Advance Journal of Econometrics and Finance
Vol-3, Issue-1, 2025

Advance Journal of Econometrics and Finance
Online ISSN
2959-8990
Print ISSN
2959-8982
https://ajeaf.com/index.php/Journal/About

Name of Publisher: SCHOLAR CRAFT EDUCATION & RESEARCH HUB
Review Type: Double Blind Peer Review
Journal Frequency: Quarterly Research Journal

Striving Towards Sustainable Development in Middle-Income Economies: The Effect of Financialization and Energy Innovation on Ecological Footprint

Aisha Imtiaz[1], Muhammad Asad Ali[2], Nasir Abbas[3*], Shahid Munir[4]

Aisha Imtiaz
Assistant Professor, Government College Women University. Faisalabad, Punjab, Pakistan. aisha.Imtiaz@hotmail.com
Muhammad Asad Ali
Department of Commerce Bahauddin Zakariya University Multan, Pakistan. autocratasad@gmail.com
Nasir Abbas*
Lecturer College of Commerce Government College University Faisalabad. Corresponding Author Email: nasirabbas@gcuf.edu.pk
Shahid Munir
Lecturer Department of Public Administration Government College University Faisalabad. shahidmunir@gcuf.edu.pk

Corresponding Author*

Abstract

Purpose-This study examines how financial development, financial technology (fintech), and green-energy innovation influence the ecological footprint of middle-income countries from 2000 to 2023, thereby illuminating the channels through which economic and technological progress can either undermine or support environmental sustainability.

Methodology-Using annual panel data for a wide sample of middle-income economies, the analysis conducts standard diagnostics that reveal cross-sectional dependence, heterogeneous slope behavior, and long-run cointegration. It then applies Method-of-Moments Quantile Regression (MMQR) to estimate effects across the full conditional distribution of ecological footprints (0.10–0.90 quantiles) and validates the results with quantile-specific Wald tests and alternative estimators. **Findings**-Financial development enlarges ecological footprints between the 0.10 and 0.70 quantiles, while fintech exerts a comparable expansionary influence at every quantile except 0.10. Economic growth intensifies environmental pressure uniformly across all quantiles, underscoring the persistence of growth-driven ecological costs. In contrast, existing green-energy policies show no statistically significant mitigation of these impacts. Robustness checks confirm the direction of these relationships, although effect sizes vary along the distribution.

Novelty-By integrating fintech and green-energy innovation into an MMQR framework, this work is the first to expose distribution-specific environmental effects of these drivers in middle-income contexts, revealing nuances that conventional mean-based estimators' obscure.

Implications-Policymakers should link financial and technological expansion to stringent environmental regulation and a carefully managed energy transition, recognizing that the ecological consequences of financial development vary across economies. Tailored, quantile-sensitive interventions rather than uniform measures are essential for decoupling economic advancement from environmental degradation and for leveraging fintech and green innovation to achieve genuinely sustainable growth.

Keywords:	Financial Development, Financial Technology, Green Energy Innovation, Ecological Footprint, MMQR

Introduction

Earth's atmosphere is a protective blanket that plays a significant role in sustaining and preserving life on the planet (Kenawy et al., 2025). However, over the preceding few decades, the Earth's average temperature has been rising significantly, causing sea levels to rise, species to become extinct drastically, decreasing ice and snow cover, violent weather conditions, and other critical disasters (Athari, 2024). Climate change imperatives, sustainability mandates, global and local conflicts, and regulations have compelled economies to realign their goals towards an environmentally conscious growth model. The economic growth of all economies worldwide depends mainly on the use of natural resources (Afzal et al., 2025), which are insufficient to meet the growing needs of people. Probing the cumulative impact on the ecosystem because of human utilization of natural resources is termed an ecological footprint (EFT) (Wackernagel and Rees, 1996) which determines the required expanse of amenable ocean and land to meet human requirements, and can also absorb the decay and waste ensuing from the activities of individuals (Mathis Wackernagel et al., 2002).

To develop the infrastructure of a country and flourish its manufacturing operations, the growing usage of material resources is crucial (Manigandan et al., 2024). However, this has given rise to various adverse effects. Efficient utilization of resources is both lively and crucial for policymakers from environmental, social, and economic perspectives (Z. Wang et al., 2025). Scientific research substantiates that global climate change exerts a substantially detrimental influence on poor nations compared to high-income countries (Afzal & Rahman, 2025) because of their solidified financial systems, technological advancements, better resources, and resilient institutional structures. Therefore, they offer valuable perspectives in addressing the issue of climate change compared with middle-income countries that are going through a transitional phase with significant economic progress and urbanization.

As climate change and environmental deterioration are prevalent global phenomena in the 21st century and have emerged as an undeniable pain for policymakers, international organizations, like the UN, have set up multiple events and implemented numerous initiatives to tackle environmental degradation on a global scale. For instance, the UN’s 2030 Agenda, adopted in 2015 along with its 17 goals relating to Sustainable Development (SDG’s), having 169 targets and 232 indicators, represents the most extensive worldwide political endeavor aimed at attaining sustainable development (Nations, 2015). Similarly, the “Paris Agreement” was signed in 2015 at the UN Conference regarding Environment (COP21). The participating parties attained a consensus to reach a maximum global warming limit of 2°C above the preindustrial level, ideally 1.5°C (Laksevics et al., 2025).

Research evaluates fintech, financial development, and energy innovation for measuring national capacities to achieve Sustainable Development in middle-income economies. These middle-income countries have shown improved performance regarding their SDG targets, yet environmental objectives raise the most difficulties during their advancement process. The implementation of SDG 15 regarding sustainable land ecosystems has not achieved the expected results since regional forest protection efforts have proved unsuccessful (Udeagha & Breitenbach, 2023). Solar energy, along with wind and hydropower, are clean energy sources that have entered the region, but their usage and transmission systems still function poorly. Renewable energy intake in middle-income nations decreased substantially during the study period. These middle-income countries work continuously to fulfil the SDGs set by the UN, yet much more improvement remains essential.

One of the strategies considered effective for improving ecological quality is the advancement of financial systems. Financial development (FID) empowers organizations and administrations to implement ecologically efficient technologies and can trim harmful emissions, and consequently boost environmental quality (Sajid et al., 2025). Financial technologies pertain to the integration of artificial intelligence, online banking, mobile payments, blockchain, cryptocurrency, and others within the monetary industry, thereby instigating a transformative impact on financial services (Sadiq et al., 2024). With the increase in financial advancement, GDP has increased, causing the demand for energy to rise. Thus, Innovations in green energy are crucial for sustainability because they make it possible to transform fossil fuels into clean energy sources. Economies that engage in fossil fuel usage, along with other traditional sources of energy, are liable to contribute to environmental deterioration and threats to human beings (Iqbal et al., 2024). Innovations in the energy sector include the development and use of techniques and technology to eliminate adverse ecological impacts. Sources of green energy, such as geothermal, hydropower, wind, and solar, have the potential to supply a significant fraction of the universal energy requirements. To expedite economic growth while minimizing negative impacts on a country’s atmosphere, prudent ecological regulations are crucial (Afzal et al., 2025).

Environmental sustainability and climate change have been acknowledged as pressing and multifaceted global tasks that have significant impacts on various aspects of environmental, socio-political, and socio-economic disciplines (Elgharib, 2024). Ecological deterioration not only presents risks to human well-being, but also to the stability and efficacy of financial systems (Kouwenberg & Zheng, 2023). The impact of FID and FIT on environmental quality has generated contradictory results. Some researchers have revealed that FID results in increased environmental degradation. However, others have reported that FID results in a reduction in environmental deterioration (Sajid et al., 2025).

Similarly, fintech (FIT) either amplifies or diminishes the ecological footprint (EFT). This implies that the specific impact of FID and FIT climate change among OECD economies remains uncertain. The production and utilization of non-renewable energy systems have detrimental impacts on the climate, resulting in adverse consequences for human well-being and marine ecosystems, which necessitates innovation in the energy sector (Rahman et al., 2024). But in earlier studies, the effect of green energy innovation on climate change has been overlooked, specifically among OECD economies

Despite the extensive academic discourse concerning the optimal alternative to mitigate environmental degradation, a plethora of literature has examined the role of the ecological footprint as a potential substitute for environmental damage. However, it is pertinent to understand that considering ecological footprint as the sole measure of environmental degradation can often be misleading, as it fails to account for the impact of humans on land extraction. It is also pointed out that a majority of studies have focused on individual countries, such as India (Manigandan et al., 2024), China (Z. Wang et al., 2025), South Africa (Udeagha & Breitenbach, 2023), and Pakistan (Iqbal et al., 2024) or investigated particular regions like the BRICS economies (Athari, 2024), MENA countries (Elgharib, 2024), E-7 economies (Liang et al., 2024), OECD countries (Appiah et al., 2024), G-7 economies (Yin et al., 2025), APEC economies (Balli et al., 2024), EU and Asian economies (Horky & Fidrmuc, 2024). Since climate change has significant global implications, resulting in severe consequences varying among various countries, this study focuses on middle-income economies for policymaking.

Environmental degradation manifests as the depletion of natural resources, global warming, and conventional economic growth models that threaten global economies. Carbon dioxide emissions serve as a primary source of greenhouse gas production, which threatens human health and the ecological system within the environmental damage scenario (Mehmood et al., 2025). The abundance of accessible data has enabled multiple scientific studies to leverage carbon emission measures as indicators of environmental pollution. The carbon emissions framework faces criticism because it primarily demonstrates how environmental costs affect economic development. In addition, single measurements of carbon emissions fail to capture the full spectrum of environmental concerns. Rees presented the ecological footprint (EFT) as a foundational measure of climate change that addresses broader concerns beyond traditional methods. Insights from ecological footprints have continued to find broad acceptance across research fields (Abdullahi et al., 2024).

Ecological footprint assessment offers a more accurate view of ecological degradation through its wide-ranging examination of both ecological pollution and human planetary impacts by measuring carbon footprints along with grazing land, built-up areas, crop areas, oceans, and forests. Higher ecological footprints indicate deteriorating environmental sustainability because they represent resource demands that exceed natural limits. Hence, EFT is considered a suitable measure to ensure sustainability in middle-income economies. An understanding of the association among environmental indicators, such as ecological footprints, financial development, financial technologies, and green energy innovations, is essential among middle-income economies.

Literature Review

Theoretical Foundation

Within the framework of environmental sustainability, the interplay between the advancement of financial institutions and markets, innovation in financial technologies, and economic expansion holds crucial significance in determining the shift towards a sustainable future. This connection is consistent with the “Environmental Kuznets Curve (EKC) theory”**.** Applying the EKC theory, which entails decoupling GDP from ecological degradation, requires the imperative development of green technological innovation**.** The EKC phenomenon was initially identified by Kuznets (Kuznets, 2019), who observed an inverted U-shaped association of economic growth with the environment. Considering the EKC hypothesis, during the initial phase of growth, per capita income rises, contributing to higher emissions and exerting a negative effect on the climate. Nevertheless, once a specific point is attained, subsequent income rises, resulting in a decline in climate change and exerting a constructive outcome on the environment. Financial advancement leads to investment opportunities, and this phenomenon has been boosted by financial technology (Yan et al., 2025). Technological advancement helps in allocating capital, progressing green innovation in the energy sector, and ultimately enhancing environmentally friendly processes. The variables in this study are based on the EKC theory to achieve sustainability along with economic growth.

Financial Development (FID) and Ecological Footprint (EFT)

Over the past few decades, there has been a notable surge in the consideration and focus of researchers, academics, economists, and policymakers toward financial development (FID) to scrutinize the interplay between FID and EFT, employing various variables and methodologies (Horky & Fidrmuc, 2024). Advances in financial institutions and the environment may be either advantageous or detrimental to ecological sustainability (Kouwenberg & Zheng, 2023). Financial development has several positive implications for a nation's financial framework, including the establishment of financial channels, thus facilitating the introduction of environmentally friendly technologies and promoting research and development. Consequently, there is a proliferation of global advertising campaigns and advanced technology (Mehmood et al., 2025). Therefore, FID have the potential to positively impact environmental quality and reduce the ecological footprint (Zhou et al., 2024). Conversely, there is an association between financial development and environmental deterioration, stemming from the ecological footprints associated with economic liberalization and a greater population. Financial institutions provide funding for environmentally beneficial initiatives to mitigate environmental damage (Ahmad et al., 2024).

There is a discernible negative linkage between FID and EFT in middle-income countries (Abdullahi et al., 2024). Bergougui (2024) centers its attention on examining the liaison between Algeria's ecological damage and its financial progress. The analyses presented in their study demonstrate that the development of financial systems negatively influences EFT. Zhou et al. (2024) revealed that the advancement of the financial, private, and banking sectors in MENA countries is associated with a decrease in EFT. In a comprehensive analysis encompassing 124 economies worldwide, a significant correlation was observed between FID and EFT. There is an established correlation between FID and EFT in APEC countries (Balli et al., 2024). However, current studies regarding the connection between FID and EFT still lack definitive conclusions and require further investigation.

Financial Technology (FIT)and Ecological Footprint (EFT)

The integration of financial technology (FIT) enables the digitalization of financial institutions, thereby facilitating the transition of traditional offline economic activities to online platforms. FIT has the potential to facilitate the transition from offline financial activities to online platforms by digital technology. This transition can result in a reduction in unnecessary economic activities (Ahmad et al., 2024). The utilization of digital online platforms enables efficient execution of financial transactions between capital suppliers and demanders. Consequently, the need for offline activities that require physical travel is substantially reduced. This reduction in travel frequency curtails environmental deterioration generated by transportation (Sadiq et al., 2024). In addition, the implementation of an online paperless office directly lessens the utilization of physical funds within the financial services sector.

Concerning the practical application of FIT in everyday consumption, the utilization of mobile payment methods enhances convenience and significantly diminishes transaction costs, along with resource utilization (Yan et al., 2025). FIT recognizes the inherent necessity of providing financial services to marginalized populations that have been overlooked by conventional financial institutions. Moreover, it is advantageous for economic development and income augmentation in underdeveloped regions (Afzal and Rahman, 2025). FIT can support businesses and aid shareholders in aligning their investments with green products (Sibt-e-Ali et al., 2025). This can be achieved through the utilization of advanced technologies, such as state-of-the-art cryptocurrencies, along with other innovative stages (Jaiwant & Kureethara, 2023).The integration of FIT with contemporary technologies enhances innovation in the financial sector (Numan et al., 2023).

Green Energy Innovations and Ecological Footprint

Technological advancement significantly fosters economic growth, promoting advancement in sustainable practices within firms and industries to cultivate environmentally conscious economic growth (Liang et al., 2024). Numerous empirical investigations have posited that technological progress contributes to the mitigation of emissions. associated with energy production (Appiah et al., 2024). For instance, a study was conducted to explore regional innovation system efficiency and EFT, focusing on regions in China. The research findings indicate the effect of CO2 emissions on the economy (Rahman et al., 2024). Research and development (R&D) plays a substantial role in exerting adverse influences on the environment within the Group of Seven (G7) nations (Yin et al., 2025). The concept of innovation and advancement in clean energy pertains to developing and implementing methodologies aimed at mitigating or eliminating the adverse environmental impacts of human activities (Kenawy et al., 2025). The advancement of green energy encounters various challenges, including technical limitations, financial limitations, policy limitations, and insufficient public backing. Green energy innovation holds significant potential in terms of stimulating economic growth and creating novel employment opportunities. The utilization of green energy sources can effectively mitigate the adverse impacts associated with climate change and ensure the sustainable viability of our planet (D. Wang et al., 2023).

Research Methodology

This study utilizes annual data from middle-income economies to probe the effects of fintech, financial development, and green energy innovation on ecological footprints. The flow of the analysis is shown in Fig. 1. Table 1 analytically explains the variables, measures, units, and data sources.

Table 1: Variables Description

Variables	Nature	Measurement Units	abbreviation	Data Source
Ecological Footprints	Dependent	Constant (per capita)	EFT	GFN
Financial Development	Independent	Financial Development Index	FID	WDI
Fintech	Independent	Created through PCA index	FIT	Statista (2023)
Green Energy Innovation	Independent	Total energy patents in a year	GEV	IRENA.Org
Economic Growth	Control	GDP per capita constant (USD)	GDR	WDI

Analysis Flow

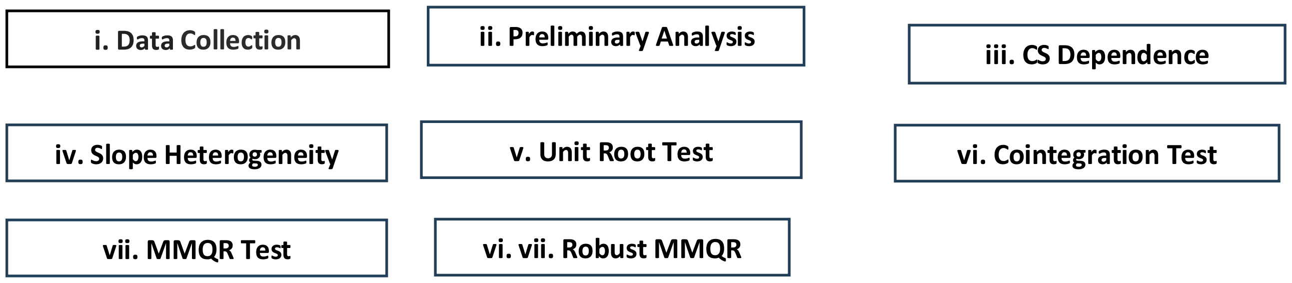

Figure 01: Analysis Flow

Data Analysis Methodology

This study incorporated the preliminary tests thoroughly detailed in a recent study (Alsaleh et al., 2023). Growing international economic integration requires panel data analysis to focus on cross-sectional dependence (CSP), since countries increasingly support each other. The accurate measurement of statistics depends on emphasizing CSP, because this practice helps prevent mistakes that could lead to incorrect policy decisions. The CSP test solves the issue of panel data by delivering accurate results. Equation (iii) elaborates on the CSP test below.

$$CSP_{TM} = \left[\frac{TN(N-1)}{2}\right]^{1/2} \bar{\rho}_N \qquad \text{(iii)}$$

The $\bar{\rho}_N$, N and T expose the pair-wise associates, units of cross-sections, and time, respectively. Later, for slope heterogeneity, the Pesaran and Yamagata test was applied (Pesaran & Yamagata, 2008). Swamy 1970) then conducted a review replication valuation. This technique is shown by Equations (iv) and (v).

$$\tilde{\Delta}_{SH} = (N)^{\frac{1}{2}}(2k)^{-\frac{1}{2}}\left(\frac{1}{N}\tilde{S} - k\right) \dots .\ being\ \ larger\ sampling \qquad (iv)$$

$$\tilde{\Delta}_{SHAdj} = (N)^{\frac{1}{2}}\left(\frac{2k(T-k-1}{T+1}\right)^{-\frac{1}{2}}\left(\frac{1}{N}\tilde{S} - 2k\right) \dots .\ being\ smaller\ sampling \qquad (v)$$

S denotes the test statistics and N depicts the cross-sectional units of the explanatory variable k. This study evaluates data stationarity during its subsequent stage. This research validates the accuracy of unit root test results through CSP and conducts CIPS and CADF cross-sectional unit root tests on crucial exogenous variables of the framework. The analysis incorporates three essential variables: financial development, fintech, and energy innovation. The unit root tests incorporated in this investigation, CADF and CIPS, are represented by equations (v) and (vi).

CADF is represented as:

$$\Delta Y_{i,t} = \gamma_i + \gamma_i Y_{i,t-1} + \gamma_i \bar{X}_{t-1} + \sum_{l=0}^{p} \gamma_{il} \Delta \overline{Y_{t-l}} + \sum_{l=1}^{p} \gamma_{il} \Delta Y_{i,t-l} + \varepsilon_{it} \qquad (vi)$$

Where: $\bar{Y}_{t-1}$ exhibits the lagged bounds at the 1st difference of $\bar{Y}_{t-1}$ exhibit $\Delta\overline{Y_{t-l}}$. In addition, the meaning of CADF has been used for the CIPS statistics below Equation (vi).

$$\widehat{\mathrm{CIPS}} = \frac{1}{\mathrm{N}}\sum_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{CADF_i} \qquad (vii)$$

The lagged parameters are illustrated as $\bar{Y}_{t-1}$ and the first difference of $\bar{Y}_{t-1}$ suggest $\Delta\overline{Y_{t-l}}$.

The cointegration test endorsed by Persyn and Westerlund (2008) was then deployed.

Afterwards, the Westerlund cointegration test is documented while the terms encircle the group statistics. $\mathrm{G_a}$and $\mathrm{G_t}$, then the panel statistics are enlightened by $\mathrm{P_a}$and $\mathrm{P_t}$

$$G_t = \frac{1}{N}\sum_{i-1}^{N}\frac{\acute{\alpha}_i}{SE\,(\acute{\alpha}_i)} \tag{viii}$$

$$G_\alpha = \frac{1}{N}\sum_{i-1}^{N}\frac{\mathrm{T}\acute{\alpha}_i}{\acute{\alpha}_i(1)} \tag{ix}$$

$$P_t = \frac{\acute{\alpha}}{SE\,(\acute{\alpha})} \tag{x}$$

$$P_\alpha = \mathrm{T}\acute{\alpha} \tag{xi}$$

This study employs the novel quantile method known as MMQR to advance its study (Machado & Silva, 2019). This method provides resistance to extreme values within the data and simultaneously recognizes different characteristics across individual groups. The method considers temporary variations in heterogeneous covariance through systematic changes to multiple mean distributions. The MMQR estimation provides a method to analyze the main outcome variables at distinct quantile levels, including lower, medium, and higher-order points.

Although the MMQR approach provides multiple benefits, it exists within constraints because it handles outliers when analyzing conditioned heterogeneous covariance effects. MMQR generates estimates with more complicated parameters than standard regression estimation methods and Gaussian regression. Not all cases can benefit from the systematic coefficient implementation of the MMQR framework. MMQR functions as an additional tool that helps estimate quantile regression while managing individual-level effects, yet it does not substitute the existing conventional methods.

MMQR produces different results based on the methodology selection between panel estimators and first-generation estimators. Pertinent first-generation models work under the condition of independent cross-sectional units until second-generation models add equations for dependencies between units (Menegaki, 2018). The adoption of the generalized method of moments (GMM) generates modified empirical findings because it includes parameters for sample errors and estimation methods (Durlauf & Blume, 2016). Statistical estimates derived from the autoregressive distributed lag (ARDL) model for panel data will differ from those obtained via MMQR. These restrictions require attention because they generate effects that impact both research data outcomes and policy recommendations.

Equation (xii) below determines the computation of the conditional quantile... $Q_y\left(\delta \middle| \hat{X}_{it}\right)$:

$$Y_{it} = \dot{a}_i + \ddot{\mathrm{X}}_{\mathrm{it}}\,\Phi + (\dot{\Lambda}_i + \mathrm{Ƶ}'_{\mathrm{it}}\,\Psi)\,\breve{\mathrm{U}}_{\mathrm{it}} \tag{xii}$$

Where: þ$\{\dot{\Lambda}_i + \mathrm{Ƶ}'_{\mathrm{it}}\,\Psi > 0\}$, signifies a probability of 1, whereas the model's parameter is represented as $(\Phi, \dot{\Lambda}_i\ \mathrm{Ƶ}'_{\mathrm{it}}\,\Psi)$; i = 1,..., n denotes the varied fixed effects, though the selected components of X's k-vector are displayed as Z, restricting discrete modifications with component l illustrated by: $\mathrm{Ƶ}_j = \mathrm{Ƶ}_j(\ddot{\mathrm{X}}), j = 1,2, \ldots \ldots, k$

$\ddot{\mathrm{X}}_{\mathrm{it}}$ It is recurrent, invariant, and consistently dispersed. Also, the term $\breve{\mathrm{U}}_{\mathrm{it}}$ is reorganized in time (t) amongst individuals I and rectangularly to $\mathrm{X_{it}}$, allowing Machado and Silva's moment condition (Machado & Silva, 2019) underneath:

$$Q_y\left(\dot{\delta} \middle| \hat{X}_{it}\right) = (\dot{a}_i + (\dot{\boldsymbol{\lambda}}_{\boldsymbol{\imath}}\,\boldsymbol{\rho}_i\,q(\dot{\delta})) + \ddot{\mathrm{X}}_{\mathrm{it}}\,\Phi + \mathrm{Ƶ}'_{\mathrm{it}}\,\Psi\,\mathrm{q}(\dot{\delta}) \tag{xiii}$$

Here: $\ddot{\mathrm{X}}_{\mathrm{it}}$ incorporates independent vector domains, whereas $Q_y\left(\dot{\delta} \middle| \hat{X}_{it}\right)$ denotes the quantile distribution of Y_{it}. Equation # (xiv) underneath the optimization links:

$$Min_q = \sum_i \sum t\,\eta_{\acute{o}}\left(Rit - [\![(\wedge\dot{Z}]\!]_i + \mathrm{Ƶ}'_{\mathrm{it}}\,\gamma\right)q\big) \tag{xiv}$$

Where; $\eta_{\acute{o}}\,(\ddot{R}) = (\delta \mathbin{\grave{-}} 1)\,\ddot{R}I\left\{\ddot{R} \le 0\right\} + T\ddot{R}I\left\{R \overset{\cdot\cdot}{>} 0\right\}$ represents a checked function.

Results

Table 2 contains descriptive statistics employing mean trends, data ranges, average score distribution and normality criteria

The findings reveal that GDT displays the highest mean value of 3.384, followed by UBN and EFT. Nonetheless, the FDP displayed the lowest mean score during the study period. After monitoring deviation from the mean, EFT discloses the most exceptional dispersion, followed by GEV and FIT. Also, maximum and minimum values specify the highest and lowest outlines in data.

The VIF value of all variables under consideration is below five, which is the threshold level assuring that no multicollinearity occurs among the variables in the model. Accordingly, the tolerance threshold (1/VIF) indicates a score exceeding 0.10 for all variables, suggesting no issue with the greater interdependence among them.

Table 2: Descriptive Outcomes with Collinearity Diagnostics

Variables	**Mean**	**Std. Dev**	**Min.**	**Max**	**VIF**	**1/VIF**
EFT	3.622	2.285	0.720	9.581	6.876	0.018
FID	2.234	1.018	0.291	3.961	2.467	0.405
FIT	3.591	0.412	2.541	3.892	2.089	0.479
GEV	1.788	1.029	0.162	3.490	1.356	0.737
GDT	3.402	0.296	2.364	3.695	3.319	0.301

Note: EFT: ecological footprint, FID: financial development, FIT: financial technology, GEV: green energy innovation, GDT: gross domestic product.

Cross-Sectional Dependence

Economic progress, together with cooperation between economies, continues to advance due to globalization and rising economic connections between nations. Acceptance of cross-sectional dependence creates the risk of estimation and policy errors. Econometric methods require a proper assessment of the presence of cross-sectional dependence for appropriate application. The CSD analysis in Table 4 features relevant variable statistics, together with test results and p-values. The results demonstrate that test statistic p-values reach significance at the 1% level, thus validating the rejection of the null hypothesis concerning no cross-sectional dependence in the data.

Table 4: Testing the CS Dependence

Variable	**CD-test**	**p-value**
EFT	7.150^{***}	0.000
FID	20.380^{***}	0.000
FIT	10.060^{***}	0.000
GEV	6.290^{***}	0.000
GDT	17.580^{***}	0.000

Note: EFT: ecological footprints, FID; financial development, FIT; fintech, GEV; green energy innovation, GDT; gross domestic product, p<0.01***, p<0.05**, p<0.1*

Slope Heterogeneity

The present research employs a slope heterogeneity analysis method introduced by Durlauf and Blume (2016). The estimated findings display $\hat{\Delta}$ and $\hat{\Delta}$ adjusted values in Table 4. The statistical analysis shows highly important findings at the 1% level that verify the existence of slope coefficient heterogeneity. Economic globalization, along with trade systems, has strengthened the global economic interdependence required to achieve different financial targets as well as economic and environmental outcomes.

Table 5: Slope Heterogeneity Testing

Description	**Test Statistics**	**P-value**
open tilde $(\widehat{\Delta})$	35.591	0.000
$\hat{\hat{\Delta}}_{\text{adjusted}}$	38.784	0.000

Unit Root Tests

The analysis in Table 6 displays the results of the CIPS and CADF panel unit root tests on variables with level and first-differenced data. Second-generation unit root tests included these two statistical procedures. The tests applying the CIPS and CADF procedures demonstrate that ecological footprints and energy patents achieve stationarity during their first difference stage. The CIPS test shows that FIT and GDT exist at this level, but GEV does not possess stationarity at their first difference. A CADF analysis demonstrates that all variables maintain stability after the first differentiation, apart from GDT, which makes them free from a unit root.

Table 6: Unit Root Tests

Variables	CIPS		CADF	
---	Level	First Difference	Level	First Difference
EFT	-1.800	-3.283***	-1.034	-2.351***
FID	-1.670	-2.645*	-1.763	-2.024***
FIT	-4.581***	--	-0.8910	-2.642**
GEV	-1.670	-3.104***	-1.574	-1.457**
GDT	-2.389*	--	-2.432*	---

Note: EFT: ecological footprints, FID; financial development, FIT; financial technology, GEV; green energy innovation, GDT; gross domestic products, p<0.01***, p<0.05**, p<0.1*

Cointegration Analysis

Subsequently, the analysis moves on to cointegration testing and reveals its results in Table 7. This study evaluated the permanent connections between ecological footprints and numerous explanatory and controlling variables. The findings reveal that no cointegration exists between ecological footprints and additional variables of financial development, financial technology, energy innovation, and economic expansion for this period. Pedroni's cointegration tests in Table 7 reinforce the indication of cointegration among the variables.

Table 7: Pedroni's Cointegration Findings

Details	Statistic	p-value
Modified Phillips–Perron t	-5.7025^{***}	0.000
Phillips–Perron t	-4.7846^{***}	0.000
Augmented Dickey-Fuller t	-3.8304^{***}	0.000

Note: p<0.01***, p<0.05, ** p<0.1 *

MMQR Estimations

The analysis uses a Method of Moment Quantile Regression (MMQR) approach to show how financial development (FID), financial technology (FIT), green energy innovation (GEV), and gross domestic product (GDT) affect the different quantiles of the dependent variable. FDI (Financial Development) generates consistently negative results for the dependent variable in the lower and middle quantiles from the 10th to 70th quantiles, which demonstrates that financial development negatively affects the dependent variable when it is low. The statistical significance of the influence of financial development disappears when examining higher levels of the dependent variable at the 90th quantile.

Financial technology (FIT) generates negative impacts on the dependent variable when measured at lower quantile points between the 10th and 40th quantiles. At lower quantile levels, the fintech demonstrates a powerful detrimental effect on EFT, but its strength weakens when moving to higher quantile ranges. GEV (green energy innovation) manifests a small positive association with the EFT only at the 90th quantile, thus minimizing its influence on variable variation throughout most quantiles. The analysis demonstrates that gross domestic product (GDT) creates a positive, statistically significant association between the dependent variable during most quantile segments, especially at lower and mid-level quantiles ranging from 10th to 70th, which indicates that GDP growth produces stronger impacts at lower value points. The effect of GDP becomes slightly smaller among the higher distribution quantiles, although it continues to be statistically significant at each point. It is pertinent that MMQR is contingent upon moment constraints. Therefore, there is no substantial necessity to address R^2.

Table 8: **MMQR Estimations**

Variables	**Location**	**Scale**	**10th**	**20th**	**30th**	**40th**	**50th**	**60th**	**70th**	**80th**	**90th**
			Lower Order			**Middle Order**			**Higher Order**		
FID	.0415***	.0255***	0.079***	0.0656***	0.058***	0.050***	0.040***	0 .034***	0.020*	0.015	0.004
	[3.72]	[3.77]	[5.07]	[5.11]	[4.76]	[4.39]	[3.56]	[3.15]	[1.77]	[1.28]	[0.39]
FIT	0.006***	0.001**	0.0033	.003**	.004**	0.005***	0.006***	0.006***	0.008***	0.008***	0.007***
	[4.17]	[2.33]	[1.37]	[2.34]	[2.80]	[3.39]	[4.06]	[4.35]	[4.75]	[4.82]	[4.68]
GEV	-0.022	-0.037	-0.033	-.011	-.0025	-0.007	-0.023	-0 .031	-0.052	-0.060	-0.075
	[-0.59]	[-1.59]	[-0.620]	[-0.25]	[-0.05]	[-0.21]	[-0.60]	[-0.80]	-1.23	[-0.171]	[-1.50]
GDT	0.067***	0.0047	0.074**	.071**	.070***	0.068***	0.066***	0.065***	0.062**	0.061**	0.059*
	[2.73]	[0.744]	[2.18]	[2.49]	[2.60]	[2.71]	[2.73]	[2.68]	[2.38]	[2.22]	[1.92]

Note: EFT: ecological footprints, FID; financial development, FIT; financial technology, GEV; green energy innovation, GDT; gross domestic product, p<0.01***, p<0.05**, p<0.1*

Discussion

The research analyzed how financial development, Fintech and Green Energy Innovation contribute to ecological footprints by employing the Method of Moment Quantile Regression (MMQR). Across multiple quantiles of data analysis, this study provides important information about environmental responses to key variables in middle-income countries. The positive link between Financial Development (FID) and ecological footprints occurs at every quantile research level but intensifies within low quantile ranges. Financial development stimulates ecological footprints, which occur most prominently in the lower and middle environmental sustainability zones, according to the positive coefficients. At the 90th quantile, the statistical importance weakens, while the effect continues to weaken. Financial Technology (FIT) produces sustainable and statistically linked relationships with environmental footprints throughout the 10th to 40th quantile ranges.

Fintech improves ecological footprints at standard deviation levels below the 50th quantile, while showing a diminishing impact at higher quantiles, which demonstrates that greater environmental stress from financial technology applies to countries with low sustainability. GEV (Green Energy Innovation) maintains an insignificant negative connection with ecological footprints throughout every quantile measurement. The analysis shows small and statistically insignificant coefficients, which demonstrate that green energy innovation has minimal potential to decrease ecological footprints, regardless of the quantile range. At the lower and middle quantile ranges between the 10th and 70th positions, Gross Domestic Trade (GDT) shows positive connections to ecological footprints. Economic and trade growth stands as a factor that leads to greater environmental damage when sustainability remains low. Economic growth plays a weakened role in decreasing the ecological footprint because environmental sustainability improves throughout the upper quantile range.

Policymakers need to develop specific policies that support financial development with technology innovation and sustainable trade practices alongside environmental impact reduction strategies. Middle-income economies must focus on integrating green financial products with green bonds and sustainable investing along with eco-friendly credit facilities (Bergougui, 2024). The financial instruments would stimulate private sector investment in clean technologies as well as renewable energy sustainability projects. Governments should offer support through tax breaks and grants, as well as subsidies for businesses investing in green technology to develop a powerful green financial network. The government should build favorable regulatory frameworks to motivate both green technology development and adoption in the energy sector.

The government provides renewable energy and energy-efficient technology businesses with research grants, tax credits, low-interest loans, and R&D awards. Clean energy financing is supported through fintech innovations, which enable sustainable projects to obtain funding through crowdfunding platforms (Sibt-e-Ali et al., 2025). Middle-income economies need to encourage circular economic systems because they reduce waste while maximizing resource reuse. Public policies enabling recycling initiatives, waste management, and resource efficiency should be established with incentives. Industrial processes should receive incentives that promote reduced resource usage and EFT levels while being subject to tax breaks or penalties that evaluate their environmental performance. The growth of domestic trade has resulted in increased environmental expenses from industrial development. Government officials should issue tighter environmental standards for manufacturing plants and energy facilities that release substantial greenhouse gas emissions. Companies should be financially motivated to implement environmentally sustainable production techniques through incentives.

Conclusion

Research shows that both Financial Development (FID) and Financial Technology (FIT) create positive effects on ecological footprints at the lower and middle quantile levels. The introduction of financial development, combined with technological innovation, results in increased environmental damage during the early stages of sustainability. Green Energy Innovation (GEV) demonstrates a minimal and statistically insignificant influence in reducing ecological footprints throughout all analysis groups because green energy innovations currently play a limited role in protecting the environment at less developed economic and environmental levels. Data reveal that economic expansion shows a positive relationship with ecological footprints, but the effect is more pronounced at lower quantile points, which demonstrates that rising industrial activities cause environmental damage in less sustainable economic areas. Economic success and ecological protection should maintain a balanced focus in countries with middle-income status through investments in green technology solutions, along with improved resource planning. Additional research is needed regarding the lasting impacts of these factors on environmental results.

References

Abdullahi, N. M., Ibrahim, A. A., Zhang, Q., & Huo, X. (2024). Dynamic linkages between financial development, economic growth, urbanisation, trade openness, and ecological footprint: An empirical account of ECOWAS countries. *Environment, Development and Sustainability*, 1–28.

Afzal, M. A., Ahmed, W., Abbas, N., & Shah, M. N. (2025). Exploring the Nexus Among Financial Advancement, Natural resources Rent, Green Innovation and Environmental Quality in Pakistan. *Sustainable Business and Society in Emerging Economies*, *7*(1), 39–52.

Afzal, M. A., & Rahman, S. U. (2025). *Unpacking the Financial Development , Financial Technology and Institutional Quality Nexus in Curbing Climate Change Among Middle-Income Countries Journal of Social & Organizational Matters*. *4*(1), 348–369.

Ahmad, M., Pata, U. K., Ahmed, Z., & Zhao, R. (2024). Fintech, natural resources management, green energy transition, and ecological footprint: Empirical insights from EU countries. *Resources Policy*, *92*, 104972.

Alsaleh, M., Yang, Z., Chen, T., Wang, X., Abdul-Rahim, A. S., & Mahmood, H. (2023). Moving toward environmental sustainability: Assessing the influence of geothermal power on carbon dioxide emissions. *Renewable Energy*, *202*, 880–893.

Appiah, M., Li, M., Taden, J., Ashraf, S., Tiwari, A. K., & Laari, P. B. (2024). Enhancing natural resource rents through industrialization, technological innovation, and foreign capital in the OECD countries: Does financial development matter? *Resources Policy*, *89*, 104520.

Athari, S. A. (2024). The impact of financial development and technological innovations on renewable energy consumption: Do the roles of economic openness and financial stability matter in BRICS economies? *Geological Journal*, *59*(1), 288–300.

Balli, E., Çatik, A. N., Uğur, M. S., & Sigeze, C. (2024). The effects of financial development, trade and energy consumption on environmental degradation: Evidence from APEC countries. *Energy Sources, Part B: Economics, Planning, and Policy*, *19*(1), 2372627.

Bergougui, B. (2024). Investigating the relationships among green technologies, financial development and ecological footprint levels in Algeria: Evidence from a novel Fourier ARDL approach. *Sustainable Cities and Society*, *112*, 105621.

Chau, K. Y., Moslehpour, M., Tu, Y.-T., Tai, N. T., Tien, N. H., & Huy, P. Q. (2022). Exploring the impact of green energy and consumption on the sustainability of natural resources: Empirical evidence from G7 countries. *Renewable Energy*, *196*, 1241–1249.

Durlauf, S., & Blume, L. (2016). *Macroeconometrics and time series analysis*. Springer.

Elgharib, W. A. (2024). Financial inclusion, financial development and financial stability in MENA. *Review of Accounting and Finance*, *23*(4), 489–505.

Horky, F., & Fidrmuc, J. (2024). Financial development and renewable energy adoption in EU and ASEAN countries. *Energy Economics*, *131*, 107368.

Iqbal, S., Wang, Y., Ali, S., Amin, N., & Kausar, S. (2024). Asymmetric determinants of renewable energy production in Pakistan: do economic development, environmental technology, and financial development matter? *Journal of the Knowledge Economy*, *15*(1), 4097–4114.

Jaiwant, S. V., & Kureethara, J. V. (2023). Green Finance and Fintech: Toward a More Sustainable Financial System. In *Green Finance Instruments, FinTech, and Investment Strategies: Sustainable Portfolio Management in the Post-COVID Era* (pp. 283–300). Springer.

Kenawy, A. El, Al-Awadhi, T., Abdullah, M., Ostermann, F. O., & Abulibdeh, A. (2025). A Multidecadal Assessment of Drought Intensification in the Middle East and North Africa: The Role of Global Warming and Rainfall Deficit. *Earth Systems and Environment*, 1–20.

Khan, Y., Liu, F., & Hassan, T. (2023). Natural resources and sustainable development: Evaluating the role of remittances and energy resources efficiency. *Resources Policy*, *80*, 103214.

Kouwenberg, R., & Zheng, C. (2023). A Review of the Global Climate Finance Literature. *Sustainability*, *15*(2), 1255.

Kuznets, S. (2019). Economic growth and income inequality. In *The gap between rich and poor* (pp. 25–37). Routledge.

Laksevics, K., Brizga, J., Mamut, P., Kreinin, H., Fuchs, D., & Belousa, I. (2025). An Eco-Social Policy Mix for 1.5° C Lifestyles: A Multi-Country Policy Delphi Analysis. *Regulation & Governance*.

Liang, Y., Rahman, S. U., Shafaqat, A., Ali, A., & Ali, M. S. E. (2024). *Assessing sustainable development in E-7 countries : technology innovation , and energy consumption drivers of green growth and environment*. 1–21.

Machado, J. A. F., & Silva, J. M. C. S. (2019). Quantiles via moments. *Journal of Econometrics*, *213*(1), 145–173.

Manigandan, P., Alam, M. S., Murshed, M., Ozturk, I., Altuntas, S., & Alam, M. M. (2024). Promoting sustainable economic growth through natural resources management, green innovations, environmental policy deployment, and financial development: Fresh evidence from India. *Resources Policy*, *90*, 104681.

Mehmood, W., Sharif, A., & Aman-Ullah, A. (2025). Revealing the nexus: financial development and environmental sustainability as remedies for corruption–A global perspective. *Management of Environmental Quality: An International Journal*, *36*(1), 277–306.

Menegaki, A. (2018). *The economics and econometrics of the energy-growth nexus*. Academic Press.

Nations, U. (2015). Transforming our world: The 2030 agenda for sustainable development. *New York: United Nations, Department of Economic and Social Affairs*.

Numan, U., Ma, B., Sadiq, M., Bedru, H. D., & Jiang, C. (2023). The role of green finance in mitigating environmental degradation: Empirical evidence and policy implications from complex economies. *Journal of Cleaner Production*, *400*, 136693.

Persyn, D., & Westerlund, J. (2008). Error-correction–based cointegration tests for panel data. *The STATA Journal*, *8*(2), 232–241.

Pesaran, M. H., & Yamagata, T. (2008). Testing slope homogeneity in large panels. *Journal of Econometrics*, *142*(1), 50–93.

Rahman, A., Murad, S. M. W., Mohsin, A. K. M., & Wang, X. (2024). Does renewable energy proactively contribute to mitigating carbon emissions in major fossil fuels consuming countries? *Journal of Cleaner Production*, *452*, 142113.

Sadiq, M., Paramaiah, C., Dong, Z., Nawaz, M. A., & Shukurullaevich, N. K. (2024). Role of fintech, green finance, and natural resource rents in sustainable climate change in China. Mediating role of environmental regulations and government interventions in the pre-post COVID eras. *Resources Policy*, *88*, 104494.

Sajid, M., Ansari, M. A. A., Tanveer, A., Safdar, N., & Faheem, M. (2025). Do financial inclusion and green growth matter for environmental sustainability? A fresh insight through nonlinear model. *Clean Technologies and Environmental Policy*, 1–27.

Sibt-e-Ali, M., Xia, X., Yi, W., & Vasa, L. (2025). Quantifying the role of digitalization, financial technology, governance and SDG13 in achieving environment conservation in the perspective of emerging economies. *Environment, Development and Sustainability*, 1–23.

Swamy, P. A. V. B. (1970). Efficient inference in a random coefficient regression model. *Econometrica: Journal of the Econometric Society*, 311–323.

Udeagha, M. C., & Breitenbach, M. C. (2023). The role of financial development in climate change mitigation: Fresh policy insights from South Africa. *Biophysical Economics and Sustainability*, *8*(1), 1.

Wackernagel, M, & Rees, W. E. (1996). Our ecological footprints of nations: reducing human impact on the earth. In *Gbyiola Island*. New Society Publishers.

Wackernagel, Mathis, Schulz, N. B., Deumling, D., Linares, A. C., Jenkins, M., Kapos, V., Monfreda, C., Loh, J., Myers, N., & Norgaard, R. (2002). Tracking the ecological overshoot of the human economy. *Proceedings of the National Academy of Sciences*, *99*(14), 9266–9271.

Wang, D., Li, J., & Liu, Y. (2023). Evaluating barriers and strategies to green energy innovations for sustainable development: developing resilient energy systems. *Frontiers in Energy Research*, *11*, 1201692.

Wang, Z., Ali, K., & Ullah, S. (2025). Revisiting natural resources and financial development nexus in China under the lens of time-frequency approach. *Natural Resources Forum*, *49*(1), 541–560.

Yan, Z., Yang, H., Sun, Q., & Shen, L. (2025). Fintech, Financial Capability and Household Financial Vulnerability: Evidence from China. *Journal of Family and Economic Issues*, 1–20.

Yin, Y., Chen, T., Pang, J., & Hussain, J. (2025). The drivers of sustainable development goals in G-7 countries: Navigating the role of climate technology and renewable energy transition. *Renewable Energy*, *240*, 122251.

Zhou, D., Saeed, U. F., Kongkuah, M., & Wiredu, I. (2024). Examining the moderating role of environmental regulations on financial development and ecological footprint in the MENA region. *Environment*, *Development and Sustainability*, 1–28.