address the challenges, stronger policy mandates, capacity building, and financial incentives need to be integrated for sustainable finance.

DATA ANALYSIS

For actual analysis, we had taken data for all six banks that include State Bank of India, HDFC Bank, ICICI Bank, Axis Bank, and Kotak Mahindra Bank, for the period 2020 - 2025, from the RBI database (<https://data.rbi.org.in/DBIE>). Later, this data was analyzed using different statistical tools, such as Microsoft Excel and Python programming version 3.0-based analysis, to identify Green Lending trends, NPA vs ESG performance, and key metric intercorrelation reflecting the actual state of the Green Financing paradigm in India.

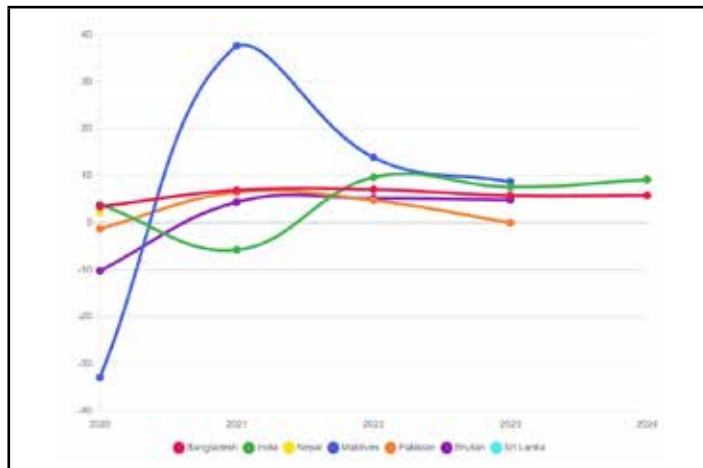
Bank Credit Growth in India: The diagram shows the growth of bank credit across different economic sectors, including Agriculture, Industry, Services, and Personal Loans, during the period of March 2024 to March 2025 (year-on-year basis). Personal loans reveal maximum and most volatile growth (~35 %) with strong consumer demand, with some risks of overheating, followed by Services reflecting steady expansion, mirroring India’s post-pandemic economic recovery. On the other hand, moderate Industrial growth (15–20%) implies restrained capital investment, whereas Agricultural credit marred by systemic constraints in rural financial inclusion recorded the lowest but steady trajectory (5–10%). These deviations hint at structural imbalances in credit allocation, with inconsistent growth in consumption-driven segments, justifying interventions to balance credit flows toward sustainable economic development (see Figure 1).

Figure 1: Bank Credit Growth



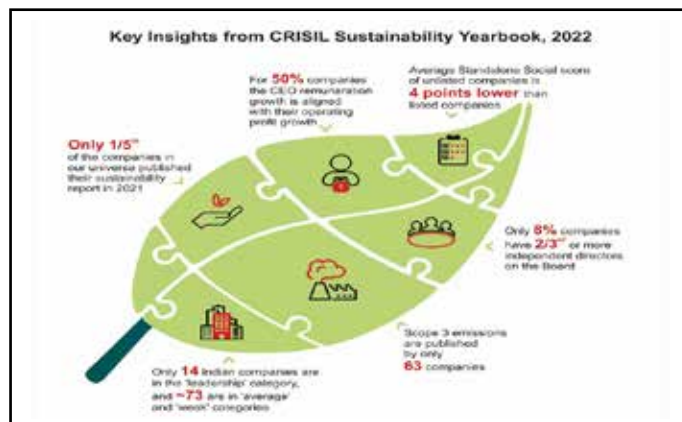
(Source: DBIE, <https://data.rbi.org.in/DBIE/#/dbie/dashboard>)

GDP comparison across SAARC Nations: The comparative analysis of India’s GDP growth with other South Asian economies during the period of 2020-2024 has revealed different aspects, with India and Bangladesh maintaining resilient growth and steady performance, while Pakistan and Sri Lanka showed cycles of negative values, exhibiting economic shocks or social stress. Both Nepal and Bhutan continue to maintain stable and consistent positions, indicating balanced development. Maldives, on the other hand, showed a differential pattern, relying heavily on tourism. These inequalities reflect the region’s heterogeneous socioeconomic landscape, influenced by factors such as external shocks, governance quality, and sectoral vulnerabilities, with India leading the cycle of development despite broader regional uncertainties (See Figure 2).

Figure 2: GDP growth of SAARC countries

(Source: RBI CIMS SAARC. <https://sfdb.rbi.org.in/#/general/home>)

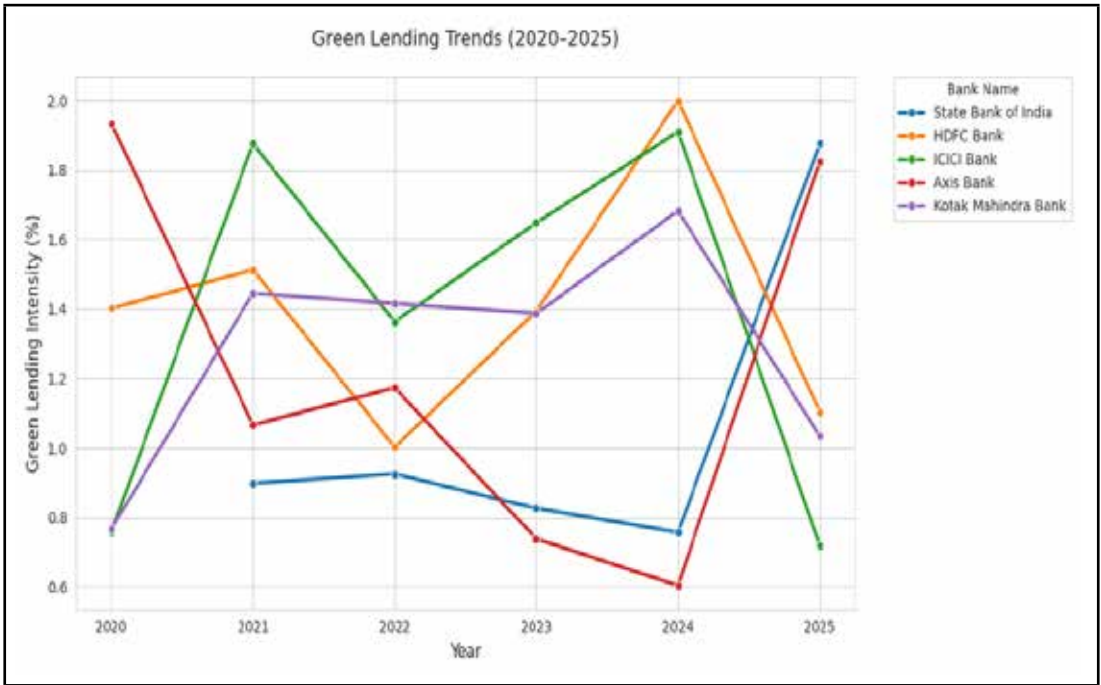
CRISIL Sustainability Report (2022): The *CRISIL Sustainability Yearbook 2022* portrays a contrasting picture where only 20 % of companies publish sustainability reports, 8 % maintain adequate board independence ($\geq 2/3$ independent directors). Further, structural inequalities with unlisted companies underperforming listed pairs by 4 points (social metrics), and 14 firms attain leadership' sustainability with 73 in 'average' or 'weak' categories. Also, 50% of cases with profit growth are aligned with CEO remuneration, representing partial integration of ESG incentives. Only 63 companies performed limited disclosure of Scope 3 emissions, highlighting systemic challenges of comprehensive sustainability reporting. This reflects the need for regulatory reforms and standardized ESG frameworks to improve transparency and accountability in India's corporate sector (see Figure 3)

Figure 3: CRISIL sustainability (Year 2022)

(Source: Sustainability Solutions, <https://www.crisil.com/content/crisilcom/en/home/what-we-do/financial-products/crisils-sustainability-solutions.html>)

Green Lending Trends: The top five banks in India, including the State Bank of India, HDFC Bank, ICICI Bank, Axis Bank, and Kotak Mahindra Bank—covering 2020 to 2025—show distinct trends in Green Lending Intensity (%). Axis Bank recorded the highest intensity in 2020, while consistent growth, peaking in 2024, was achieved by HDFC Bank, indicating a strategic shift toward sustainable finance. In contrast, ICICI Bank and the State Bank of India displayed volatility, with ICICI’s intensity dropping sharply to 0.718% in 2025, highlighting inconsistency in ESG initiatives. Overall intensities (~2%) have declined compared to global benchmarks (e.g., 5–10%), underscoring the need for stronger policy measures or market incentives to promote green financing in India’s banking sector (see Figure 4).

Figure 4: Green lending trends

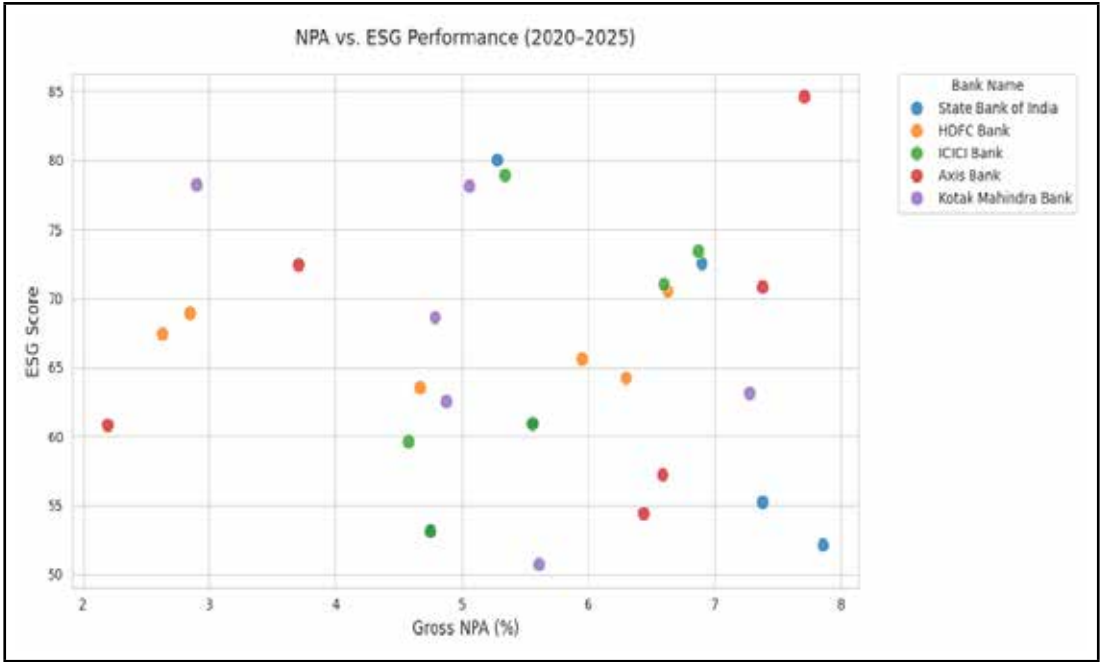


(Source: Author’s analysis)

NPA vs ESG performance: The scatter plot depicts the inverse relationship between Gross NPA (%) and ESG Scores for India’s top five banks from 2020 to 2025, revealing critical risk-performance dynamics. HDFC Bank emerges as an outlier, combining low NPAs (2.63–6.63%) with consistently high ESG scores (64.2–70.5), suggesting that robust ESG integration may mitigate credit risk. Critical analysis was conducted to identify the inverse relationship between Gross NPA (%) and ESG scores for India’s top five banks from 2020 to 2025, highlighting the critical risk dynamics. On the other hand, one can see highly volatile ESG performance (52.1–72.5) related to higher NPAs (peaking at 7.86%) for the State Bank of India, underscoring operational and governance challenges. Also, Axis Bank

displays elevated NPAs (7.71%) regardless of leading ESG scores (84.6 in 2020), which hints at the need for ESG metrics to be combined with other metrics to capture asset-quality risks. Evidence of divergence underlines the need for banks to associate ESG frameworks with core risk management practices to optimize both financial stability and sustainability outcomes (See Figure 5).

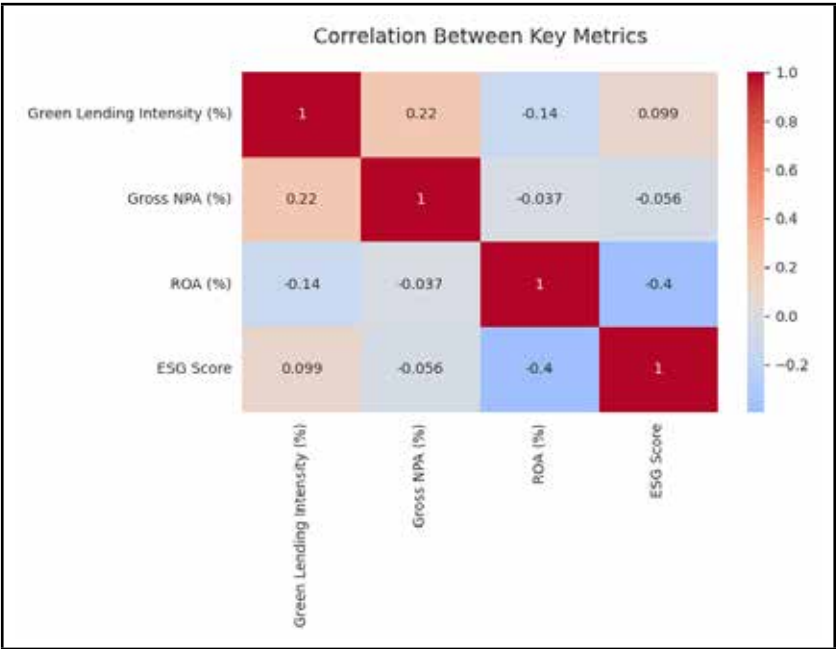
Figure 5: NPA vs ESG performance



(Source: Author’s analysis)

Key metrics inter-correlation: The association of Green Lending intensity (%) with Green NPA (%), ROA (%), and ESG score in the banking platform has been highlighted in the correlation matrix diagram. Results suggest minimal association between sustainable lending and credit risk, indicated by weak correlation between Green Lending Intensity (%) and Gross NPA (%) ($r=0.22$). Evidence suggests short-term profitability trade-offs for ESG investments, with a modest negative correlation between ROA (%) and ESG Score ($r=-0.4$). The existence of near-zero correlation between Green Lending Intensity and ESG Score ($r=0.099$) highlights some level of disengagement between banks’ sustainability commitments and actual green financing deployment, signaling that ESG scores may only partially capture operational sustainability efforts. The results describe the presence of complexity in the process of alignment of financial performance with sustainability goals, suggesting more structural and regulatory changes for strengthening linkages. The word ‘Green’ banks doesn’t imply higher profits in the short term, especially if they appear more environment-friendly on paper rather than being actively committed in real-life situations.

Figure 6: Correlation between Metrics



(Source: Author’s analysis)

RECENT DEVELOPMENTS

- As per the RBI, credit to Agriculture and Allied activities registered a growth of 9.2 per cent (y-o-y) (19.8 per cent in the corresponding fortnight of the previous year). Credit to Industry recorded a growth of 6.7 per cent (y-o-y), compared with 6.9 per cent in the corresponding fortnight of the previous year. Among major industries, outstanding credit to ‘Basic Metal and Metal Products’, ‘All Engineering’, ‘Vehicles Parts and Transport equipment’, ‘Textiles and ‘Construction’ recorded an accelerated y-o-y growth. However, credit growth in the Infrastructure segment decelerated.
- Credit to the Services sector moderated to 11.2 per cent (y-o-y) (19.5 per cent in the corresponding fortnight of the previous year), primarily due to decelerated growth in credit to ‘Non-Banking Financial Companies’ (NBFCs). Credit growth (y-o-y) to ‘Trade’ and ‘Computer Software’ segments remained elevated.
- Credit to the Personal loans segment registered a decelerated growth of 14.5 per cent (y-o-y), as compared with 17.0 per cent a year ago, largely due to a decline in growth of ‘Other Personal loans’, ‘Vehicle loans’, and ‘Credit Card Outstanding’.

FINDINGS AND CONCLUSIONS

- Available literature indicates that strict obedience to China’s Green Credit Policy (GCP) for the attainment of environmental lending criteria reduced credit risk and improved bank stability. Similarly, ECB’s Green TLTROs also elucidate the impact of policy incentives

(e.g., low-interest loans) to enhance renewable energy financing.

- Innovative Green products (e.g., fintech-driven EV loans) have been marketed by private banks owing to market forces, in contrast to large-scale renewable projects dominated by public banks through State mandates and typically delayed by bureaucratic rules.
- From India's context, green lending capacity remains below 2% (Figure 4), below global benchmarks (5–10%), affected by fragmented adoption, awareness gaps, and undefined “Green” taxonomies (Ozili, 2022; Gilchrist *et al.*, 2021).
- The use of Artificial Intelligence and machine learning can suitably assist decision-making related to risk assessment and transparency in Green Lending (Hemanand *et al.*, 2022). Furthermore, the blockchain technology can also reduce SME financing costs (Nassiry, 2018), although data quality and ethical concerns persist (Yigitcanlar *et al.*, 2021).
- Environmental, Social, and Governance (ESG) scores are normally associated with the contribution of NPA (Non-performing assets). As observed during the analysis, HDFC Bank had a high ESG score (70.5 %) with low NPAs (2.63%), and Axis Bank's 84.6% ESG score coexists with 7.71% NPAs (Figure 5), highlighting the need for operational integration to mitigate credit risks beyond ESG metrics coverage.
- India's credit growth is marked by personal loans (35% YoY) that dominate observable growth in sectors such as agriculture (5–10%) and industry (6.7%), indicating the need to incentivize the credit sector in financing (RBI, 2024).
- Calculated weaker correlation ($r=0.099$) between Green Lending intensity and ESG scores (Figure 6) points towards “cosmetic sustainability,” which prefers disclosures over tangible Green financing (Gilchrist *et al.*, 2021).

The results of analysis mandate the necessity for standardized definitions, use of blended finance applications, and AI-driven monitoring for upscaling Green finance (Punzi, 2018; Setyowati, 2023).

SUMMARY OF FINDINGS

The findings from this study indicate the relevance of greenwashing and its key contribution to economic growth, with visible benefits of financial stability and risk reduction as per evidence from China's Green Credit Policy (GCP) and the ECB's Green TLTROs. Green financing with the assistance of artificial intelligence tools and blockchain can mitigate challenges, including risk aversion and transparent implementation in both private and public sector banks. On the implementation scale, the use of standardized taxonomies, robust impact measurement frameworks, and integrated policy can lead to higher growth and contribution of green financing in the economic development of India.

RECOMMENDATIONS

- Restructuring of regulatory frameworks to facilitate green lending targets and standardized taxonomies for ensuring impartial implementation mechanisms that reduce policy

fragmentation while mitigating risks;

- Encouraging PPP (public-private partnership) ventures for development and usage of blended finance models that include innovative Green banking products such as fintech solutions, besides long-term infrastructural projects, to be jointly monitored by both private and public sector banks;
- Boosting the adoption rate of AI-driven transparency tools for managing Green loan allocations and ESG impact, with systemic alignment of disclosures and actual sustainability outcomes;
- Reducing awareness gaps with targeted campaigns with subsidized technical assistance for SMEs, for easy access to Green credit with simplified processes of certification.

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