

Is Going Cashless Green? The impact of Digital Financial Inclusion on Environmental Quality in South Asia

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Abstract: Digitalization of finance as measured by the adoption of cashless transactions, presents key novelties for both financial inclusiveness and environmental sustainability. This study investigates the effect of Digital Financial Inclusion (DFI) and Traditional Financial Inclusion (TFI) on environmental quality amid South Asian countries. Principal Component Analysis technique is employed for the construction of DFI and TFI indices while the long-run relation was calculated using the Pooled Mean Group (PMG) estimator. The findings suggest that the environmental impact of financial inclusion vary depending on how it is implemented. TFI significantly influence environmental degradation, probably by the extension in the physical infrastructure of banks and their financing in carbon-intensive projects. On the other hand, the study affirms the impact of DFI in enhancing green alternatives and lessened environmental burdens via reduced carbon emissions in the long run. This study suggests that promoting digital finance should be accompanied by investments in green technologies and access to technology, to strengthen the environmental sustainability. The study provides empirical evidence in explaining the environmental quality in South Asia by distinguishing between DFI and TFI, where TFI aggravate environmental degradation, while DFI improves environmental quality by lowering carbon emissions and fostering cleaner alternatives.

Keywords: Cashless, digital finance, environmental degradation, pooled mean group, South Asia, sustainability, technology, traditional financial inclusion.

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INTRODUCTION

Financial inclusion (FI) is featured as a target in eight sustainable development goals. It plays a vital role in economic growth, job creation, and social stability (World Bank, 2025). Traditional Financial inclusion (TFI) often relies on the physical expansion of banking networks, which can demand resources and infrastructure development. The advent of Digital Financial Inclusion (DFI) via e-wallets, mobile technology and digital



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platforms has extended technological transformation having environmental gains by lowering dependence on paper-based systems and physical infrastructure.

World Bank (2025) emphasises that a strong financial system can lay robust grounds for economic growth, employment generation, small businesses, and encourage financial and social development. Financial inclusion (FI) is crucial for sustainable global development, while digital financial inclusion is the future way to improve environmental quality by reducing CO₂ emissions. The digital platforms and e-forums are substituting the physical modes of corporate and financial actions (Pyka, 2017; World Bank, 2025).

The difference between Traditional Financial Inclusion (TFI) and Digital Financial Inclusion (DFI) is not just technological. TFI drives through material-intensive systems, e.g., bank branches demand physical infrastructure and energy, ATMs operate via electricity and cash, cash logistics lead to vehicle fleets, thereby emitting carbon dioxide. Generally recognized, carbon dioxide emissions are the key drivers of global warming, with significant impacts on economy and society impacts (Rode et al., 2021). In contrast, DFI facilitates financial dealings via virtual platforms whereby replacing physical infrastructure with digital systems. This modification brings great environmental implications that remained underexplored in the academic literature.

South Asia is rapidly expanding its fintech (finance & technology) sector and experiencing a booming growth. The whole region of South Asia is witnessing a promising market for fintech, with an encouraging and enabling environment for digital payments, extensive internet and smartphone saturation, consumer inclinations towards social media, and prospering online commerce. Also, the Central Banks of the region support and provide robust regulations, which serve as a foundation for fintech development (Rizvi, Naqvi, & Tanveer, 2018). Cashless banking and the transition towards digital wallets are the central for fintech ecosystem within South Asia. South Asia is an intricate fusion of economics, contrasted cultural traditions, and social dynamics, including countries such as Afghanistan, Bangladesh, India, Maldives, Nepal, and Pakistan. There is a substantial variation in financial inclusion across the region, highlighting differences in access to banking services, digital financial services, and credit facilities. In particular, Pakistan and India are leading the cashless economy in terms of the development of digital wallets. A digital wallet, an e-wallet or mobile wallet, is an electronic payment tool or software application that securely stores digital procedures of payments, serving as a virtual replacement for a physical wallet. According to the World Intellectual Property Organization (2025) Pakistan has been considered an attractive global innovation hub. Other than that, Pakistan is becoming a mobile-first economy as its smartphone penetration rate has risen to 82%. Similarly, digitalization in South Asia holds immense potential for a cashless economy. Furthermore, in Bangladesh, everyday transactions are mobile-based as financial services have become deeply integrated into the system. It is crucial to mention that a low level of financial inclusion will create major obstacles and hindrances in economic growth, and hence, sustainable development will be affected too. Financial inclusion is, therefore, considered a great challenge for developing countries, such as South Asia. There is a large number of populations in developing countries that lack access to banks, resulting in a huge number of unbanked people.

The South Asia region is experiencing extensive fintech growth, propelled by rapid internet penetration, supportive regulations that lead to cashless economies in countries like Pakistan, Bangladesh and India (Rizvi et al., 2018). Even though a substantial population still remains unbanked, thus the region faces unrelenting challenges like poverty and inequality. The environmental effects of a cashless transition, as reduced resource use, are often noted, but the net impact endures complexities due to enhanced energy demands for digital infrastructure. Crucially, the differential environmental effects of DFI versus Traditional Financial Inclusion (TFI) are not yet well-understood empirically.

South Asian Countries are generally categorized as developing countries. The region's progress is uneven and faces challenges of poverty, social inequality, and limited access to fundamental services. That is why these countries have a large unbanked population. Globally, more than 1.7 billion adults cannot access financial services. Specifically, approximately 67% of adults in South Asia are unbanked and do not hold any account in a financial institution (World Bank, 2025).

The environmental implications of going cashless across the region of South Asia are quite challenging. Although there are lots of ecological benefits associated with the reduced use of natural resources for physical currency production, at the same time, a high environmental cost is associated with the inclusion of digital

financial infrastructure. Access, usage, and barriers linked with the financial services will impede the progression of a smooth transition. However, the adoption and widespread use of digital services such as digital wallets are not fully understood yet, and their impact on the broader financial sector needs a comprehensive investigation. Despite the fact that the impact of financial development on carbon emissions is explored extensively in scholarly publications (Charfeddine & Kahia, 2019; Shahbaz, Tiwari, & Nasir, 2013), hardly any studies explored the linkage between financial inclusion in terms of a paperless economy and reduced carbon emissions. Digitalization is pushing organizations to bring innovative changes to their business models (Bharadwaj, El Sawy, Pavlou, & Venkatraman, 2013). Massive use of mobile devices in financial business dealings has given new directions of digital /mobile payment systems (Kaur, Dhir, Bodhi, Singh, & Almotairi, 2020; Le & Pham, 2024). This study examines the role of technology access in reducing carbon emissions, while explicitly integrating digital financial inclusion into the analytical framework. Moreover, to unveil the differential effects of traditional financial inclusion, a comparative analysis is performed that provides deeper theoretical and empirical insights, supporting the adoption of cashless transactions (Rani, Amjad, Asghar, & Rehman, 2022; Sadiq et al., 2024).

The significance of this research is multifaceted, i.e., modernizing technological advancement, enhancing economic development, inculcating financial inclusion through system efficiency, supporting policy making, and transforming societal behaviours. This research is useful in advocating eco-friendly financial solutions by steering policymakers, financial institutions, and tech developers. In addition, it emphasizes overall economic and social well-being ahead of the financial context (Shashwat, Chhabra, & Giri, 2025).

Generally, this study persuades cognizant environmental financial behaviour of society. Additionally, this research will improve the body of knowledge for developing strategies that harness digital wallets' benefits for economic development and financial inclusion (Faton & Chabossou, 2024). Nevertheless, the paybacks of financial inclusion encompass beyond convenience, i.e., it promotes a country's economic growth, which can be observed in improved financial stability, ecological soundness and sustainable environment. According to Hannig and Jansen (2010) the fundamental purpose of financial inclusion is to safeguard that historically excluded vulnerable sections of society, who can access financial services and products at an affordable cost (Ozili, 2018). Burgess and Pande (2005) bring a lot of benefits to the economies, including poverty alleviation, decreasing income gaps, improved financial decisions, increased savings, and more productive investments. Thus, financial inclusion can be considered as a catalyst for economic growth in the developing countries (Pradhan & Sahoo, 2021; Sethi & Acharya, 2018).

Conversely, financial exclusion with limited access to financial services and products is usually associated with poverty and inequality, affecting individuals and regions both (Beck, Demirgüç-Kunt, & Levine, 2007; Demirgüç-Kunt, Klapper, & Singer, 2013). Despite the emerging phenomenon of financial inclusion in the international policy framework for sustainable development and economic research on this topic is still in its infancy stages.

The financial development and carbon emissions nexus has been explored at length (Sadorsky, 2010; Shahbaz et al., 2013). Nevertheless, few studies recognized the difference between traditional and digital financial inclusion whilst studying environmental effects. Some research implies that financial inclusion can decrease emissions by facilitating green investments (Zhao, He, & Zhang, 2021) while others correlate it with enhanced energy consumption and increased emissions (Bekhet, Matar, & Yasmin, 2017). This indistinctness directs towards a significant gap, i.e., the environmental outcomes probably vary with the mode of financial inclusion. Additionally, coordinating factors such as access to electricity, an essential condition for digital finance, are commonly neglected in this nexus.

This study addresses these gaps by exploring the impact of Digital Financial Inclusion (DFI) and Traditional Financial Inclusion (TFI) on environmental quality in South Asian countries for the period 2001–2023. Comprehensive indices for DFI and TFI have been constructed using Principal Component Analysis. For exploring the long-run panel analysis, the Pooled Mean Group (PMG) estimator is employed. This research brings about three unique contributions to the literature. First, it clearly constructs and validates independent indices depicting the multidimensional digital and traditional financial inclusion indexes. Secondly, it provides empirical evidence on the long-run impacts of DFI and TFI on carbon emissions, showing that the mode of

financial inclusion significantly influences its environmental outcomes. Thirdly, by exploring the role of electricity access, the study suggests policy recommendations for sustainable digital finance in developing regions.

LITERATURE REVIEW

The World Bank (2014) highlights the phenomenon of financial inclusion as the fraction of households and organizations that use major financial services. The International Monetary Fund (IMF) describes Financial Inclusion as a measure of access and use of financial services at an affordable price by society's most vulnerable segment (Sahay et al., 2015). From an academic point of view, financial inclusion can be viewed as a situation where basic financial services are accessible to everyone owing to efficiency (Mialou, Amidzic, & Massara, 2017). Hannig and Jansen (2010) emphasize that the primary objective of FI is to engage the unbanked population with the formal financial system. The growing popularity of financial inclusion and digital wallets has increased the competition among traditional banks. Research by KPMG International (2020) indicates that financial institutions are facing pressure to refine technological advancements and offer digital solutions to maintain their customer base. Digital financial services propose a distinctive opportunity to marginalized groups in order to promote financial inclusion among them, so that challenges related to cost, distance, and transparency could be overcome. It will also allow them to access and fulfill their financial needs (Kulkarni & Ghosh, 2021). World Bank (2018) mentioned that financial inclusion rates have significantly increased for the developing nations, mainly due to the rise in the use of digital wallets.

The Finance-Emissions Nexus

The nuanced relationship between financial inclusion and environmental quality is a contested domain in contemporary research, characterized by diverse theoretical propositions and ambiguities. Many researchers in the field argue that digital financial advancement leads to ecological degradation, as greater accessibility to institutional credit facilitates lead to household and corporate investment activity that amplifies energy consumption and accelerates carbon emissions (Sadorsky, 2010). Conversely, others contest that financial inclusion can accelerate environmental improvement through the cleaner technologies and the adoption of sustainable production frameworks (Ahmad, Khan, & Ali, 2022; Bekhet et al., 2017; Le, Le, & Taghizadeh-Hesary, 2020). This ongoing debate underscores the context-dependent nature of the financial inclusion–environment relationship, wherein the direction of environmental impact is mediated by institutional quality, technological capacity, and policy orientation. In this vein, evidence from Pakistan illuminates a more granular dimension as physical currency logistics managed by the State Bank of Pakistan and affiliated commercial banks generate approximately 25,000 metric tons of CO₂ annually. This is attributed to the substantial utilization of carbon-intensive deployment of armored vehicles across the country's cash distribution network. However, comparative lifecycle evidence shows that digital payment infrastructures require 62% less energy per transaction relative to cash-based systems, positioning financial digitization not only as a measure of economic access but as a substantive lever for decarbonization policy (Khan, Ahmad, Sheikh, & Yu, 2022).

Conversely, the other group recommends that financial inclusion can increase environmental quality. Bekhet et al. (2017) show that financial inclusion in GCC countries embraces cleaner technologies by incentivizing capital for environmentally friendly investments. Ahmad et al. (2022) argue that financial growth facilitates firms to capitalize on energy-efficient equipment and sustainable production methods. Le and Pham (2024) find that digitalization in financial services can cut down emissions by switching physical processes to virtual options. However, the environmental implications of digitising the financial systems are inseparable from the energy structures because economic expansion requires resources and energy utilization, reinforcing emissions trajectories, and industrializing economies (Ahmad et al., 2022). This limitation can be tackled by structural transformation toward service-oriented sectors by reducing the carbon intensity of aggregate output. Existing research shows that environmental dividends of cashless transitions are largely concentrated in urban settings owing to reduced transportation emissions and economies of scale in digital infrastructure (Mahmood & Furqan, 2025). Whereas, in rural contexts, the concurrence of cash operations and digital systems

exists (Renzhi & Baek, 2020). The inverted U-shaped relationship of financial inclusion and CO₂ emissions shows that beyond a threshold level of inclusion, environmental quality improves (Zaidi, Hussain, & Zaman, 2021). A viable financial system lowers the cost of capital for green technology adoption and at the same time creates consumer environmental awareness through digital transactions, hence promoting sustainable financial behaviour (Zhao et al., 2021).

The literature on finance and CO₂ emissions remained the centre of attention (Sadorsky, 2010; Shahbaz et al., 2013), but recently, digital finance – CO₂ emissions has taken the central place in the scholarly research with inconclusive results (European Climate Pact, 2025; Hao, Ye, & Zhang, 2025; Lee, Wang, & Lee, 2025). A few studies have explicitly differentiated between digital and traditional forms of financial inclusion, shaping environmental outcomes. The transition from conventional to digital financial models may advance economic development, extend financial access to the population, and reduce emissions. Furthermore, bridging the gap between digital financial inclusion and technological access can address the literature gap (Jose & Ghosh, 2025). Relating the missing link, this research study enquires into the effectiveness of digital financial inclusion with the mediating role of technological access to energy.

Financial Inclusion and Economic Growth

Financial inclusion has emerged as a cornerstone of development strategies across Asia, reflecting its growing role in promoting inclusive and sustainable economic growth. There is a consensus of researchers that improved and wider availability of financial services enhances social welfare by expanding opportunities for sustainable livelihoods, employment generation, and income equality (Helmy, 2024; Miranda-Lescano, Muinelo-Gallo, & Roca-Sagalés, 2023), which encouraged many countries to incorporate financial inclusion into their national development frameworks (Loukoianova et al., 2018). However, the extent to which these benefits materialize varies considerably across countries, suggesting that access to financial inclusion may not guarantee inclusive outcomes. Recent literature highlights digital finance as an important driver of financial inclusion. The growth of digital finance significantly enhances users' access to information, thereby minimizing the information anomaly between users and their external environment, which leads to a lower cost of funds acquisition (Liu, Luan, Wu, Zhang, & Hsu, 2021). Moreover, the large volume of data generated through digital financial services facilitates information dissemination, supports industrial transformation, and contributes to broader economic and ecological development. This raises an important question that previous research failed to address: why do Asian economies, despite targeted intervention, continue to report high levels of financial exclusion as compared to other regions (Li, Wang, Zhou, Wang, & Mardani, 2023)?

Despite sustained policy efforts across Asia, significant gaps in financial inclusion continue to exist. Li, Guo, and Zhu (2024) argue that unrealistic policy targets and weak implementation frameworks may partly explain why many Asian economies still experience relatively high levels of financial exclusion compared with other regions. This observation suggests that the effectiveness of financial inclusion policies depends not only on their design but also on the quality of governance and institutional capacity underpinning them. Access to formal financial institutions is substantially higher in developed economies, where stronger economic performance, higher income levels and a high literacy rate provide individuals with greater opportunities to utilize financial services (Asli Demirgüç-Kunt & Klapper, 2013). On the contrary, higher employment rates negatively affect financial inclusion, which suggests that labour market participation alone may not translate into greater engagement with formal financial systems. Hence, the literature indicates that financial inclusion is shaped by a complex interaction of economic development, technological progress, institutional quality, and human capital. Consequently, understanding these interdependencies remains critical for designing policies that can effectively broaden financial access and support long-term economic development.

Theoretical Perspective

This study builds upon two corresponding theoretical views to realize the distinct environmental impressions of traditional and digital financial inclusion.

Ecological Modernization Theory, initiated by Mol (1995) and further developed by Jänicke (2008). They argue that the trade-off between economic development and environmental protection can be resolved via

technological innovation. Traditional Financial Inclusion characterizes natural resource-intensive financial development, which increases the ecological footprint. Digital Financial Inclusion, on the other hand, illustrates ecological modernization, thereby decreasing natural material intensity. When a farmer makes his payments via a smartphone instead of traveling with cash, or an employee gets wages via mobile account instead of queuing up at a bank branch, the financial system develops in ways that reduce its environmental burden.

The second theory of Dematerialization was recognized by Herman, Ardekani, and Ausubel (1989). They explained that dematerialization is the tendency for economic activity, where technological substitution has led to the efficient utilization of fewer material resources per unit output. Physical currency demands continuous material throughput, i.e., trees for paper, metals for coins, and diesel for transport, thereby generating tons of CO₂ emissions (Sustainability Directory, 2025). Digital transactions derive their footprint from data centres and device manufacturing, which can be mitigated by switching to renewable energy. Von Weizsäcker, Hargroves, Smith, Desha, and Stasinopoulos (2009) cautioned that rebound effects of digital financial inclusion may offset gains if lower transactions dramatically expand volume. Moreover, environmental products depend on energy sources powering digital infrastructure. Concluding from these theories, the study framework suggests that DFI decreases emissions through modernization and dematerialization pathways, while TFI rises emissions by expending physical infrastructure and material throughput. This supports the empirical anticipation that DFI and TFI shows contrasting relationships with CO₂ emissions in South Asia.

Amalgamating these theories generates a distinct framework, i.e., Digital Financial Inclusion would decrease carbon emissions via modernization and dematerialization pathways, whereas Traditional Financial Inclusion would raise emissions through substantial infrastructure development and material throughput. This theoretical foundation affirms the empirical likelihood of contrasting relationships of DFI and TFI with CO₂ emissions in South Asia.

Research Gap and Contribution

The existing research solely focuses on homogeneous constructs of traditional finance or digital banking lacking the comparative analysis of the two. Furthermore, the electricity access is also overlooked as the main prerequisite of digital financial inclusion.

This research study substantiates the literature in various ways. First, it clearly constructs and evaluates distinct indices for DFI and TFI in South Asia. Second, it analyses their long-run, differential impacts on environmental degradation using the PMG estimator. Third, it reaffirms and authenticates the results by the model robustness check. The findings aim to drive policymakers in coupling digital finance for economic inclusion as well as environmental sustainability in South Asia.

DATA AND METHODOLOGY

Green finance, in terms of digital financial inclusion, is the way to transact to achieve economic stability. By adopting non-contact transactions and digital payments, businesses can decrease their carbon footprint and, at the same time, provide a modern way of payment to the customers. According to the U.S. The progression of technology, digital payment solutions such as mobile wallets, are providing a cashless transaction experience to businesses and customers. These digital payments significantly cut down the natural resource use and thus reduce the carbon emissions associated with cash handling.

The research methodology comprises data collection, index construction, model selection, and theoretical grounding. Data collected for the study is panel data for South Asian Countries over the period of 23 years, i.e., 2001 -2023, to thoroughly examine the environmental implications of cashless transactions via digital wallets across South Asian countries of Afghanistan, Bangladesh, Maldives, India, Nepal and Pakistan. The data is sourced from World Bank Open Data and the Financial Access Survey – IMF. The study is grounded upon Ecological Modernization Theory and Dematerialization Theory, to explore the relationship between technological innovations on environment.

This study has taken CO₂ emissions of the country to represent the environmental degradation or environmental impact. Moreover, other control variables as Foreign direct investment, Gross Domestic Product (GDP), and natural resource rents have been added. The econometric model of the study is given below.

$$\text{Environmental Degradation} = \beta_0 + \beta_{1,it} \text{Financial Inclusion} + \beta_{2,it} \text{Tech access} + \beta_{3,it} \text{Control Variables} + \xi_{it} \quad (1)$$

$$\text{Environmental Degradation} = \beta_0 + \beta_{1,it} FI + \beta_{2,it} MAE + \beta_{3,it} NRE + \beta_{4,it} FDI + \beta_{5,it} GDP + \xi_{it} \quad (2)$$

Environmental degradation in the above equation is the dependent variable. The independent variables are financial inclusion (FI), which is further segregated as digital financial inclusion and traditional financial inclusion. Access to Electricity (MAE) was also recognized as an important factor in this stance, whereas economic growth in terms of GDP per capita, Foreign Direct Investment (FDI) and Natural resource rents are taken as control variables. As there is no conventional method for assessing the dimension of DFI, a multifaceted index is developed that is based on the methodology outlined by Yaqin and Safuan (2023) and Ismael and Ali (2021). A separate index was developed to understand the digital financial inclusion (DFI) on carbon output. Another index was constructed to examine the effect of Traditional Financial Inclusion (TFI) on carbon emissions. Both indices of DFI and TFI are better constructed through Principal Component Analysis (PCA). Therefore, the basic equation has separately examined the impact of DFI and TFI on carbon emissions. Financial inclusion indexes were constructed considering the “access”, “usage” and “barrier” in financial sector. Indexes are constructed considering these aspects. Table 1 explains the different aspects of traditional and digital financial inclusion.

Table 1: Financial Inclusion Indicators

Traditional Financial Inclusion Indicators	Data Source	Digital Financial Inclusion Indicators	Data Source
Access		Access	
Number of ATMs (100,000 adults)	World Bank	Mobile Cellular subscription	World Bank
Number of Branches (100,000 adults)	World Bank	Number of registered mobile money accounts	FAS-IMF
	World Bank	Percentage of mobile internet users	World Bank
Usage		Use	
Number of deposits accounts with commercial banks (1000 adults)	World Bank	Number of mobile transactions (1000 adults)	FAS- IMF*
Number of borrowers from conventional bank (1000 adults)	World Bank	Value of mobile transactions	
Number of debit cards (1000 adults)	FAS – IMF*	Active mobile accounts	FAS- IMF*
Number of credit cards (1000 adults)	FAS – IMF*		FAS – IMF*
Barrier			
Number of commercial bank branches (1000 Km ²)	FAS – IMF*		
Number of ATMs (per 1000 Km ²)	FAS – IMF*		

Note: * FAS – IMF means “Financial Access Survey -International Monetary Fund”

For every indicator, the principal component score has been calculated considering its different aspects. In order to calculate Principal components, following equation has been used:

$$PC_k = \sum_{p=1}^n n_{kp} X_p \quad (3)$$

Where,

PC_k = The kth Principal Component.

$\sum$ = Summation of series of term.

n_{kp} = Weight of the pth original variable in the kth principal component. It tells the influence of original variable on principal component.

X_p = the pth original variable.

The component selection was based on its eigenvalues. TFI and DFI first components have weighted 59.5 and 43 percent among the various components. The composite index was subsequently generated and used in the final model.

After PCA for TFI and DFI, the study utilized the Auto-regressive and Distributed Lag (ARDL) modelling process to effectively capture the short and long-run links of various variables on carbon emissions. Empirical investigation of the model was done by employing advanced econometric approaches such as the Pooled Mean Group (PMG) model, amplifying the long-run and short-run dynamics of the variables. Prerequisite tests, as the cross-sectional dependency test, unit root analysis and co-integration test, have been performed for the verification and the authentication of the model. The step-by-step analysis of the model is given in Figure 1.

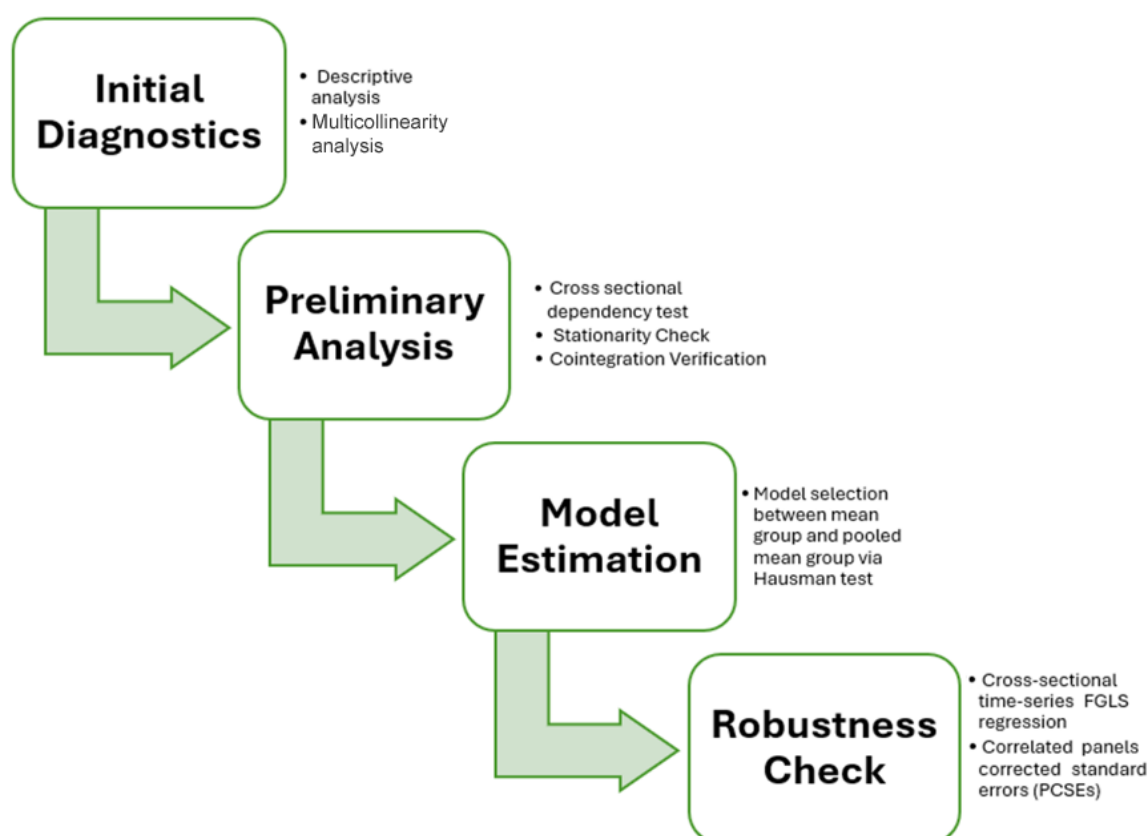


Figure 1: Step-by-Step Analysis

RESULTS AND DISCUSSION

Financial inclusive development for instance, contributes to decreased environmental quality while technological innovation facilitates emission reduction. As observed in Argentina, an increase in the share of its renewable energy via technological innovation has cut down emission levels across their energy, manufacturing, building, and transportation sectors (Mahmood & Furqan, 2025). The positive influence of financial development on green growth and economic development was found to be effective in the 15 emerging countries of the world (Arzova & Şahin, 2024).

The study analysis started with descriptive analysis of the study, which is given in Table 2.

Table 2: Descriptive Analysis

Variables	Obs.	Mean	Std. Dev.	Min.	Max.
Carbon Emissions	138	1.140	1.294	0.038	5.468
Traditional Financial Inclusion	138	0.007	1.013	-1.164	4.940
Digital Financial Inclusion	138	0.001	1.022	-0.611	6.697
GDP	138	3.21	6.646	-34.831	33.769
Foreign Direct Investment	138	-3.888	9.538	-53.24	0.088
Access to Electricity	138	68.453	24.157	.777	100
Natural Resources Rents	138	1.304	1.218	.003	7.109

Moving ahead towards the multicollinearity analysis, Table 3 shows correlations and variance inflation factor (VIF) of the different variables of the model. The Variance Inflation Factor (VIF) values for all explanatory variables are below the critical threshold of 5, indicating the absence of serious multicollinearity in the model. Therefore, the estimated coefficients are reliable and not distorted by high inter-variable correlations. Moreover, the light and dark shades of the table highlight the strength of correlation among different variables.

Table 3: Pairwise Correlations and Variance Inflation Factor (VIF)

Variables	1	2	3	4	5	6	7	VIF	1/VIF
Carbon Emissions	1								
Traditional Financial Inclusion	0.609***	1						3.088	0.324
Digital Financial Inclusion	0.132	-0.004	1					1.061	0.943
GDP	0.041	0.106	0.197***	1				1.122	0.891
Foreign Direct Investment	-0.149**	-0.377***	-0.035	-0.046	1			1.768	0.566
Access to Electricity	0.643***	0.781***	-0.17*	-0.126	-0.175**	1		2.792	0.358
Natural Resources	-0.198***	0.122	0.059	0.082	-0.507***	0.016	1	1.564	0.639

Note: *, ** and *** Refers to the significant probabilities at 10%, 5% & 1% respectively.

The cross-sectional dependence in the dataset is checked using Pesaran (2004) CD test. The empirical form of cross-sectional dependency tests is given below.

$$CD_p = \sqrt{(\sum_{i=1}^{N-1} \sum_{j=i+1}^N \widehat{r_{ij}}^2)} \quad (4)$$

Table 4 gives the two test results, i.e., Pesaran (2004) test for Cross-sectional dependence (CSD) and the Pedroni test for Cointegration. The high CD-test values of all variables illustrate strong interdependence in these variables across South Asian countries.

Table 4: Pesaran (2004) Cross-sectional dependence Test (CSD), Hadri Stationarity Test and Pedroni Cointegration Test

Variable	Pesaran (2004) for Cross-sectional dependence (CSD)
Carbon Emissions	9.980***
Traditional Financial Inclusion	6.290***
Digital Financial Inclusion	3.520**
GDP	9.920***
Foreign Direct Investment	0.030*
Access to Electricity	14.450***
Natural Resources	7.290***
Pedroni Test for Cointegration	
Modified Phillips-Perron	2.7806***
Phillips-Perron	-1.6351**
Augmented Dickey-Fuller	-1.6613**

Note: *, ** and *** Refers to the significant probabilities at 10%, 5% & 1% respectively.

Panel cointegration analysis using the Pedroni test was done to investigate the existence of cointegration among variables in the long run. The t-statistics were indicating evidence of cointegration in parts of the dataset, thus supporting the presence of a long-term relationship among the variables.

The Fisher–Phillips–Perron panel unit root tests in Table 5 reveal that the majority of variables, including carbon emissions, financial inclusion (traditional and digital), GDP, FDI, natural resources, and electricity access, are stationary at levels, though carbon emissions and GDP exhibit marginally weaker evidence under the inverse normal criterion.

Table 5: Fisher Panel Unit Root

Variables	Fisher: Phillips-Perron tests (Unit Root)			
	Inverse chi-squared	Inverse normal	Inverse logit	Modified inv. chi-squared
Carbon Emissions	32.086***	-0.871	-2.08**	4.100***
Traditional Financial Inclusion	29.675***	-1.734**	-2.172**	3.608***
Digital Financial Inclusion	56.650***	-5.500***	-6.420***	9.114***
GDP	56.305***	-1.166	-3.684***	9.043***
Foreign Direct Investment	27.407***	-3.047***	-2.951***	3.144***
Access to Electricity	303.927***	-15.915***	-34.734***	59.589***
Natural Resources	19.825***	-0.922	-1.182	1.597**

Note: ** and *** Refers to the significant probabilities at 5% & 1% respectively.

The above results affirms cross sectional dependence, cointegration and normality at various levels among the variables. The Mean Group Estimates (MG) and Pooled Mean Group Estimates (PMG) were evaluated using statistical software: STATA. The selection of the PMG model was based on the Hausman (1978) model specification criteria. The empirical model of the PMG estimates is given below.

$$\Delta y_{i,t} = \phi \psi \Delta Y_{i,t} + \sum_{j=0}^{q-1} \Delta X_{i,t-j} \beta_{i,t} + \sum_{j=1}^{p-1} \lambda_{i,y} * \Delta y_{i,t-j} + \varepsilon_{i,t} \quad (5)$$

$$EC_{i,t} = y_{i,t-1} - X_{i,t} \theta \quad (6)$$

After rigorous analysis and selection between Mean group and Pooled Mean group (PMG) via Hausman Test, the final results of PMG estimators of the long run and short run is given in Table 6.

Table 6: Pooled Mean Group Model Estimates

Long-run Analysis	Model 1	Model 2	Model 3
Traditional Financial Inclusion	0.014 (0.057)		0.108*** (0.031)
Digital Financial Inclusion		-0.016*** (0.006)	-0.108*** (0.006)
GDP	0.232** (0.133)	0.165*** (0.043)	0.240*** (0.020)
Foreign Direct Investment	0.148*** (0.024)	0.015 (0.023)	-0.004 (0.020)
Natural Resources	-0.074*** (0.024)	0.010 (0.016)	0.032** (0.016)
Access to Electricity	0.142** (0.086)	0.175*** (0.044)	0.131*** (0.042)
Short-Run Analysis			
ECT	0.418** (0.186)	0.398** (0.156)	0.450*** (0.175)
Traditional Financial Inclusion	-163.48 (605.94)		1819.24 (2498.65)
Digital Financial Inclusion		0.242 (0.168)	0.228 (0.182)

Long-run Analysis	Model 1	Model 2	Model 3
GDP	0.088 (0.198)	0.117 (0.224)	0.077 (0.196)
Foreign Direct Investment	0.067 (0.044)	0.032 (0.036)	0.017 (0.037)
Natural Resources	-0.060 (0.070)	0.012 (0.078)	-0.004 (0.067)
Access to Electricity	0.171 (0.120)	0.233 (0.177)	0.204 (0.158)
Constant	-0.109 (0.087)	-0.138 (0.129)	-0.140 (0.141)

Note: ** and *** refer to the significant probabilities at 5% & 1% respectively.

The long-run analysis of the paper shows that digital financial inclusion (DFI) exerts a significant reduction on carbon emissions. The model also explains the mitigating effect of digital finance on the system. The negative coefficient of DFI affirms the Ecological Modernization Theory and the Dematerialization Theory. However, it is important to note that some of the short-run coefficients for TFI are relatively large with considerable standard errors. This pattern is normal in heterogeneous panel ARDL models, where countries may differ significantly in responding to changes over the short term. These differences in adjustment can contribute to greater variability in the estimated short-run effects.

Traditional financial inclusion effects measured depict a positive and significant association with carbon emissions. It highlights concerns that expansion in traditional financial access might amplify carbon-intensive consumption.

In all three models, access to electricity and natural resource rents consistently aggravate environmental pressures, aligning with the Dematerialization Theory. They also highlight the probability of resource-driven investments in cleaner energy.

The long-run estimates disclose that traditional financial inclusion substantially affects environmental outcomes in South Asia. In Models 1 & 3, a positive coefficient advocates that improved access to finance may increase environmental degradation, possibly due to increased energy consumption, digital infrastructure extension, and significant commercial activity (Ali, Khan, & Shahbaz, 2023; Chen & Xu, 2022). Contrarily, the negative long-run coefficient of digital financial inclusion in Model 2 & 3 models implies that stable digital ecosystems can encourage environmental efficiency through decreased paper use, enhanced transaction accuracy, thus advocates green financing (Usman & Jahanger, 2021; Zhang, Wang, & Wang, 2022). The dual behavior of technology and financial developments initially degrades but later upgrades environmental quality as economies evolve (Dinda, 2004; Grossman & Krueger, 1995).

Furthermore, the positive and significant coefficients of GDP and FDI across most models suggest that economic development and foreign investment, while enhancing development, are also linked with higher environmental pressures. Shahbaz, Balsalobre-Lorente, and Sinha (2019) and Nathaniel, Adeleye, and Bello (2021) studies also affirm that industrial and investment-driven growth in developing economies often intensifies environmental degradation before transitioning to cleaner production systems. Natural resource rents present mixed results with environmental quality, supporting the resource curse hypothesis, where excessive reliance on natural resources impedes sustainable development (Adedoyin, Agboola, Ozturk, Bekun, & Agboola, 2021).

The mixed results of natural resources suggest that while improved energy access can accelerate production and emissions in the long run, its environmental impact is contingent upon the energy mix, i.e., clean versus fossil-based (Acheampong, 2018). Traditional financial inclusion depicts a positive link with environmental degradation, indicating that conventional banking and credit networks still financing carbon-intensive sectors (Murshed, Haseeb, & Alam, 2022).

In the short run, less robust results are seen. FDI continues as a notable factor for emissions increase, while other variables show a weak or insignificant relationship. The positive error correction terms support the possibility of instability in models, advising divergent adjustment dynamics rather than convergent

adjustments in the long-run equilibrium. This result may indicate structural dynamics in the sampled economies, where fast-paced financial and technological changes indicate transitional instability before equilibrium is restored. Similar findings have been affirmed in the literature under conditions of financial liberalization and digital disruption, where short-term shocks can induce overshooting effects (Narayan & Smyth, 2006; Pesaran, Shin, & Smith, 1999). While unconventional, such results emphasize the density of the adjustment mechanism in the incidence of digital finance and energy transitions. Nevertheless, robustness checks have also been done using Cross-sectional time-series FGLS regression and Correlated panels corrected standard errors (PCSEs). The results of the model are given in Table 7.

Table 7: Cross Validation

Variable	Cross-sectional time-series FGLS regression	Correlated panels corrected standard errors (PCSEs)
Traditional Financial Inclusion	0.068 (0.043)	0.068 (0.040)
Digital Financial Inclusion	-0.032 (0.028)	-0.032** (0.029)
GDP	0.637*** (0.065)	0.637*** (0.076)
Foreign Direct Investment	0.226*** (0.037)	0.226 *** (0.047)
Access to Electricity	0.218*** (0.051)	0.218*** (0.055)
Natural Resources	0.191*** (0.034)	0.191*** (0.037)
constant	0.004 (0.027)	0.004 (0.021)
Chi-square	1114.701***	1390.43***

Note: ** and *** refer to the significant probabilities at 5% & 1% respectively.

The PCSE results show a significant negative effect, whereas the FGLS estimates remain negative but are not statistically significant at conventional levels. DFI has a negative coefficient across the alternative estimation methods; however, this does not compromise the statistical significance of the relationship. Therefore, the robustness evidence supports the direction of the relationship, although the statistical strength of the results varies across estimators. The alternate models of Cross-sectional time-series Feasible Generalized Least Square (FGLS) regression and Correlated panels corrected standard errors (PCSEs) that support the heterogeneous data also reaffirm the existence of a stable relationship, thereby indicating that the negative effect of DFI and positive effects of other variables on environmental quality.

CONCLUSIONS AND RECOMMENDATIONS

The study investigated the dynamic association between financial inclusion (both digital and traditional) and environmental degradation across South Asia. The control variables, such as FDI, GDP and natural resource rents have played a vital role in realizing sustainability goals and modeling environmental performance. Two separate indices of DFI and TFI were constructed to study the impact of DFI and TFI on carbon emissions and environmental degradation. Panel data techniques were used along with the unit root test, co-integration analysis and PMG framework was employed for empirical research.

The findings reveal that DFI significantly and negatively impacts carbon emissions in the long-run, thus improving environmental quality. Digital financial inclusion enables easy financial access and exhibits a relatively more sustainable pattern. To achieve the low emissions goal, it is suggested that digital financial inclusion should be infused into the financial system. In contrast, traditional financial inclusion is significantly

contributing towards the CO₂ emissions. It is likely due to its association with higher industrial activity, production of physical currency, and credit allocation towards carbon-intensive sectors. Moreover, this study reveals that FDI inflows may drive environmental degradation; hence, deteriorate the environmental quality. Lastly, economic growth in terms of GDP is the primary driver of CO₂ emissions. It indicates that the economies of South Asian countries rely heavily on fossil-fuel consumption, which misaligns with the countries' sustainable development goals. A major limitation of the study is data constraints, particularly for Afghanistan, which may affect full regional comparability, and the analysis does not capture broader digital infrastructure indicators such as electricity reliability and network quality. In addition, potential rebound effects of increased digital financial activity are not explicitly captured, which may influence the net environmental outcomes.

In this vein, the important point to note is that without access to electricity and reliable digital infrastructure, the environmental advantages of digital finance remain limited, and its expansion is unlikely to produce a significant reduction in carbon emissions. Limited resources restrict the effectiveness of digital transactions, while inadequate infrastructure can lead to higher energy consumption and operational inefficiencies that offset potential carbon savings across the South Asian region. Accordingly, in the absence of supporting factors, the development of digital financial services is unlikely to yield an extensive enhancement in environmental quality and progression towards environmental sustainability. In such instances, there is a risk that digital financial services may develop as an auxiliary and parallel system that works side by side with traditional financial services rather than utterly switching traditional banking models. Consequently, it is recommended that policymakers adopt a multifaceted approach and an all-inclusive strategy that deals with both technological and socioeconomic obstacles in the path of digital financial adoption. Investment in strong electricity infrastructure, expansion of mobile network coverage to rural and underserved areas, and the launch of digital literacy programs under government support can lead to a smooth transition towards the cashless economy across South Asia. Regulatory frameworks should also validate safe and secure payment systems to foster trust among the public in using digital financial services. Furthermore, incorporating environmental goals into financial inclusion strategies by promoting green fintech solutions can couple the goal of financial innovation with environmental sustainability. To realize sustainable development goals, policymakers of the South Asia region should stress renewable energy adoption instead of fossil fuel energy. Additionally, firms may propose eco-friendly procedures, helping the host country reduce its carbon footprint over time. These intuitions, taken from this research study, serve as a valuable guide for policymakers and the financial sector in applying the emergent phenomenon of financial inclusion and digital technologies in crafting financial services to make them more accessible, competent, and affordable, thus supporting both economic growth and environmental sustainability.

Future research requires exploring technological barriers, access, usage, and security concerns in depth to improve user trust and acceptance rates. There is a need to focus on cross-country differences, thorough analyses of user behaviours, prospective risks related to digital wallet adoption, its impact on macroeconomic policy and economic stability. Furthermore, digital wallets of various forms might also be evaluated environmentally with the global alternatives.

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