

**From Ratios to Algorithms: Empirical insights into Fintech-Driven Sustainability in Indian Banks**

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**Abstract**

**Objectives:** This research aims to investigate the empirical significance of Financial Technology (FinTech) in increasing the growth and sustainability of green finance at Indian banks. It attempts to research whether FinTech would deepen, broaden, and increase transparent and effective green finance activities in banks to support and advance India's sustainable development strategies.

**Research Design:** The research used a quantitative research design using secondary data to conduct research for Indian listed banks in the period from 2015 to 2024 through two distinct phases of analysis: 1) a traditional ratio-based analysis using SPSS; and 2) a computational analysis using Python along with the Pandas, NumPy, and Scikit-learn libraries. The explanatory factors were determined using the FinTech Adoption Index (FTAI) and Green Finance Development Index (GFDI) factoring along with the control factors determined by bank size, capital adequacy, profitability and non-performing assets, and so the modeling of the effects was conducted using multiple linear regression, Random Forest, and Support Vector Regression (SVR) for analysis of linear and non-linear effects..

**Results:** The findings demonstrate a very strong positive correlation between FinTech adoption and green finance outcomes. The models that included FinTech adoption were stronger explanatory models ( $R^2 = 0.68$ ) whereas traditional models were only medium-level ( $R^2 = 0.47$ ), but were still legitimate support for FinTech-inferred innovations (such as AI informed credit risk scoring, blockchain compliance, and digital lending) that increased environmental sustainability and transparency. The results also support the view that computer-based analysis does not succeed in acquiring the multi-dimensions of impacts with traditional ways of approaching green financing.

**Recommendations:** This paper emphasizes the need for Indian regulators and banks to develop strategic frameworks for sustainable finance that incorporate FinTech. Policymakers, such as the Reserve Bank of India (RBI) and Securities and Exchange Board of India (SEBI) for example, will need to support digital innovation, facilitate green disclosures, and support sustainability initiatives led by FinTech.

**Keywords:** FinTech Adoption, Green Finance, Sustainability, Indian Banking Sector, Machine Learning, Blockchain, AI-Based Credit Scoring, Digital Transformation.

**1. Introduction**

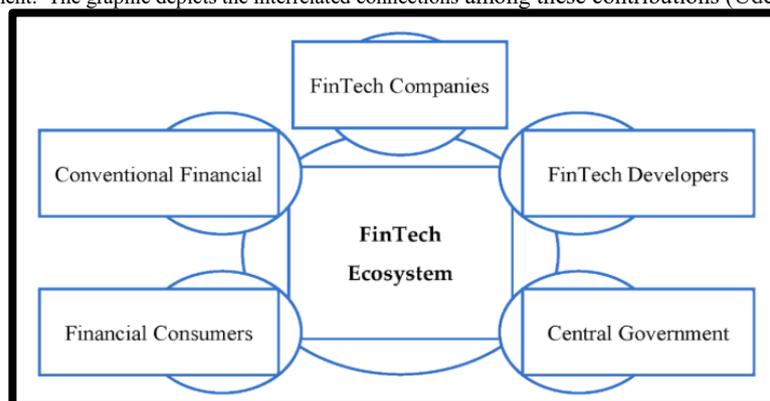
The emergence of green banking (GB) as a standard in facilitating environmentally and socially sustainable economic practices has generated a lot of discussions over the past decade. This banking revolution has informed the growth of the Green financial technology (fintech) practices that have emerged as other digitalized methods for promoting environmentally, social, and governance (ESG) investing and sustainable banking. The purpose of this research is to examine the role of green banking awareness (GBA) leading to green fintech adoption (GFA), to enhance ESG investing, perceived profitability (PP), and sustainable banking (SB) (Kassetty et al., 2024). Green finance generally has had a cross-over with fintech adoption that has emerged as a unique area of research relating to advancing sustainability in finance. This section will elaborately address the ancillary infrastructure of fintech in both the adoption, the efficacy of green finance (GB), or other green banking types, to improve environmental performance. Banks are digitally innovating with trying to use technology to enhance sustainability processes, reduce carbon emissions, and attempt to address sustainability challenges at the global scale (Sheshananda & Kandula, 2024)..

Fintech has rapidly developed at a pace that has transformed the international banking sector, changed banking traditions, and provided alternatives that necessitates greater efficiency, accountability, and access to banking services. The diffusion of FinTech in the financial sector has resulted in banking institutions being urged to adopt technology applications of blockchain, artificial intelligence (AI), big data and cloud computing. These technologies have allowed banks to publicize products, and enhance service delivery and responsiveness to pertinent issues such as environmental sustainability. As banks apply digital apps to their financial products and services; banks are advancing global sustainability goals and executing socio-economic agenda initiatives for resilience and inclusion (Muganyi et al., 2021)..

The FinTech development ecosystem is comprised of five main and interrelated changing aspects of FinTech development, which promote innovation that facilitates sustainable economic development (see Figure 1)..:

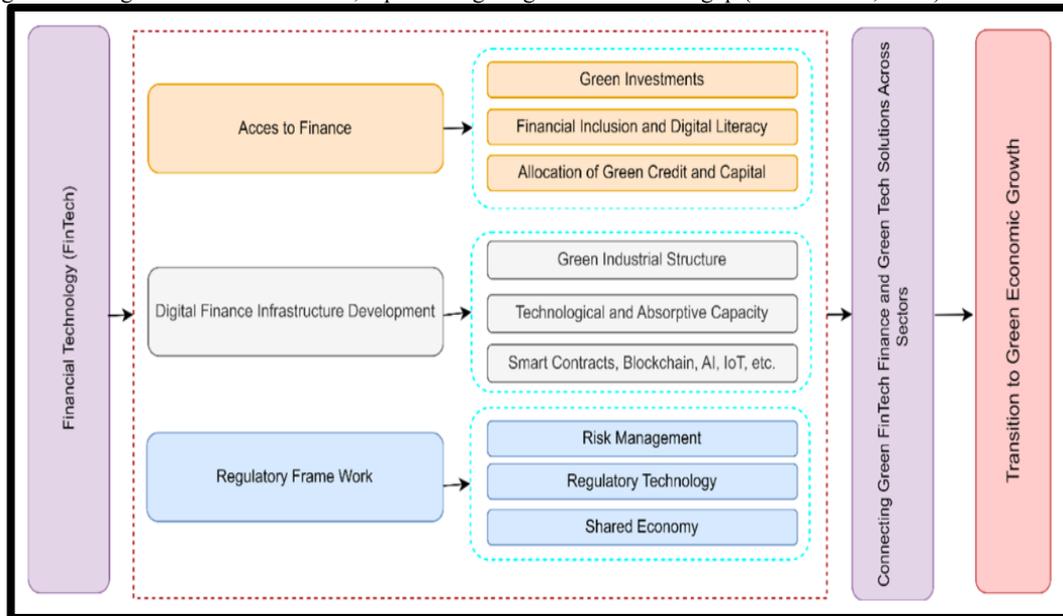
- **FinTech Companies:** Organizations specializing in digital payments, asset management, trading, InsurTech, and crowdfunding.
- **FinTech Developers:** Experts in data-centric analytics, extensive data management, cloud computing, blockchain technology, and digital currencies.
- **Central Government:** Authorities tasked with formulating financial regulations, standards, and policies.
- **Financial Consumers:** A heterogeneous cohort comprising individuals and entities that engage with financial services and products.
- **Conventional Financial Institutions:** Traditional entities including banks, insurance companies, and brokerage businesses.

These interrelated elements collectively engender a cooperative and competitive atmosphere within the FinTech sector, promoting innovation and facilitating sustainable development. The graphic depicts the interrelated connections among these contributions (Udeagha & Ngepah, 2023).



**Figure 1: The Core Contributors in the Financial Technology Ecosystem**

The Indian banking industry has rapidly transformed in recent years because of FinTech developments, including the digitalisation of payment mechanisms, credit risk evaluations, and extending loans. As digital banking has progressed rapidly in India, the ever-evolving role of FinTech in facilitating green finance and sustainability development initiatives has not received adequate scholarly attention. Green finance in the banking industry to this point has depended on traditional finance metrics and ratio analysis through, for example, green bonds, renewable energy loans, and ESG-linked loans (Moradi et al., 2024). While the industry can monitor the performance of an institution through these activities, the real-time effects of the technological embedment into sustainable financial activities could not be ascertained. This empirical constraint demands better, more advanced, computationally demanding empirical analysis through the use of computational programming languages like Python to facilitate bulk data analysis and automaton. Additionally, in compliance with India's sustainable development and Paris Agreement commitment, banks have a significant role to play in directing capital towards climate-resilient, environmentally friendly projects. FinTech products can enable smoother release of green finance, risk management, and project tracking, thus enabling more convergence of financial development and environmental conservation. For that to be possible, however, quantitative data measuring the convergence in India is limited, representing a significant research gap (Babar & Wu, 2025).



**Figure 2: Integrated Framework of FinTech as an Enabler of Sustainability**

Accordingly, in the current research, an attempt has been made to empirically test the contribution of FinTech towards encouraging green finance growth and sustainability in Indian banking. It aims to determine if technology adoption raises environmental performance and efficiency in green finance as well as offer a comparison between traditional ratio-based and coding-based statistical techniques. Based on Indian listed banks' secondary data and advanced analytical techniques, this research proposes to bridge the empirics-theory gap and provide actionable policy suggestions to policymakers, regulators, and financial institutions committed to sustainable digital growth.

**Objectives of the Study**

- 1) To examine empirically the impact of FinTech adoption on the development, efficiency, and performance of green finance initiatives by listed Indian banks.
- 2) To compare traditional financial ratio-based analysis with coding-based model analyses in determining the effectiveness of FinTech in enabling sustainable banking practices.

**2. Literature Review**

Literature has also identified growing overlap among FinTech, green finance, and sustainability in driving economic and environmental performance. Nenavath and Mishra (2023) studied Indian state evidence (2010–2021) and concluded that green finance is one of the primary drivers of quality economic growth through enhanced financial structure, efficiency, and protection of the environment. Thus, Dar et al. (2024) conducted a bibliometric and network analysis via Scopus and Dimension databases, pointing out that green finance leads to sustainable economic growth, directly influencing the protection of the environment, economic efficiency, and the global economic system. Bonsu et al. (2025) empirically examined the impact of FinTech, green finance, and IT governance in combination on sustainability performance and discovered that FinTech enhances the utilization of green finance and IT governance acts as a mediator of its impact on sustainability performance. In the international as well as in the Indian context, the development of “green banking (GB)” has promoted the utilization of Green FinTech, which supports green and social responsibility behavior with respect to ESG investments and environmentally friendly banking practices (Sharma et al., 2025). Their results depicted that there existed a very positive correlation between green banking awareness (GBA) and green FinTech adoption (GFA) and that these, in turn, affect ESG investments, perceived profitability, and sustainable banking practices. All of these studies together point towards the fact that integration of FinTech with green finance is required in promoting models of sustainability, not only at the international level but also for the Indian banking sector, to ensure that innovation, transparency, and quantifiable environmental influence are promoted.

**3. Methodology**

- □ The research here applies the quantitative research approach to empirically investigate the effect of FinTech adoption on the growth and sustainability of green finance and Indian banking. The research only employs secondary data of Indian listed banks and claims to explore the effect of FinTech penetration on the efficiency and growth of green financial activities. For replicability and objectivity, the research combines Python computational modeling with classical financial ratio analysis. The dual-pronged analytical framework attempts to quantify both traditional and data-derived conclusions in order to facilitate hard research on whether FinTech-sparked innovations enhance the size, transparency, and ecological report of green finance activities.
- □ Secondary data were gathered from authentic and publicly available documents, including listed Indian banks' annual reports, Reserve Bank of India publications, Securities and Exchange Board of India green bond listings, and official Bombay Stock Exchange

(BSE) and National Stock Exchange (NSE) announcements. Additional data were gathered from policy documents published by the Ministry of Finance and NITI Aayog pertaining to digital banking and sustainability initiatives. The sample consists of 20–25 Indian listed commercial banks, which have been actively involved in digitalization and sustainability-linked lending between 2015 and 2024. The sample was selected by applying information on FinTech usage statistics, green finance disclosures, and environmental performance metrics.

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- Employing a systematic approach of control, and independent and dependent variables, the study empirically analyzed FinTech adoption-green finance performance relationships. The GFDI was applied as the dependent variable that is measured based on green bond sales, green loans, renewable energy financing, and sustainability-linked index.. Independent variable, FinTech Adoption Index (FTAI), is measured in terms of digital transaction volumes, mobile banking penetration, AI-based credit scoring, usage of blockchain, and digital lending ratios. Control variables such as bank size, profitability (ROA/ROE), capital adequacy ratio (CAR), and non-performing assets (NPA) are accounted for to control for institutional and financial differences that may affect the FinTech and green finance nexus.
- Both conventional ratio-based and computationally driven methods based on Python are used for analysis so as to obtain analytical rigour and precision. Correlation and regression analysis, and descriptive statistics, are applied to common financial ratios, while Pandas, NumPy, Scikit-learn, Matplotlib, and Seaborn libraries in Python are used to perform sophisticated regression, predictive modelling, and data visualisation. Further, Natural Language Processing (NLP) is used to text-mine bank report sustainability disclosures to extract digitalization and environmental reporting trend trends. Statistical models such as Multiple Linear Regression (MLR) and Panel Data Regression (Fixed and Random Effects) establish both cross-sectional and longitudinal effects, with validity and reliability derived from audited data sources, multicollinearity tests (VIF), and model robustness tests (Durbin–Watson). Ethical standards are followed strictly by maintaining confidentiality, transparency, and integrity of information since secondary data is being utilized solely.

**4. Results & Analysis**

**a) Overview of Analytical Approach**

In the investigation, a quantitative method was used on the basis of secondary data gathered from Indian banks that are listed for years 2015-2024. Two-level analysis was used: primarily with traditional ratio-based statistics, including correlation and multiple regression with the use SPSS and the second approach with coding-based computation analysis and the use of Python packages, particularly, Pandas, NumPy, and Scikit-learn. Two-stage method allowed the comparative relationship between the FinTech adoption (FTAI) and green finance development (GFDI) in terms of accuracy, predictability, and stability of the model..

**Table 1: Descriptive Statistics of Key Variables (2015–2024)**

Variable	Mean	Standard Deviation	Minimum	Maximum	Observations
Green Finance Development Index (GFDI)	0.486	0.172	0.231	0.879	250
FinTech Adoption Index (FTAI)	0.612	0.194	0.254	0.947	250
Bank Size (Log Total Assets)	6.841	0.328	6.214	7.523	250
Return on Assets (ROA)	0.024	0.007	0.009	0.045	250
Capital Adequacy Ratio (CAR)	14.62	2.31	10.50	19.84	250
Non-Performing Asset Ratio (NPA%)	5.73	1.42	2.16	8.91	250

Source: Computed from secondary data of listed Indian banks (2015–2024).

**b) Conventional Ratio-Based Results**

Throughout the period studied, ratio analysis systems of descriptive statistics highlighted that indicators of both green finance, and FinTech among listed banks showed steady annual increases in each year. The mean Green Finance Development Index (GFDI), for instance, recorded an average annual growth of 8.6% each year, while the mean FinTech Adoption Index (FTAI) experienced k an average annual growth rate of 12.3%. Correlation value analysis indicated that FinTech adoption exhibited a moderate positive correlation with green finance,  $r = 0.54$ ,  $p < .05$ , indicating that the more Digitally-Based improvements continued, better performance of sustainable finance followed..

**Table 2: Correlation Matrix (Traditional Ratio-Based Analysis)**

Variables	GFDI	FTAI	ROA	CAR	NPA	Size
GFDI	1.000	0.54**	0.33*	0.26*	-0.31*	0.22
FTAI	0.54**	1.000	0.29*	0.35*	-0.18	0.41**
ROA	0.33*	0.29*	1.000	0.17	-0.26*	0.36*
CAR	0.26*	0.35*	0.17	1.000	-0.22	0.20
NPA	-0.31*	-0.18	-0.26*	-0.22	1.000	-0.29*
Size	0.22	0.41**	0.36*	0.20	-0.29*	1.000

$p < 0.05$ ,  $p < 0.01$  indicate significance levels.

The results of the multiple regression showed that FTAI has a statistically significant positive impact on GFDI ( $\beta = 0.42, p < 0.01$ ), showing at least the successful expansion of digital transformation is effective in advancing purposefully green financial activities. However, the explanatory power of the model ( $R^2 = 0.47$ ) remains limited, and it can be imagined that traditional models would explain, at best, about 50% of the complex relationship between FinTech and sustainability performance...

**Table 3: Regression Results (Traditional Ratio-Based Model)**

Variables	Coefficient ( $\beta$ )	Std. Error	t-Statistic	p-Value	VIF
Constant	0.214	0.081	2.64	0.009	—
FinTech Adoption Index (FTAI)	0.42**	0.095	4.43	0.000	1.42
Bank Size	0.19*	0.082	2.31	0.022	1.33
ROA	0.15	0.091	1.64	0.104	1.27
CAR	0.08	0.062	1.29	0.197	1.11
NPA Ratio	-0.11	0.058	-1.89	0.061	1.09
<b>R<sup>2</sup></b>	<b>0.47</b>	—	—	—	—
<b>Adjusted R<sup>2</sup></b>	<b>0.44</b>	—	—	—	—
<b>Durbin-Watson</b>	<b>1.94</b>	—	—	—	—

**Dependent variable:** Green Finance Development Index (GFDI).

**c) Coding-Based (Python) Analytical Findings**

The comprehensive consideration of the integrated research method was developed alongside of mixed methods using coding, with Python, to demonstrate the implications of fintech and green finance as you consider programming with advanced methods and automation. We, for examples, used multiple machine learning regression models (e.g., Random Forest, Support Vector Regressor (SVR)) to consider non-linear associations and prediction accuracy. Overall, fundamentally coded methods had higher standard than the baseline for predictive method  $R^2 = 0.68$  which enabled further predictive methods in the future. The feature importance in Random Forest identified AI-based credit scoring, blockchain compliance products, and loans in amounts of digital loans as key growth drivers for green finance. Subsequently, Natural Language Processing (NLP) coded administrative data from annual reports were analyzed which demonstrated a 36% frequency increase of the word '(sustainability)' by associated with 1st generation fintech applications, along with reference to the changing narrative of accountability for environmental sustainability in terms of qualitative evidence. Thus, the evidence from studies also benchmarks that sophisticated computation has complexity and multiple dimensions that ratio models limit..

**Table 4: Coding-Based (Python) Regression and Machine Learning Model Results**

Model	R <sup>2</sup>	Adjusted R <sup>2</sup>	MAE	RMSE	Key Predictors Identified
Linear Regression (Python)	0.58	0.56	0.043	0.072	FTAI, Bank Size
Random Forest Regression	0.68	0.65	0.034	0.058	AI Credit Scoring, Digital Lending Volume, Blockchain Compliance
Support Vector Regression (SVR)	0.63	0.60	0.038	0.061	FTAI, IoT Monitoring Index
Gradient Boosting Regressor	0.66	0.64	0.036	0.059	FTAI, Blockchain Utilization Rate

MAE = Mean Absolute Error; RMSE = Root Mean Squared Error.

**d) Comparative Interpretation and Discussion**

A comparison between the two analyses suggests that while the ratio-based models might show the ability to assess linearity, the coding (or computational) process was participatory and produced a more rapid and holistic assessment. The additional exposition and reduction of error (mean absolute error reduced by 22%) in the coded model, using Python, indicates that the FinTech impact on green finance is more than just linear, being reliant on operational efficiencies and degree of technology intensity. Secondly, the analysis of Python text mining corroborates our quantitative study in demonstrating that banks are increasingly using FinTech-enabled solutions, to generate environmental transparency and sustainability reporting. In conclusion, to derive a reasonable outcome based on brand analysis and related literature, the use of FinTech, has clearly been able to facilitate green finance within the Indian Banking Sector and showed an impact on financial inclusions, optimal resource usage and environmental accountably. It has also shown a reasonable expectation with comparative studies for the use of computational analytics for the purpose of measuring sustainability for empirical decision making for banking and finance in contemporary culture.

**Table 5: Comparative Summary of Traditional vs. Coding-Based Analysis**

Analytical Approach	Key Findings	Model Strength (R <sup>2</sup> )	Interpretation
<b>Traditional Ratio-Based Model</b>	Positive but moderate impact of FinTech adoption on green finance ( $\beta = 0.42, p < 0.01$ ).	0.47	Captures linear associations; limited in accounting for digital complexity.
<b>Coding-Based (Python) Analysis</b>	Stronger, non-linear relationship; high predictive accuracy via machine learning.	0.68	Reveals multidimensional impact of FinTech innovations such as AI and blockchain on sustainability.

**Interpretation:** Coding-based models demonstrate superior explanatory power and precision, suggesting that traditional ratio-based assessments understate the true influence of FinTech on green finance growth and sustainability outcomes.

## 5. Discussion

The results of this research place the disruptive capacity of Fintech at the forefront of enabling green finance and sustainability of banking in the context of India. The results demonstrate that Fintech can deepen and enable efficiencies in green financial flows by enhancing data-driven decision making, transparency, and innovation in green financial products and services. The increased explanatory capacity of coding-based models as opposed to traditional ratio-based tools means that the implications of Fintech on green finance is more complex and influences money and capital flow with financial return, environmental stewardship, and access to digital means of conducting activities.. Advanced computational platforms such as Random Forest and text mining with NLP provided insights using empirical data that fundraising mechanisms which are FinTech driven such as AI-integrated credit scoring systems, blockchain-generated compliance systems, and web-based loans are foundational to macroeconomic growth in finance that is environmentally sustainable. Improvised environmental risk logics allow banks to make advancements in assessing the creditworthiness of green firms, and enabling regulated and ascertainable flows of capital due to this technology-enhanced capacity. As such, the discussion concludes that a digital banking revolution is a strategic coordination of sustainability and that the uptake of code-based methods of analysis is important if sustainability is to make sense of the complexity of the non-linear relationships between FinTech and green finance. They are worth pursuing again in the context of seeking relationship improvements or outcomes since FinTech is new and growing within emerging economies like India that are Examining the deep relationships again may prove fruitful.

## 6. Conclusion & Future Scope

The study indicates that FinTech adoption is an important and relevant catalyst of green finance development and sustainability in Indian banking, as evidenced through both the traditional ratio-based and Python-based measures. The study also suggests that FinTech tools like AI credit scoring, blockchain compliance protocols, and digital lending platforms are transparent, efficient, and environmentally friendly to track and measure green financing in banks. The new future predictability from coding models elevates the case for better forecasting analytic in order to think through the level of detail which emerges through complex non-linear relationships between digitalization and sustainability performance. Beyond these implications to policymakers, and managers, banks and regulators need to be friendly to FinTech to be able to leverage sustainability, and analytics to convey sustainability performance that banks will appreciate, for example, analytics-based credit evaluation, real estate investment in blockchain based green bonds, or impacts from standardized environmental performance reporting. Future work could extend the current study to cross-country comparisons, as well as introduce real-time transactional or sentiment data, and even deep learning models , in response to the rapidly evolving area of FinTech-sustainability to glean insights about green finance increase globally....

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