World Development Sustainability 8 (2026) 100277

Contents lists available at ScienceDirect

World Development Sustainability

journal homepage: www.elsevier.com/locate/wds

Unveiling the roles of green tax, financial development, banking development, fintech adoption, and economic growth on sustainable development in Bangladesh

Rejaul Karim [a,b,*], Md. Amdadul Hoque [c], Rosli Mahmood [c], Reday Chandra Bhowmik [d], Sohidul Islam [e], Sharmila Devi Ramachandaran [b]

[a] Department of Business Administration, Varendra University, Rajshahi 6204, Bangladesh
[b] Faculty of Business and Communications, INTI International University, Putra Nilai 71800, Malaysia
[c] Putra Business School, Universiti Putra Malaysia, Selangor, Malaysia
[d] Department of Finance and Banking, Comilla University, Comilla 3506, Bangladesh
[e] Department of Economics and Banking, International Islamic University Chittagong, Chattogram 4318, Bangladesh

ARTICLE INFO

Keywords:
Sustainable development
Green tax
Fintech adoption
Banking development
ARDL model

ABSTRACT

This study examines how green taxation (GTX), fintech adoption (FIN), banking development (BAD), financial development (FD), and economic growth (GDP) affect sustainable development (SD) in Bangladesh using annual data from 1990 to 2023. We estimate an Autoregressive Distributed Lag (ARDL) model to capture short-run and long-run dynamics and validate the results using Fully Modified Ordinary Least Squares (FMOLS), Dynamic OLS (DOLS), and Canonical Cointegrating Regression (CCR) estimators. The long-run estimates indicate that GTX, BAD, and FD are negatively associated with SD, suggesting that weak institutional alignment and limited ESG-orientation may hinder sustainability benefits from fiscal and financial expansion. In contrast, FIN and GDP improve SD in the long run. Short-run effects show transitional trade-offs, implying that sustainability gains depend on policy sequencing and implementation capacity. Policy implications emphasize redesigning GTX with revenue earmarking and equity safeguards, strengthening ESG-linked lending targets and disclosure for banks, and leveraging fintech for inclusive green finance (e.g., solar microfinance and climate-smart SME credit). This paper contributes by integrating fiscal, financial, and digital mechanisms within a unified Bangladesh-specific time-series framework and explicitly distinguishing short-run from long-run sustainability effects.

1. Introduction

Emerging economies face new challenges and opportunities driven by the twin imperatives of climate resilience and digital transformation. For Bangladesh, which belongs to the world's most climate-exposed group of countries [1], incorporating green finance into digital financial technology is not a strategic choice, but a developmental necessity. Although the global rhetoric is shifting towards sustainable development as arguably a trade-off between wealth creation and environmental conservation alongside social equity [2], developing nations, including Bangladesh, are hampered by structural and institutional impediments in aggregating much-needed green capital and in mainstreaming climate-aligned practices in finance [3].

Bangladesh faces a dual challenge—sustaining economic growth while managing climate vulnerability and environmental degradation, as Bangladesh ranks among the most climate-vulnerable nations globally, with recurrent exposure to floods, cyclones, and sea-level rise [1]. Climate inaction is projected to reduce GDP by 6.8 % by 2050, with severe losses in agricultural productivity (−17 %) and human development [4]. Although policy instruments such as environmental taxation and sustainable finance guidelines exist, sustainability outcomes remain uneven—raising concerns about whether fiscal tools and financial deepening are effectively aligned with ESG priorities. At the same time, fintech expansion offers new pathways for inclusion and potentially for green finance mobilization. Two essential elements that are transforming the financial sector are the growing demand for environmental

* Corresponding author.
E-mail addresses: karim@vu.edu.bd (R. Karim), amdad527@gmail.com (Md.A. Hoque), rosli@putrabs.edu.my (R. Mahmood), redaybhowmik42@gmail.com (R.C. Bhowmik), sohidulislam60ctg@gmail.com (S. Islam), sharmila.devi@newinti.edu.my (S.D. Ramachandaran).

https://doi.org/10.1016/j.wds.2026.100277
Received 6 October 2025; Received in revised form 24 January 2026; Accepted 10 February 2026
Available online 13 February 2026

sustainability and the rapid adoption of digital technologies. Developing countries have a strategic opportunity to create more resilient, inclusive, and sustainable financial systems through the integration of financial technology (fintech), which uses innovation to improve financial services [5,6], and green finance, which allocates capital toward environmentally beneficial activities [7]. Meeting the SDGs will require increased funding and the development of new, innovative, and environment friendly financing instruments. Green finance may help channel finance with environmental objectives aligned with sustainable development in Bangladesh [8]. This existential threat has elevated climate adaptation financing to a national priority, positioning green finance as a critical policy response [9,10].

This research aims to empirically investigate the relationship between green taxation, financial sector development, banking development, fintech adoption, and economic growth, and their impact on Bangladesh's capacity to achieve sustainable development. Specifically, it addresses a few research questions (RQs):

RQ1: What are the short-run and long-run effects of green taxation on sustainable development?
RQ2: Does fintech adoption improve sustainable development beyond traditional banking and financial development?
RQ3: How do banking development, financial development, and economic growth jointly influence sustainability in Bangladesh?

Although Bangladesh Bank pioneered sustainable banking guidelines in 2011—a first among developing economies [11]—implementation remains fragmented due to institutional inertia, misaligned incentives, and overdependence on traditional financial intermediaries [12]. Fintech innovations—including AI-driven credit scoring, blockchain-based remittances, and pay-as-you-go solar microfinance—demonstrate potential to address financial exclusion [13]. Despite these policy directives and the recognized benefits, the widespread adoption of green banking practices in Bangladesh remains in its nascent stages. A limited number of commercial banks actively engage in comprehensive in-house environmental management and sustainable financing initiatives [14, 15]. However, fintech applications remain concentrated in payments (82 % of transactions), with negligible penetration (<5 %) in green finance sectors [16], and fintech and green taxes both provide separate avenues for sustainable development, but their combined influence within a framework for financial development is still little understood, especially in low- and middle-income nations.

Empirically, the previous studies conducted on Bangladesh's green finance, fintech adoption, or banking development resulted in a partial understanding of the collective impact of these on sustainable development. few studies have examined these factors collectively in a single setting based on time-series analyses. This study contributes conceptually and methodologically in four ways. First, it integrates green taxation, fintech adoption, banking development, and financial development within a single time-series framework for Bangladesh, where most prior work examines these factors in isolation. Second, it explicitly distinguishes short-run dynamics from long-run equilibrium effects using Autoregressive Distributed Lag (ARDL), addressing the common gap in Bangladesh-focused sustainability analyses. Third, it provides robustness checks using a robust methodology—Ordinary Least Squares (FMOLS), Dynamic OLS (DOLS), and Canonical Cointegrating Regression (CCR) to assess sensitivity to endogeneity and cointegration estimation choices. Fourth, it offers policy-actionable implications by linking the long-run effects of financial technology, green tax laws, and the general growth of the banking industry with the sustainable development in Bangladesh for ESG-oriented credit allocation and disclosure reforms.

The rest of this paper is organized as follows. The theory and reviewed literature on green taxation, fintech adoption, banking development, financial development and economic growth, and sustainable development are presented in Section 2. The data, variables, and econometric methodology used are described in Section 3, including the ARDL model and robustness tests. Empirical results are presented in Section 4, while Section 5 finally concludes the paper by summarizing the main results, highlighting the policy implications for Bangladesh and other similar developing countries, and limitations and suggestions for further research.

2. Theoretical framework and literature review

2.1. Theoretical framework

This study, grounded in Ecological Modernization Theory (EMT) and the Brundtland conception of sustainable development, also draws on the policy mix perspective, which emphasizes complementarities among price-based instruments (e.g., environmental taxes), market development (financial/banking development), and technology diffusion (fintech) to achieve environmental goals without derailing growth. Brundtland's [2] Sustainable Development Theory advocates for a development paradigm that balances social and environmental well-being with economic advancement. EMT places a strong emphasis on how market-oriented reforms, technical innovation, and institutional modernization may address ecological issues without impeding economic growth [17].

Businesses are encouraged to adopt cleaner technology and lower emissions by a green tax, which is seen as a governmental tool to internalize environmental costs. According to empirical research, environmental taxes have a good impact on sustainability and environmental quality [18,19]. Adoption of fintech has become a significant force behind digital transformation and financial inclusion, providing effective financial services that can increase access to sustainable finance and enable green investments [20]. The financial sector's ability to invest in sustainable projects is enhanced by banking development; research indicates that robust banking systems are essential to finance green projects [21]. In order to finance green infrastructure and achieve long-term sustainability, financial development encourages capital mobilization and investment diversification [22]. When paired with sustainable practices, economic growth helps reduce poverty and boosts environmental protection capabilities [23]. In low- and middle-income contexts, governance quality and institutional capacity condition the effectiveness of these instruments; poorly designed green taxes or shallow ESG practices can shift burdens onto low-income groups and resource-intensive sectors, undermining social equity even when aggregate indicators improve [24,25]. Bangladesh's evolving policy architecture—Green Banking Guidelines (2011), Sustainable Finance Policy (2020), and Green Bond Financing Policy (2022)—creates an enabling environment for EMT-style transitions, but implementation heterogeneity remains.

By encouraging environmental responsibility, expanding financial inclusion, and boosting economic efficiency, green taxation, fintech adoption, banking and financial development, and economic growth all have a positive impact on sustainable development in Bangladesh [26, 27]. To achieve environmental and economic resilience, these factors interact to influence sustainable development outcomes in Bangladesh, underscoring the need for integrated financial, technological, and policy-based approaches.

2.2. Review of related empirical studies

The extant literature is categorized in this section into five subject categories that correspond to the main factors of the study: economic growth, banking development, financial development, green tax, and fintech acceptance. A summary of the gap in the literature is included at the end.

2.2.1. Green taxation and sustainable development

Environmental ("green") taxes internalize externalities by aligning private and social costs. Recent cross-country panels for developing economies find that environmental taxes promote inclusive green growth, particularly when combined with sound institutions (e.g., control of corruption, regulatory quality). Comparative evidence also links environmental taxation to long-run emission reductions and innovation incentives [28,29]. By penalizing pollution-intensive activities, the green tax is a fiscal mechanism that seeks to internalize environmental externalities [18,30]. While some high-income nations have found success with environmental taxes, their use in developing nations has produced a range of outcomes. Due to inadequate regulatory frameworks and mismatched economic incentives, Bangladesh's environmental levies continue to have a restricted scope and enforcement, with minimal effects on long-term sustainability [31,32].

The green taxes have the potential to improve sustainability, but their implementation and design must take socioeconomic inequality and sectoral dynamics into account [26]. Overall, environmental taxes tend to improve sustainability when institutional quality supports enforcement, transparency, and revenue recycling; otherwise, distributional burdens and weak compliance can produce limited or even adverse sustainability outcomes. This institutional-conditioning debate motivates examining Bangladesh using short-run and long-run estimates rather than assuming a uniform positive effect.

2.2.2. Fintech and green finance integration

The global literature now conceptualizes green fintech as a distinct domain that applies digital finance (payments, alternative data, decentralized finance, tokenization) to accelerate environmental outcomes [24]. Case studies such as Ant Forest document how gamified digital payments and behavioral nudges translate into measurable environmental projects and pro-environmental behaviors [14,33]. Fintech has emerged as a disruptive force in promoting financial inclusion and digital transformation.

In Bangladesh, the financial services such as bKash, Nagad, and agent banking have penetrated underserved rural regions, reducing financial exclusion [34]. Globally, fintech platforms like Ant Forest (China) and M-KOPA (Kenya) demonstrate the potential of digital finance in fostering pro-environmental behaviors and enabling green microfinance. However, fintech applications in Bangladesh remain heavily skewed toward basic payment services, with <5 % of activity directed toward sustainable investments (KPMG, 2021). Regulatory inertia, weak ESG alignment, and inadequate digital infrastructure further limit fintech's contribution to sustainable development [35]. The concept of "green fintech," though gaining traction globally, remains under-theorized and underutilized in Bangladesh.

Recent work suggests fintech can support sustainability through financial inclusion, efficiency gains, and green-finance channels, but effects may differ over time: early adoption can create regulatory and capability frictions, while mature fintech ecosystems may enhance long-run sustainability. This motivates separating short-run from long-run impacts in Bangladesh.

2.2.3. Banking development and sustainability

Banking institutions play a pivotal role in mobilizing capital for sustainable projects. Bangladesh's banks have implemented some green lending practices under regulatory compulsion, yet studies reveal that these initiatives are often superficial and compliance-driven [10]. ESG-aligned industries continue to be marginalized by traditional banking's preference for short-term, profit-oriented investments. Banking development may unintentionally contribute to environmental degradation if sustainability principles—such as ESG grading and green loan instruments—are not deeply integrated into banking operations [36,37].

Bangladesh Bank's policy sequence—ERM Guidelines (2011), Green Banking Guidelines (2011–2013), Sustainable Finance Policy (2020), and the Green Bond Financing Policy (2022)—formalized governance structures (Sustainable Finance Units/Committees) and reporting. Quarterly Sustainable Finance Reviews (2024–2025) benchmark banks on green lending, sustainability indices, and disclosure. Independent studies, however, still find compliance-driven adoption and limited penetration of ESG-aligned credit, especially for SMEs and agriculture. Survey-based evidence suggests banks perceive green finance as riskier and costlier absent taxonomy clarity, pipeline development, and concessional risk-sharing instruments.

2.2.4. Financial developmentand environmentalimpact

Beyond banking, broader financial development can either catalyze diversification and green innovation or amplify resource-intensive growth, depending on regulation and market signals. For developing economies, several studies report that financial deepening without binding environmental standards expands carbon-intensive sectors and the ecological footprint [23]. Governance and policy mixes (environmental taxes, green taxonomies, green bond frameworks) appear to moderate these effects. Bangladesh's rollout of sustainable finance reporting and a domestic green bond policy is a step toward aligning market depth with green outcomes. Still, secondary-market liquidity and verifiable pipelines remain bottlenecks.

Financial development enhances capital availability and market efficiency but may exacerbate ecological risks if decoupled from sustainability metrics. Empirical evidence from developing countries shows that while financial depth increases investment, it may also stimulate resource-intensive sectors, thereby undermining sustainability goals [35]. In Bangladesh, the absence of a green taxonomy, fragmented ESG regulations, and weak coordination among regulatory agencies constrain the potential of financial development to support green outcomes [38].

2.2.5. Economic growthand the growth–sustainabilitynexus

Economic growth and sustainability are deeply interconnected, yet often at odds. Recent studies show that while GDP expansion can finance renewable energy adoption and spur innovation—particularly in more sustainable or developed countries—it may also intensify environmental degradation in less sustainable contexts [39]. Similarly, post-pandemic research highlights how government effectiveness mediates the growth-sustainability nexus: growth improves well-being when governance is strong, but can hinder sustainability where institutions are weak [40,41].

The relationship between GDP growth and sustainable development follows a non-linear pattern, often explained by the Environmental Kuznets Curve (EKC) hypothesis [23]. While growth initially increases environmental stress, it can enhance sustainability when directed toward green infrastructure, education, and renewable energy [42]. For Bangladesh, empirical studies show that unregulated growth leads to environmental degradation in the short term but may support sustainability in the long run if channeled responsibly.

2.2.6. Literature gap

Despite growing global evidence on environmental taxation, sustainable finance, and fintech, three gaps remain in the Bangladesh context. First, most studies assess green finance, fintech, banking development, and fiscal instruments separately, limiting understanding of their combined and potentially offsetting effects. Second, Bangladesh-focused time-series evidence that distinguishes short-run transitional dynamics from long-run equilibrium effects remains scarce, even though policy instruments may generate short-term trade-offs before long-term gains emerge. Third, proxies of fintech adoption used in long-run time-series data capture inclusion rather than frontier innovation (e.g., AI credit scoring or blockchain), creating measurement constraints that require careful interpretation and robustness validation. Finally, the regulatory and institutional challenges that limit the effective integration of green fintech in developing economies have not been sufficiently addressed in the literature [38]. This study addresses these gaps by estimating a unified ARDL model for Bangladesh (1990–2023) and validating the long-run relationship using FMOLS, DOLS, and CCR estimators, marking a pioneering attempt to empirically assess their interconnectedness in the context of Bangladesh, thus providing valuable insights for both scholars and policymakers.

3. Methods

3.1. Data and sources

This study used time series data from 1990 to 2023 to examine the impact of green tax (GTX), fintech adoption (FIN), banking development (BAD), financial development (FD), economic growth (GDP), and sustainable development (SD) in Bangladesh. The data were collected from the World Development Indicators [43], Sustainable Development Index [44], and International Monetary Fund [45].

All series were checked for completeness after merging sources; the final dataset contains 34 annual observations (1990–2023) for each variable. No imputation procedures were needed because the final dataset had a balanced annual time series with 34 observations (1990–2023) for each variable and no missing values were found. Before estimate, all variables were converted using natural logarithms. In order to stabilize variance, lessen the impact of outliers, limit potential heteroskedasticity, and enable coefficient estimates to be read as elasticities, this modification was used. Logarithmic transformation is frequently used in time-series econometric research to enhance model linearity and lessen bias resulting from scale differences among variables. It is especially suitable for macroeconomic and financial variables that show exponential growth trends over time.

A detailed breakdown of the data is shown in Table 1, which also includes descriptions, units of measurement, and the sources from which the data were obtained. Fig. 1 illustrates the historical trends (with yearly data) and variations in these variables over the study period, highlighting key economic and environmental transitions in Bangladesh. Fintech adoption (FIN) is proxied by the percentage of the adult population (aged 15+) with an account at a financial institution or a mobile-money service provider, which primarily reflects digital financial inclusion rather than frontier fintech innovation (e.g., blockchain-based platforms or AI-driven credit scoring), it is widely adopted in macro-level empirical studies due to its long time coverage, consistency, and cross-country comparability [13,33]. In the context of Bangladesh, fintech development is overwhelmingly concentrated in mobile money, agent banking, and digital payment systems [34], which constitute the foundational layer of fintech ecosystems in developing economies [20].

Sustainable development (SD) is measured using SDI, which integrates economic, social, and environmental dimensions into a single composite indicator. Unlike conventional development indices, the SDI explicitly adjusts human development outcomes for ecological overshoot, thereby capturing whether improvements in income, health, and education are achieved within planetary boundaries. The SDI is preferred over alternative measures because embedding environmental constraints directly into development outcomes, the SDI aligns more closely with the study's focus on green taxation, financial development, and sustainability trade-offs [23,39].

Table 1
Variables, descriptions, and data sources.

Variables	Description	Measurements	Sources
SD	Sustainable development	Sustainable Development Index (SDI), which aggregates economic, social, and environmental dimensions to represent overall sustainability progress.	[44]
GTX	Green tax	% of GDP	[45]
FD	Financial development	Financial development index	[45]
BAD	Banking development	Deposit money banks assets to GDP (%)	[43]
FIN	Fintech adoption	% of the adult population (15+) with an account at a financial institution or a mobile-money service provider	[43]
GDP	Economic growth	GDP Per Capita (Constant 2015 US$)	[43]

Source: Author's compilation from SDI, WDI, and IMF.

3.2. Conceptual framework

The conceptual framework, presented in Fig. 2 visually represents the analytical structure of the study on sustainable development in Bangladesh. Sustainable Development (SD) is positioned at the center of the framework as the core outcome variable. Five key determinants—-Green Tax (GTX), Financial Development (FD), Banking Development (BAD), Fintech Adoption (FIN), and Economic Growth (GDP)—are shown as exogenous variables, each connected to sustainable development through directional arrows, indicating their direct influence on SD. The framework highlights the integrated role of fiscal, financial, banking, technological, and macroeconomic factors in shaping sustainability outcomes. Green Tax reflects environmental fiscal policy aimed at discouraging pollution and promoting greener practices. Financial Development and Banking Development capture the depth, efficiency, and intermediation capacity of the financial system, which can either support or constrain sustainability depending on institutional quality and ESG orientation. Fintech Adoption represents digital financial innovation that enhances financial inclusion, efficiency, and access to green finance. Economic Growth signifies the expansion of economic activity that can provide resources for social and environmental development.

3.3. Model specification

This study addresses the association between green tax (GTX), fintech adoption (FIN), banking development (BAD), financial development (FD), economic growth (GDP), and on sustainable development (SD) in Bangladesh at time t, extending prior studies that have examined similar relationships [26,33]. Adopting the Cobb–Douglas production function framework [46], the study develops an econometric models to dynamically capture these relationships over time. The corresponding regression models utilized in this research can be specified as follows:

$$\mathrm{SD}_t = \beta_0 + \beta_1 \mathrm{GTX}_t + \beta_2 \mathrm{FIN}_t + \beta_3 \mathrm{BAD}_t + \beta_4 \mathrm{FD}_t + \beta_5 \mathrm{GDP}_t + \varepsilon_t \tag{1}$$

In model (1), the variable SD denotes sustainable development, measured by the Sustainable Development Index, which integrates economic, social, and environmental dimensions to assess a country's overall progress toward achieving the SDGs. This composite index serves as the dependent variable and provides a holistic measure of long-term national well-being and ecological balance. GTX refers to green tax, expressed as a percentage of GDP, representing fiscal instruments aimed at internalizing environmental externalities by taxing pollution or resource depletion. FD represents financial development, measured by a comprehensive Financial Development Index, which captures the depth, access, and efficiency of financial institutions and markets. BAD denotes banking development, quantified as the ratio of deposit money banks' assets to GDP (%), serving as a proxy for the role of banking systems in financing economic activities. FIN stands for fintech adoption, measured by the percentage of the population (ages 15 and above) with an account at a financial institution or with a mobile-money service provider. Finally, GDP denotes GDP per capita, measured in constant 2015 US dollars, which captures the average economic output per person, while $\in$ denotes the error term of the regression equation.

3.4. Econometric methodology

The econometric approach of the study utilizes the ARDL model to

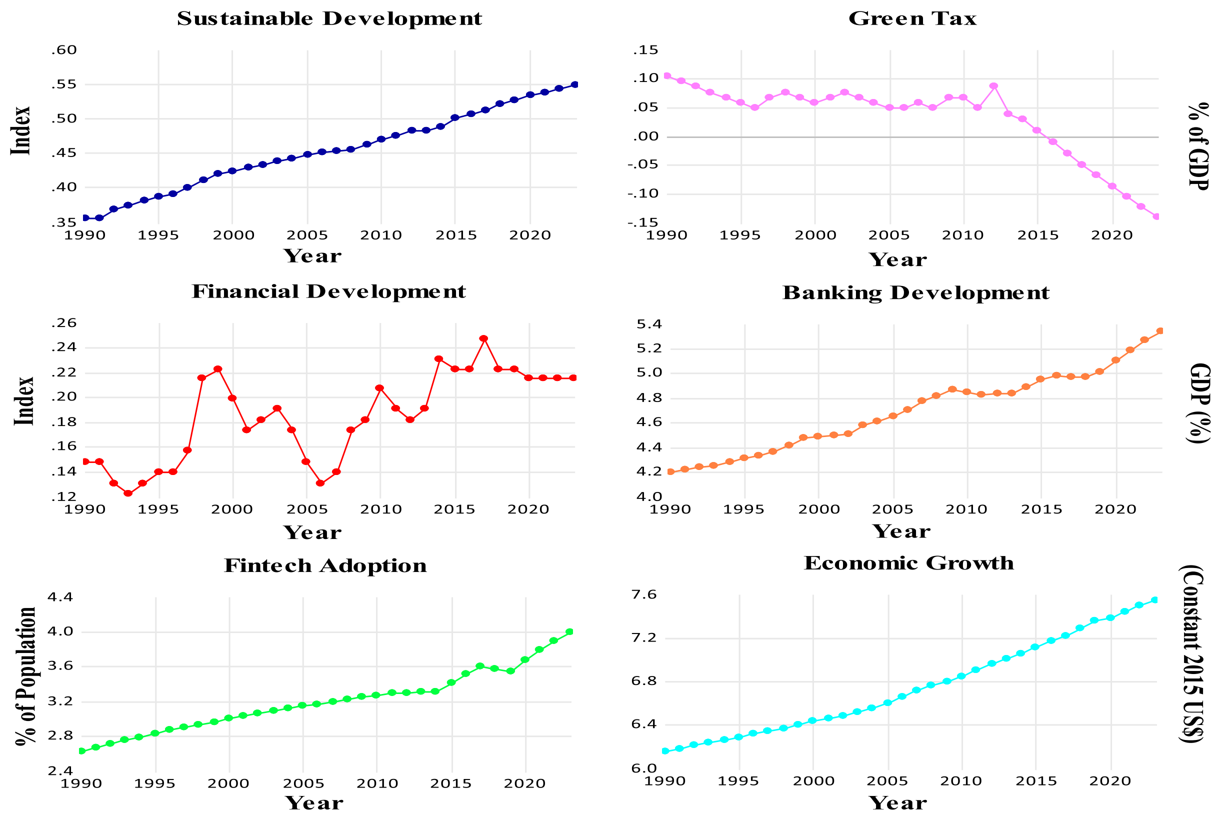

Fig. 1. Annual trends of the variables from 1990–2023.
Source: Authors' Illustration using STATA.

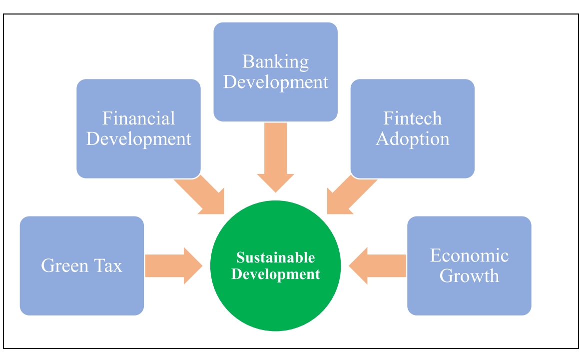

Fig. 2. The Conceptual Framework of the Study.
Source: Authors' Illustration.

reflect both short- and long-term interdependences of the variables. The ARDL bounds-testing framework is well-suited for small samples and mixed integration orders I(0)/I(1), whereas Johansen cointegration typically requires larger samples for stable inference and is sensitive to lag length and system specification. VAR-based approaches also focus on short-run dynamics and may be less efficient when the primary goal is to estimate interpretable long-run elasticities under cointegration. Given the sample size (34 annual observations), ARDL offers more reliable finite-sample performance while allowing simultaneous estimation of short-run adjustments and long-run relationships. It supports mix integration orders and small sample sizes and the robustness of the result is verified through FMOLS, DOLS and CCR estimates which also control for endogeneity, autocorrelation and offer believable and subtle glimpse into the financial–environmental sustainability nexus under consideration of the study. Some other essential pre-and-post estimation tests have been done for supporting the reliability of the results.

3.4.1. Unit root test

The integration of the data series should be examined prior to conducting a thorough analysis. In order to do this, the integration qualities of the series were assessed using unit root tests. First, the conventional unit root test, like the Dickey-Fuller Generalized Least Squares (DF-GLS) test put forth by Elliott et al. [47], which increases power by de-trending data prior to testing; the Phillips-Perron (PP) test put forth by Phillips & Perron [48], which corrects for heteroskedasticity and serial correlation without needing lag length specification; and the Augmented Dickey-Fuller (ADF) test proposed by Dickey & Fuller [49], which adds lagged differenced terms to account for higher-order serial correlation. However, if there are structural breakdowns in the series, the traditional unit root test could provide inaccurate findings. Because the ZA [50] unit root test may identify both stationary and a single structural break in data, it was also used in this investigation.

3.4.2. ARDL model

Once the stationarity of the data is confirmed, the study proceeds with estimation using the ARDL model. The ARDL method, commonly used in econometric studies, is employed to assess long-run cointegration among variables and examine the impact of explanatory variables on the dependent variable from both long- and short-run perspectives [51,52]. Following Pesaran et al. [53], the ARDL approach follows three key phases. The initial stage involves conducting a cointegration test using Eq. (2) along with a bound test, which is then followed by the estimation of the long-run ARDL model.

$$\Delta SD_t = \beta_0 + \beta_1 \Delta SD_{t-1} + \beta_2 \Delta GTX_{t-1} + \beta_3 \Delta FIN_{t-1} + \beta_4 \Delta BAD_{t-1} + \beta_5 \Delta FD_{t-1} + \beta_6 \Delta GDP_{t-1} + \sum_{i=1}^{p} \beta_{7i} \Delta SD_{t-i} + \sum_{i=1}^{p} \beta_{8i} \Delta GTX_{2t-i} + \sum_{i=1}^{p} \beta_{9i} \Delta FIN_{3t-i} + \sum_{i=1}^{p} \beta_{10i} \Delta BAD_{4t-i} + \sum_{i=1}^{p} \beta_{11i} \Delta FD_{5t-i} + \sum_{i=1}^{p} \beta_{12i} \Delta GDP_{6t-i} + \varepsilon_t \quad (2)$$

The Eq. (1) mentioned earlier, the value consigned to the drift parameter is represented by β_0. In the model equation, the symbol Δ represents the first difference estimates. Pesaran et al. [53] examined the long-run relationships by comparing the F-statistics with upper bound values. If the F-statistics exceeds this threshold, a persistent relationship exist. Once cointegration is affirmed, the model estimates long-run and short-run coefficients, with long-run values from Eq. (2) and short-run coefficients from following Eq. (3). The error correction model (ECM) then measures the adjustment speed towards equilibrium.

$$\Delta SD_t = \beta_0 + \beta_1 \Delta SD_{t-1} + \beta_2 \Delta GTX_{t-1} + \beta_3 \Delta FIN_{t-1} + \beta_4 \Delta BAD_{t-1} + \beta_5 \Delta FD_{t-1} + \beta_6 \Delta GDP_{t-1} + \sum_{i=1}^{p} \beta_{7i} \Delta SD_{t-i} + \sum_{i=1}^{p} \beta_{8i} \Delta GTX_{2t-i} + \sum_{i=1}^{p} \beta_{9i} \Delta FIN_{3t-i} + \sum_{i=1}^{p} \beta_{10i} \Delta BAD_{4t-i} + \sum_{i=1}^{p} \beta_{11i} \Delta FD_{5t-i} + \sum_{i=1}^{p} \beta_{12i} \Delta GDP_{6t-i} + \varphi ECM_{t-1} + \varepsilon_t \quad (3)$$

Where φ is recognized as the parameter that represents the pace at which adjustments occur, while ECM_{t-i} refers to the residual values of the estimated equation. This study employs an econometric framework to analyze time series data concerning green tax (GTX), fintech adoption (FIN), banking development (BAD), financial development (FD), economic growth (GDP), and on sustainable development (SD) in Bangladesh. Traditional methods like Vector Auto Regression (VAR), Engle-Granger causality, Ordinary Least Squares (OLS), and Johansen co-integration have limitations that might weaken the results. To address this concern, this study applies the Autoregressive Distributed Lag (ARDL) model, introduced by Pesaran et al. [53], which has been widely used to explore both long-run and short-run relationships [54]. The ARDL model is preferred for several reasons. First, it gives reliable results even with small data sets, unlike standard error correction models. Second, it allows for analyzing both long-run and short-run relationships at the same time using linear equations. Third, it works well with variables that are stationary at level I(0) or first difference I(1), affirmed by unit root tests, while avoiding variables that are stationary at second difference I(2), following [55]. These features help the ARDL model overcome the challenges faced by traditional methods. To choose the number of lags in the ARDL model, this study uses Akaike Information Criterion (AIC), which performs well in small samples by minimizing information loss while keeping a good balance between accuracy and simplicity [56,57]. Choosing lags based on AIC helps include the most important lag effects without making the model too complex, improving the quality of both long-run and short-run estimates [58]. The maximum lag length was set to 3 due to the small sample size, and the final ARDL specification was selected using AIC. Estimation was performed in Stata, and the bounds test used Pesaran et al. [53] critical values with standard small-sample caution. For instance, Kripfganz & Schneider [59] discusses the application of the ARDL model, which can be reparametrized into an error-correction form to disentangle long-run relationships from short-run dynamics.

3.4.3. *Robustness check*

This study employed “Fully Modified Ordinary Least Squares (FMOLS)” [60], “Dynamic Ordinary Least Squares (DOLS)’ [61] and “Canonical Cointegrating Regression (CCR)” [62] estimation approaches to examine the long run impact of GTX, FD, BAD, FIN and GDP on SD as a robustness check for the ARDL approach. The cointegration condition for parameters must be met before FMOLS, DOLS, and CCR can be utilized. FMOLS correct for endogeneity and serial correlation by applying semi-parametric adjustment, ensuring consistent and unbiased estimators in cointegrated systems. DOLS enhances estimation accuracy by incorporating leads and lags of differenced regressors, effectively mitigating endogeneity and serial correlation concerns. CCR transforms the data to eliminate endogeneity and serial correlation, providing reliable estimates of long-term parameters and serving as a robust framework for cointegration analysis [32].

3.4.4. *Diagnostic assessments*

This study employed several diagnostic tests to ensure the accuracy of the outcomes. The ARCH test [63] was used to detect heteroscedasticity, while the Ramsey RESET test [64] assessed specification errors. Serial correlation was investigated using the Durbin-Watson test [65], and the Jarque-Bera test [66] was employed to assess normality. Moreover, the stability of the estimated model was examined using the CUSUM and CUSUM square tests [55].

Table 2
Descriptive Statistics.

Variables	Obs.	Mean	Std. Dev.	Min	Max	Skew.	Kurt.
SD	34	0.240	0.071	0.160	0.406	0.949	2.487
GTX	34	1.172	0.179	0.842	1.454	0.002	1.795
FIN	34	3.202	0.353	2.626	3.994	0.401	2.504
BAD	34	4.696	0.322	4.204	5.341	0.100	1.997
FD	34	0.609	0.069	0.445	0.678	−1.213	3.180
GDP	34	2.046	0.055	1.969	2.145	0.280	1.773

Source: Authors’ Calculation using STATA.

Table 3
Unit root tests outcomes.

Variable	ADF		DF-GLS		PP	
	Level	1st Diff.	Level	1st Diff.	Level	1st Diff.
SD	−1.815	−5.375***	−1.371	−3.316*	−1.442	−7.046***
GTX	−2.999	−5.253***	−3.126*	−5.435***	−2.896	−5.573***
FIN	−1.066	−4.398***	−1.777	−4.357***	0.263	−3.339*
BAD	−2.493	−3.342*	−2.769	−3.417**	−1.739	−3.508**
FD	−0.867	−6.324***	−1.064	−4.333***	−0.244	−5.870***
GDP	−2.283	−4.477***	−0.892	−3.167*	−2.225	−4.505***

Note: The asterisk symbols (***, **, and *) are utilized for 1 %, 5 %, and 10 % significance levels, accordingly.
Source: Authors' Calculation using STATA.

4. Empirical results

4.1. Summary statistics

Table 2 displays the summary statistics for the variables SD, GTX, FIN, BAD, FD, and GDP. The mean values provide insight into the central tendency of the data, with SD emissions having a mean of 0.24 and BAD showing the highest mean of 4.69. The standard deviations highlight the level of variation, with FIN showing the greatest dispersion (3.35) and GDP the lowest (0.055). The skewness value suggests that most variables show a positive skew, indicating that their values tend to be concentrated on the lower end of the spectrum, with a longer tail on the right. The kurtosis values signify that FID has a leptokurtic distribution, as it exceeds a value of 3, while FIN tend to be closer to a normal distribution. These outcomes give a detailed view of the statistical characteristics, revealing diverse patterns of skewness and kurtosis that may influence further analysis.

4.2. Unit root test results

Table 3 presents the unit root test outcomes for the study variables using the ADF, DF-GLS, and PP tests. The results indicate that all the variables are non-stationary at I(0) but become stationary at I(1) across all tests. GTX is stationary at I(0) according to DF-GLS but is non-stationary at I(0) in ADF and PP, achieving stationarity at I(1). These outcomes indicate that the study variables exhibit a first-order integration, necessitating an econometric approach, such as the ARDL method, for further analysis.

4.3. Structural break unit root

The accuracy of time series forecasting and analysis relies on the assumption of stationarity, which implies that statistical properties such as mean, variance, and trend remain constant over time. A structural break occurs when these properties change abruptly within observed period, leading to inconsistencies in theoretical structure and forecasting errors. To determine such structural shifts, this study employed the Zivot-Andrews unit root test with intercept and trend. The result shown in Table 4 also indicated that GTX observed significant structural break in 2012 at the I(0). SD, GTX, FIN, FID, and GDP showed significant structural breaks in 2008, 2009, 2015, 2002, and 2005, respectively, at the I(1).

Table 4
Structural break tests outcomes.

Variables	Zivot-Andrews Structural Break			
	I(0)	Break Point	I(1)	Break Point
SD	−3.545	1996	−7.925***	2008
GTX	−4.635*	2012	−6.076***	2009
FIN	−0.237	2017	−5.959***	2015
BAD	−3.047	2013	−4.494	2010
FD	−1.614	1996	−6.085***	2002
GDP	−3.087	1996	−6.775***	2005

Note: The asterisk symbols (*** and *) are utilized for 1 % and 5 % significance levels, respectively.
Source: Authors' Calculation using STATA.

Table 5
ARDL bound test outcomes.

Test statistic	Value	Significance	I(0)	I(1)
F-statistic	11.098***	At 10 %	2.26	3.35
K	5	At 5 %	2.61	3.79
		At 1 %	3.41	4.68

Note: The asterisk symbol (***) is utilized for 1 % significance level.
Source: Authors' Calculation using STATA.

Table 6
Diagnostic tests outcomes.

Test	Null Hypothesis	Test Statistics	P-Value
ARCH heteroscedasticity test	Ho: Homoskedasticity	0.212 (F-statistic)	0.6484
B-G LM test	Ho: No serial correlation	0.367 (F-statistic)	0.6964
Jarque Bera/Normality	Ho: residuals have a normal distribution	5.380	0.067
Ramsey RESET test (F)	Ho: The model's functional form is valid	0.432 (F-statistic)	0.5173
Durbin-Watson value		1.296	
CUSUM		Stable	
CUSUM Square		Stable	

Note: 5 % significance level as the threshold for statistical decision-making.
Source: Authors' Calculation using STATA.

4.4. ARDL bound test

The ARDL bound test results are presented in Table 5, offering valuable insights into the cointegration among the examined variables. The F-statistic of 11.098 exceeds the upper critical bound; the outcomes confirm the presence of a cointegrating relationship among the variables.

4.5. Diagnostic test results

To ensure the accuracy and reliability of the ARDL error correction model, several diagnostic and stability tests were employed. These tests assessed homoscedasticity, heteroscedasticity, normality, serial correlation and model specification. The outcomes showed in Table 6 affirm that the model does not suffer from issues related to measurement errors, heteroscedasticity, serial correlation, or deviation from normality. This validates the credibility of the study's outcomes for drawing reliable conclusions. In addition, Fig. 3 illustrates the results of the CUSUM and CUSUM square tests, indicating that the blue line remains within the

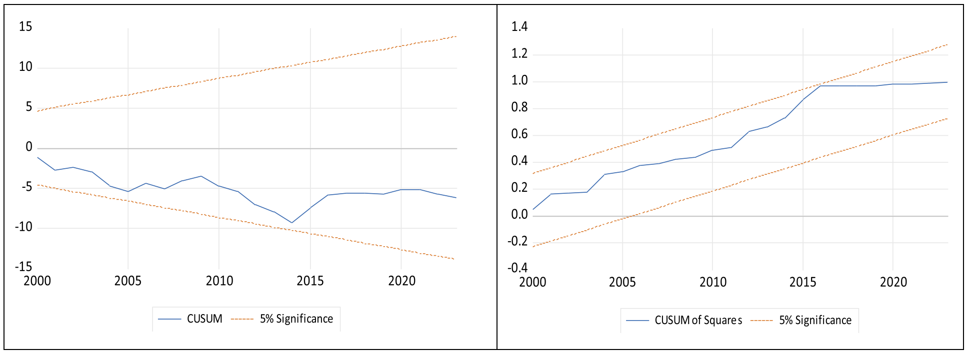

Fig. 3. CUSUM and CUSUM square tests.
Source: Authors' Illustration using STATA.

Table 7
ARDL long-run and short-run outcomes.

Variables	Long-Run Coeff.	Std. Err.	t-values
GTX	−0.115***	0.026	−4.423
FIN	0.056**	0.024	2.333
BAD	−0.146***	0.021	−6.952
FD	−0.573***	0.019	−30.158
GDP	0.446***	0.108	4.130
	Short-Run Coeff.	**Std. Err.**	**t-values**
D.GTX	0.182**	0.077	2.364
D.FIN	−0.186**	0.075	−2.480
D.BAD	0.209**	0.083	2.518
D.FD	1.982***	0.347	5.712
D.GDP	−7.101***	2.192	−3.240
ECT (Speed Adjustment)	−0.979***	0.409	−2.394
Constant	2.117**	0.704	
R^2	0.9337		

Note: (a) The asterisk symbols (***, **, and *) are utilized for 1 %, 5 %, and 10 % significance levels, accordingly; (b) Optimal lag selected by AIC criterion.
Source: Authors' Calculation using STATA.

red boundaries at the 5 % significance level.

4.6. ARDL long-run and short-run outcomes

ARDL long-run and short-run outcomes are shown in Table 7 and illustrate how different factors are linked to sustainable development in Bangladesh. In the case of GTX, the results reveal a significant negative long-term impact on sustainable development, where a 1 % increase in GTX reduces SD by 0.115 %. This suggests that over time, the financial burden imposed by green taxes may outweigh their environmental benefits, potentially discouraging investment and innovation in sustainability sectors. This negative long-run effect is consistent with the argument that environmental taxes may underperform where enforcement and recycling mechanisms are weak, potentially creating burdens without sustained green investment [18]. However, in the short run, D.GTX shows a positive and statistically significant effect on SD, with a 1 % increase in green tax resulting in a 0.182 % increase in sustainability. This implies that green taxes may initially incentivize environmentally responsible behavior and discourage pollution-intensive practices. This finding aligns with the evidence of Ma et al. [26], who argue that poorly designed environmental taxes can reduce economic competitiveness and distort investment incentives in developing economies. For Bangladesh, this highlights the importance of coupling green tax policies with supportive mechanisms such as green subsidies and technology grants to maintain both environmental and economic sustainability over time.

Regarding FIN, the study finds a positive long-run impact on SD, where a 1 % increase in FIN leads to a 0.056 % rise in sustainability, significant at the 5 % level. This indicates that digital financial services contribute to financial inclusion and efficient resource allocation, which are key drivers of sustainable development in the long term. In the short run, however, D.FIN has a negative impact on SD, with a 0.186 % decline following a 1 % increase in FIN. This could reflect short-term challenges such as regulatory gaps, digital illiteracy, or transitional disruptions in the financial sector. The result aligns with Kishor et al. [67], who noted that while fintech improves financial access and sustainability in the long term, initial stages may introduce instability. Therefore, for Bangladesh to harness fintech's full potential, it must focus on improving digital infrastructure, regulatory frameworks, and consumer protection mechanisms. The long-run positive effect aligns with the emerging "green fintech" and inclusion-sustainability literature emphasizing resource allocation efficiency and behavioral change channels [24,33]

For BAD, the long-run coefficient shows a significant negative impact on SD, where a 1 % increase in banking development leads to a 0.146 % decline in sustainable development. This outcome suggests that traditional banking in Bangladesh may prioritize profit-oriented or environmentally harmful investments over sustainable financing. The negative long-run impacts support findings that financial deepening can worsen ecological pressure when credit allocation favors carbon-intensive activity and ESG screening is limited [23,37]. Conversely, in the short run, D.BAD has a positive effect, with a 1 % increase contributing to a 0.209 % improvement in SD. This indicates that banking institutions may temporarily support sustainability through targeted credit or CSR programs, but lack a long-term green finance vision. The findings were reported by Tsindeliani et al. [37], who observed that in many developing countries, banks fail to integrate ESG (Environmental, Social, Governance) criteria into lending practices. Policymakers in Bangladesh should therefore promote sustainable banking reforms, including green loan policies, ESG disclosures, and incentives for financing eco-friendly businesses.

In terms of FD, the ARDL results demonstrate a strong negative long-run impact on SD, with a 1 % increase in financial development reducing sustainability by 0.573 %, which is highly significant. This implies that unchecked financial expansion may fuel activities detrimental to social and environmental well-being. The inverse long-run association support results that financial development may worsen ecological pressure when credit allocation favors carbon-intensive activity and ESG screening is limited [37]. However, the short-run results D.FD contrast sharply, as a 1 % increase in FD improves SD by 1.982 %. The immediate benefits may come from increased access to credit, capital mobilization, and investment in infrastructure, which temporarily boost sustainable development. Akhtar & Rashid [35] argue that in the absence of strong regulatory oversight, financial development can eventually lead to environmental degradation. To reverse this pattern, Bangladesh must reorient its financial system toward sustainability, encouraging the growth of green finance instruments such as ESG funds, green bonds,

Table 8
Outcomes from the robustness check.

Variables	FMOLS	DOLS	CCR
Dependent variable: SD			
GTX	−0.132***(0.008)	−0.264***(0.005)	−0.098***(0.007)
FIN	0.054***(0.006)	0.167***(0.005)	0.026***(0.004)
BAD	−0.392***(0.009)	−0.013***(0.005)	−0.275***(0.008)
FD	−0.461***(0.007)	−0.594***(0.005)	−0.481***(0.007)
GDP	0.703***(0.037)	0.128***(0.036)	0.484***(0.035)
Constant	0.934***(0.058)	1.276***(0.054)	0.897***(0.038)
R^2	0.8859	0.9927	0.9324

(a) The asterisk symbols (***) are utilized for 1 % significance levels.
Source: Authors' Calculation using STATA.

and sustainability-linked loans.

Finally, for GDP, the findings show a positive and significant long-run effect on sustainable development. A 1 % increase in GDP results in a 0.446 % rise in SD, suggesting that economic growth can provide the resources and fiscal capacity necessary for environmental investment and social progress. In the short run, however, D.GDP has a significant negative effect, where a 1 % rise leads to a 7.101 % reduction in SD. This striking short-term tradeoff may be attributed to rapid industrialization, environmental degradation, and overexploitation of natural resources during periods of accelerated growth. These results are aligned with the Environmental Kuznets Curve (EKC) hypothesis and supported by Armutcu et al. [42], who highlighted the dual nature of growth in developing economies. The short-run trade-off and long-run improvement is consistent with EKC-type reasoning and recent cross-country evidence showing growth can finance sustainability once policy and institutions support decoupling [39]. For Bangladesh, this underscores the urgent need to promote "green growth" strategies—investing in renewable energy, sustainable urbanization, and low-carbon technologies—to ensure that economic progress does not come at the cost of environmental and social sustainability.

4.7. Robustness check results

This study also applied several estimation methods, including FMOLS, DOLS, and CCR to verify the robustness of the ARDL outcomes. The outcomes from these methods are documented in Table 8 and the results demonstrate that GTX has a negative and statistically significant effect on Sustainable Development Index (SD) across all three estimation methods. This finding implies that green taxation is an effective policy tool for promoting sustainable development by potentially reducing environmentally harmful activities. FIN is found to have a positive and statistically significant impact on SD in all models, indicating that the expansion of financial technology supports sustainable development, possibly through improved financial inclusion, digital services, and efficient resource allocation. In addition, BAD shows a negative and significant association with SD under all estimation techniques, suggesting that current developments in the banking sector may not be aligned with sustainability objectives, potentially due to environmentally unfriendly lending practices or lack of green finance initiatives. However, FD consistently exhibits a negative and statistically significant relationship with SD, implying that while the financial sector is expanding, it may be contributing to unsustainable practices or is not sufficiently oriented toward green investments. Lastly, GDP demonstrates a positive and significant influence on SD across all three methods. This confirms the growth–sustainability nexus and indicates that economic expansion in Bangladesh is contributing positively to sustainable development, potentially through increased income, infrastructure development, and investments in human capital.

Overall, the robustness of the results across FMOLS, DOLS, and CCR confirms the consistency and reliability of the ARDL model findings. These outcomes underscore the complex but critical roles of fiscal policy, financial innovation, and economic development in shaping sustainable development in Bangladesh.

The DOLS specification includes leads and lags of differenced regressors to correct endogeneity and serial correlation; this design can inflate model fit (high R^2) and may introduce multicollinearity among regressors and their dynamic terms. Importantly, the direction (sign) and statistical significance of key variables remain consistent across FMOLS, DOLS, and CCR, supporting robustness. Differences in coefficient magnitudes (e.g., GTX and BAD across DOLS vs. FMOLS/CCR) reflect estimator-specific sensitivity to dynamic corrections rather than a reversal of inference; thus, interpretation emphasizes sign consistency and cross-estimator agreement.

5. Concluding remarks

5.1. Conclusion

This study contributes to the literature on sustainable development by analyzing the impact of green tax, fintech adoption, banking development, financial development, and economic growth on the Sustainable Development in Bangladesh—an area with limited empirical investigation. Employing ARDL, FMOLS, DOLS, and CCR techniques over the period 1990–2023, the findings offer robust insights into the financial and economic drivers of sustainability in a developing context.

The results reveal that GTX significantly enhances sustainability by reducing environmental pressure, while FIN has a positive influence on SD, suggesting that digital financial inclusion supports development goals. Conversely, BAD and FD negatively impact SD, indicating that current financial and banking practices may not align with environmental priorities. GDP has a positive contribution to SD, reaffirming the role of economic growth in advancing sustainable outcomes when paired with responsible policies.

Overall, the study highlights the importance of integrated strategies that leverage green taxation, responsible fintech, and sustainable financial development. The findings provide actionable guidance for policymakers in Bangladesh and similar economies to harmonize economic growth with long-term sustainability objectives.

5.2. Policy implications

This study has some policy recommendations that should be acknowledged. First, the negative relationship between green tax and SD confirms its role in promoting sustainability. Bangladesh should gradually expand the coverage of environmental taxes, starting with the most polluting sectors, such as brick kilns, tanneries, and transportation. Earmark a defined share of GTX revenues for green infrastructure and climate adaptation (e.g., flood protection, resilient agriculture, solar mini-grids in rural areas and urban waste management systems) and introduce targeted rebates or subsidies for low-income households and SMEs to address. To increase public and industrial compliance, the government must ensure transparency in tax use and provide incentives (e.g., tax rebates) for adopting cleaner technologies.

Second, the positive impact of fintech on SD suggests that digital finance can promote inclusive and sustainable economic activity. Bangladesh should expand its mobile banking and digital payment systems—especially in rural areas—linked with green microfinance options for solar panels, clean cook stoves, and sustainable farming practices. It is suggested to scale fintech-enabled green microfinance (solar home systems, clean cooking, climate-smart agriculture) using mobile platforms, agent banking, and digital credit scoring with consumer protection safeguards. Policy should also promote energy-efficient fintech infrastructure (e.g., low-power data centers), and digital financial literacy should be integrated into national education campaigns to reduce exclusion.

Third, the negative impact of banking development on SD indicates that traditional banking may still support unsustainable sectors. Bangladesh Bank should enforce green banking guidelines by strengthening the Green Banking Policy and requiring banks to report green asset ratios. It should also set enforceable ESG-linked lending targets (e.g., minimum green asset ratio) and require bank-level disclosure of green portfolio shares and sectoral carbon exposure, directly addressing the negative BAD coefficient. Soft loans or interest subsidies can be introduced for sustainable sectors (renewables, energy efficiency, agro ecology). Capacity-building for bank officers on green finance is crucial, especially in local branches that serve SMEs and agriculture.

Fourth, the adverse effect of financial development on SD suggests that financial flows may not be supporting green outcomes. Bangladesh should develop a green finance taxonomy and require financial institutions to report ESG-aligned investment ratios. It is also recommended to develop and operationalize a national green taxonomy and strengthen green bond/sustainability-linked instruments so financial deepening shifts away from carbon-intensive expansion—addressing the negative FD coefficient. The government can encourage the development of a domestic green bond market with sovereign backing and create public-private risk-sharing mechanisms for green projects. Redirecting financial incentives toward clean sectors—especially energy, housing, and transport—can guide the financial system toward sustainability.

Lastly, the positive association between GDP and SD supports the potential for green growth. Bangladesh should integrate sustainability into its 5-year plans, focusing on green industrialization, energy efficiency, and eco-tourism. Investment should be focused on sectors that create jobs and improve the environment, such as waste recycling, solar power, and climate-smart agriculture. Public-private investment models and clear green procurement policies can help align economic growth with sustainability. Thus, the results explicitly align green tax recycling, green credit targets, and fintech-enabled green finance programs with Bangladesh's Nationally Determined Contributions (NDC) under the Paris Agreement to ensure measurable mitigation and adaptation outcomes.

5.3. Limitations and future research direction

Despite the robustness of the results, this study has certain limitations. This study has several limitations. First, fintech adoption is proxied by account ownership and mobile-money usage, which captures national-level digital financial diffusion rather than frontier fintech innovation; future work could use fintech transaction intensity, digital credit volumes, or fintech investment indicators where available. Second, the analysis relies on a composite sustainable development index. Third, the annual sample size limits complex nonlinear modeling.

Future research should explore panel data across South Asian countries to enable comparative analysis and capture cross-country heterogeneity. Additionally, incorporating environmental quality indicators such as water pollution, biodiversity loss, and climate resilience could offer a more comprehensive view of sustainable development. Future research could test alternative sustainability measures (e.g., ecological footprint, CO_2 intensity, or SDG-specific subindices) to assess indicator sensitivity. Future studies may also apply threshold ARDL, asymmetric specifications, or structural break models to test whether policy reforms (e.g., green banking guidelines) change the slope of finance–sustainability relationships over time. The study is limited to Bangladesh, and the findings may not be directly generalizable to other developing countries with different financial and institutional structures. Finally, sectoral decomposition (industry, transport, agriculture) could identify where banking and financial development most strongly drive sustainability outcomes.

Ethical approval

Not applicable.

Funding statement

The research did not receive any funding from any individual or organization.

Data availability

Data will be made available upon reasonable request.

Consent for publication

N/A

CRediT authorship contribution statement

Rejaul Karim: Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Md. Amdadul Hoque:** Writing – review & editing, Writing – original draft, Visualization, Investigation, Conceptualization. **Rosli Mahmood:** Validation, Software, Resources, Methodology, Formal analysis, Data curation. **Reday Chandra Bhowmik:** Writing – original draft, Software, Resources, Methodology, Formal analysis, Conceptualization. **Sohidul Islam:** Writing – review & editing, Project administration, Investigation, Funding acquisition, Data curation. **Sharmila Devi Ramachandaran:** Writing – review & editing, Methodology, Funding acquisition.

Declaration of competing interest

No potential conflict of interest was reported by the authors.

References

[1] Bangladesh Bank, Sustainable Finance Policy for Banks and Financial Institutions, Bangladesh Bank, Dhaka, 2020.
[2] G.H. Brundtland, Our common future—Call for action, Environ. Conserv. 14 (4) (1987) 291–294.
[3] M. Sadiq, M.A. Amayri, C. Paramaiah, N.H. Mai, T.Q. Ngo, T.T.H. Phan, How green finance and financial development promote green economic growth: deployment of clean energy sources in South Asia, Environ. Sci. Poll. Res. 29 (43) (2022) 65521–65534, https://doi.org/10.1007/s11356-022-19947-9.
[4] United Nations Development Programme, UNDP annual report 2021, May 4, UNDP, 2022, https://www.undp.org/publications/undp-annual-report-2021.
[5] M.A.I. Gazi, H. Islam, M.A. Islam, R. Karim, S.M. Momo, A.R.B.S. Senathirajah, Unlocking sustainable development in East Asia Pacific and South Asia: an econometric exploration of ESG initiatives, Sustain. Environ. 10 (1) (2024) 66, https://doi.org/10.1080/27658511.2024.2366558.
[6] P. Gomber, R.J. Kauffman, C. Parker, B.W. Weber, On the Fintech revolution: interpreting the forces of innovation, disruption, and transformation in Financial services, J. Manage. Inf. Syst. 35 (1) (2018) 220–265, https://doi.org/10.1080/07421222.2018.1440766.
[7] U. Volz, Fostering green finance for sustainable development in Asia. Routledge Handbook of Banking and Finance in Asia, Routledge, 2018, pp. 488–504.
[8] G.W. Zheng, A.B. Siddik, M. Masukujjaman, N. Fatema, Factors affecting the sustainability performance of financial institutions in Bangladesh: the role of green finance, Sustainability 13 (18) (2021) 10165, https://doi.org/10.3390/su131810165.
[9] S. Islam, Md.M. Roshid, R. Chandra Bhowmik, B.K. Dhar, A. Raihan, R. Karim, Policy pathways for renewable energy, health, and sustainability in sub-saharan Africa: an empirical assessment of energy access and life expectancy, Energy Policy 206 (2025) 114801, https://doi.org/10.1016/j.enpol.2025.114801.
[10] A.K. Sarker, A.K. Azad, M.G. Rasul, A.T. Doppalapudi, Prospect of green hydrogen generation from hybrid renewable energy sources: a review, Energies (Basel) 16 (3) (2023) 1556, https://doi.org/10.3390/en16031556.
[11] Bangladesh Bank, Policy on Green Bond Financing for Banks and Financial Institutions, Bangladesh Bank, Dhaka, 2022.
[12] M.S. Uddin, C.E. Haque, D. Walker, M.U.I. Choudhury, Community resilience to cyclone and storm surge disasters: evidence from coastal communities of Bangladesh, J. Environ. Manage. 264 (2020) 110457.
[13] A. Demirguc-Kunt, L. Klapper, D. Singer, S. Ansar, J. Hess, The Global Findex Database 2017: Measuring Financial Inclusion and the Fintech Revolution, World Bank Publications, 2018.
[14] Z. Chen, Md.M. Hossen, S.S. Muzafary, M. Begum, Green Banking for environmental Sustainability-present status and future agenda: experience from Bangladesh, Asian Econ. Finan. Rev. 8 (5) (2018) 571, https://doi.org/10.18488/journal.aefr.2018.85.571.585.

[15] Md.M. Roshid, S. Saiyed, R. Karim, T. Haque, Md.S.R. Siddique, Md.A. Haque, V. Kumar, S.Bin Habib, The role of green entrepreneurship in driving sustainable innovation in Bangladesh's startup ecosystem: insights from a belt and road emerging market, Environ. Innov. Manage. 01 (2025) 2550010, https://doi.org/10.1142/S3060901125500103.

[16] KPMG (2021). KPMG P/S Annual Report, 1 October 2020–30 September 2021. https://assets.kpmg.com/content/dam/kpmgsites/dk/pdf/2022/dk-KPMG-annual-report-2021.pdf.coredownload.inline.pdf.

[17] A.P.J. Mol, G. Spaargaren, Ecological modernisation theory in debate: a review, Env. Polit. 9 (1) (2000) 17–49.

[18] H. Liu, M.W. Zafar, A. Sinha, I. Khan, The path to sustainable environment: do environmental taxes and governance matter? Sustain. Dev. 31 (4) (2023) 2278–2290, https://doi.org/10.1002/sd.2505.

[19] R. Zhu, H. Islam, M. Rana, K. Rahman, R. Karim, T. Chakrobortty, Md.M. Rahman, Towards sustainable development: how resource depletion, emissions, and renewable energy shape progress in OECD nations, Air Qual. Atmos. Health (2025), https://doi.org/10.1007/s11869-025-01774-9.

[20] R.P. Buckley, D.A. Zetzsche, D.W. Arner, R. Veidt, FinTech, financial inclusion and the UN Sustainable Development Goals. Routledge Handbook of Financial Technology and Law, Routledge, 2021, pp. 247–272.

[21] L. Jamel, S. Maktouf, The nexus between economic growth, financial development, trade openness, and CO2 emissions in European countries, Cogent Econ. Finan. 5 (1) (2017) 1341456, https://doi.org/10.1080/23322039.2017.1341456.

[22] R. Levine, in: P. Aghion, S.N.B.T.H.of E.G. Durlauf (Eds.), Chapter 12 Finance and Growth: Theory and Evidence, Chapter 12 Finance and Growth: Theory and Evidence, 1, Elsevier, 2005, pp. 865–934, https://doi.org/10.1016/S1574-0684(05)01012-9.

[23] M.A. Destek, S.A. Sarkodie, Investigation of environmental Kuznets curve for ecological footprint: the role of energy and financial development, Sci. Total Environ. 650 (2019) 2483–2489, https://doi.org/10.1016/j.scitotenv.2018.10.017.

[24] S. Geetha, A.V.B. Nair, Is green fintech reshaping the finance sphere? Environ. Sci. Poll. Res. 31 (15) (2024) 18123–18138, https://doi.org/10.1007/s11356-023-31234-5.

[25] World Bank. (2019). Options for a Carbon Tax in Bangladesh: A Policy Note. Washington, DC: World Bank.

[26] Z. Ma, J. Zhao, J. Ni, Green tax legislation for sustainable development in China, Singap. Econ. Rev. 63 (04) (2018) 1059–1083, https://doi.org/10.1142/S0217590817420103.

[27] D. Mhlanga, Prospects and challenges of digital financial inclusion/fintech innovation in the fourth industrial revolution, Digital Financial Inclusion: Revisiting Poverty Theories in the Context of the Fourth Industrial Revolution (2022) 163–182, https://doi.org/10.1007/978-3-031-16687-7_9.

[28] B. Ouvrard, J. Abildtrup, G. Bostedt, A. Stenger, Determinants of forest owners attitudes towards wood ash recycling in Sweden-can the nutrient cycle be closed? Ecol. Econ. 164 (2019) 106293.

[29] H.K. Sing, N. Sritharan, L.L.H. Ngui, Impacts of environmental taxes on sustainable development goals: balancing environment and equity, J. Tax Reform 11 (1) (2025) 175–199, https://doi.org/10.15826/jtr.2025.11.1.197.

[30] A. Raza, A.B. Alavi, L. Asif, Sustainability and financial performance in the banking industry of the United Arab Emirates, Discov. Sustain. 5 (1) (2024) 223, https://doi.org/10.1007/s43621-024-00414-z.

[31] F. Alsulami, A. Raza, Sustainable accounting and energy choices: emission impacts in BRICS+ economies 2024, Discov. Sustain. 6 (1) (2025) 935, https://doi.org/10.1007/s43621-025-01870-x.

[32] L.C. Voumik, M. Ridwan, M. Hasanur Rahman, A. Raihan, An investigation into the primary causes of carbon dioxide releases in Kenya: does renewable energy matter to reduce carbon emission? Renewable Energy Focus 47 (September) (2023) 100491 https://doi.org/10.1016/j.ref.2023.100491.

[33] Y. Zhang, J. Chen, Y. Han, M. Qian, X. Guo, R. Chen, D. Xu, Y. Chen, The contribution of Fintech to sustainable development in the digital age: ant forest and land restoration in China, Land Use Policy 103 (2021) 105306, https://doi.org/10.1016/j.landusepol.2021.105306.

[34] S.S. Huda, R.R. Rimthi, T. Islam, S.M. Mowla, Adoption of cashless economy in Bangladesh, J. Inf. Tech. Teach. Cases (2024), https://doi.org/10.1177/20438869241279586.

[35] N. Akhtar, A. Rashid, Financial development and sustainable development: a review of literature, Sustain. Dev. 32 (6) (2024) 7114–7139, https://doi.org/10.1002/sd.3068.

[36] M. Ali, M. Seraj, F. Türüç, T. Tursoy, A. Raza, Do banking sector development, economic growth, and clean energy consumption scale up green finance investment for a sustainable environment in South Asia: evidence for newly developed RALS co-integration, Environ. Sci. Poll. Res. 30 (25) (2023) 67891–67906, https://doi.org/10.1007/s11356-023-27023-z.

[37] I.A. Tsindeliani, M.M. Proshunin, T.D. Sadovskaya, Z.G. Popkova, M.A. Davydova, O.A. Babayan, Digital transformation of the banking system in the context of sustainable development, J. Mon. Laund. Cont. 25 (1) (2022) 165–180, https://doi.org/10.1108/JMLC-02-2021-0011.

[38] N. Sultana, S. Shoha, M.S.A. Dolon, S.A. Al Shiam, R.M. Zakaria, A.H. Shimanto, S. I. Abir, Machine learning solutions for predicting stock trends in BRICS amid global economic shifts and decoding market dynamics, J. Econ. Finan. Account. Stud. 6 (6) (2024) 84–101, https://doi.org/10.32996/jefas.2024.6.6.7.

[39] N. Teixeira, R. Rodrigues, A. Rodrigues, Economic growth and environmental sustainability in more and less sustainable countries, Discov. Sustain. 6 (1) (2025) 1–15, https://doi.org/10.1007/s43621-025-01546-6.

[40] R. Karim, R.C. Bhowmik, M.O. Faruq, M.M. Roshid, S. Islam, S.D. Ramachandaran, Harnessing growth for ecological sustainability through exploring the drivers of load capacity factor in G7 nations, Discov. Sustain. 6 (1) (2025) 1–23, https://doi.org/10.1007/s43621-025-01757-x.

[41] A. Raza, M. Ali, T. Tursoy, M. Seraj, Y.O. Habeeb, Evaluating the Scandinavian economy's transition to a sustainable environment. Fresh evidence from newly developed CS-ARDL approach, Resour. Pol. 89 (2024) 104566, https://doi.org/10.1016/j.resourpol.2023.104566.

[42] B. Armutcu, R. Zuferi, A. Tan, Green product consumption behaviour, green economic growth and sustainable development: unveiling the main determinants, J. Enterp. Comm. Peop. Plac. Glob. Econ. 18 (4) (2024) 798–819, https://doi.org/10.1108/JEC-05-2023-0074.

[43] WDI. (2023). World Development Indicators. https://www.worldbank.org/ext/en/home.

[44] SDI. (2023). Sustainable Development Index. https://www.sustainabledevelopmentindex.org/.

[45] International Monetary Fund (IMF). (2023). https://www.imf.org/en/Home.

[46] C.W. Cobb, P.H. Douglas, A theory of production, Am. Econ. Rev. 18 (1) (1928) 139–165.

[47] G. Elliott, T.J. Rothenberg, J.H. Stock, Efficient Tests for an Autoregressive Unit Root, National Bureau of Economic Research, Cambridge, Mass., USA, 1992.

[48] P.C.B. Phillips, P. Perron, Testing for a unit root in time series regression, Biometrika 75 (2) (1988) 335–346, https://doi.org/10.1093/biomet/75.2.335.

[49] D.A. Dickey, W.A. Fuller, Distribution of the estimators for autoregressive time series with a unit root, J. Am. Stat. Assoc. 74 (366a) (1979) 427–431.

[50] E. Zivot, D.W.K. Andrews, Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis, J. Busi. Econ. Stat. 10 (3) (1992) 251–270, https://doi.org/10.1080/07350015.1992.10509904.

[51] T.P. Nguyen, T.T.T. Duong, Asymmetric Effects of Fiscal Policy and Foreign Direct Investment Inflows on CO2 Emissions–an Application of Non-Linear Ardl (2025).

[52] A. Raihan, M. Ridwan, G. Zimon, J. Rahman, T. Tanchangya, A.M. Bari, F. G. Atasoy, A.I. Chowdhury, R. Akter, Dynamic effects of foreign direct investment, globalization, economic growth, and energy consumption on carbon emissions in Mexico: an ARDL approach, Innov. Green Dev. 4 (2) (2025) 100207, https://doi.org/10.1016/j.igd.2025.100207.

[53] M.H. Pesaran, Y. Shin, R.J. Smith, Bounds testing approaches to the analysis of level relationships, J. Appl. Econ. 16 (3) (2001) 289–326, https://doi.org/10.1002/jae.616.

[54] U.K. Pata, S. Karlilar, M.T. Kartal, On the road to sustainable development: the role of ICT and R&D investments in renewable and nuclear energy on energy transition in Germany, Clean. Technol. Environ. Policy 26 (7) (2024) 2323–2335.

[55] R.L. Brown, J. Durbin, J.M. Evans, Techniques for testing the constancy of regression relationships over time, J. R. Stat. Soc. Ser. B Stat. Method. 37 (2) (1975) 149–163, https://doi.org/10.1111/j.2517-6161.1975.tb01532.x.

[56] P.K. Narayan, The saving and investment nexus for China: evidence from cointegration tests, Appl. Econ. 37 (17) (2005) 1979–1990, https://doi.org/10.1080/00036840500278103.

[57] M.H. Pesaran, Y. Shin, An Autoregressive Distributed Lag Modelling Approach to Cointegration Analysis 9514 (1995).

[58] J. MacCarthy, The effect of sustainability reporting on the firm's value: application of panel autoregressive distributed lag (ARDL) approach, J. Afr. Busi. (2025) 1–40.

[59] S. Kripfganz, D.C. Schneider, ardl: estimating autoregressive distributed lag and equilibrium correction models, Stata J. 23 (4) (2023) 983–1019.

[60] P.C.B. Phillips, B.E. Hansen, Statistical inference in instrumental variables regression with i(1) processes, Rev. Econ. Stud. 57 (1) (1990) 99–125, https://doi.org/10.2307/2297545.

[61] J.H. Stock, M.W. Watson, A simple estimator of cointegrating vectors in higher order integrated systems, Econometrica 61 (4) (1993) 783, https://doi.org/10.2307/2951763.

[62] J.Y. Park, Canonical cointegrating regressions, Econometrica 60 (1) (1992) 119, https://doi.org/10.2307/2951679.

[63] R.F. Engle, Autoregressive conditional heteroscedasticity with estimates of the variance of United Kingdom inflation, Econometrica 50 (4) (1982) 987, https://doi.org/10.2307/1912773.

[64] J.B. Ramsey, Tests for specification errors in classical linear least-squares regression analysis, J. R. Stat. Soc. Ser. B Stat. Method. 31 (2) (1969) 350–371, https://doi.org/10.1111/j.2517-6161.1969.tb00796.x.

[65] J. Durbin, G.S. Watson, Testing for serial correlation in least squares regression. III, Biometrika 58 (1) (1971) 1–19.

[66] C.M. Jarque, A.K. Bera, Efficient tests for normality, homoscedasticity and serial independence of regression residuals, Econ. Lett. 6 (3) (1980) 255–259, https://doi.org/10.1016/0165-1765(80)90024-5.

[67] K. Kishor, S.K. Bansal, R. Kumar, The role of fintech in promoting financial inclusion to achieve sustainable development: an integrated bibliometric analysis and systematic literature review, J. Know. Econ. 16 (1) (2025) 5664–5692, https://doi.org/10.1007/s13132-024-02168-5.