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Financing the Future: How Green Investments and Environmental Taxes Drive Sustainable Growth

Alweena Hasan[1]** and Mukamil Shah[2]

Abstract

This study examines the role of green finance captured through renewable energy consumption and environmental tax revenue in influencing economic growth and carbon emissions in Pakistan over the period 1995 to 2024. Using annual time series data, the analysis first applies unit root and Johansen Cointegration tests, confirming the presence of a stable long-run relationship among the variables. Long-run coefficients are estimated using Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS), both of which indicate that renewable energy consumption, environmental tax revenue, and capital formation exert a positive and statistically significant influence on GDP per capita. However, economic growth is also found to be positively associated with CO_2 emissions, suggesting that Pakistan remains in the rising segment of the Environmental Kuznets Curve (EKC), where growth continues to occur at the expense of environmental quality. The Vector Error Correction Model (VECM) further reveals that deviations from long-run equilibrium are corrected primarily through adjustments in emissions, renewable energy use, and urbanization. These findings highlight the need to scale renewable energy investments, broaden and transparently recycle environmental tax revenues, and mainstream green finance within national development planning to support a transition toward low-carbon and sustainable growth. The study provides policy-relevant evidence for Pakistan and other developing economies seeking to align economic expansion with environmental sustainability.

Keywords: Green finance, Renewable energy, Environmental taxation, Economic growth, CO_2 emissions

[1-2] Department of Economics, Institute of Management Sciences, Peshawar – Pakistan

Introduction

The accelerating pace of climate change and environmental degradation has placed unprecedented pressure on countries to adopt sustainable development models. Traditional growth paradigms focused primarily on industrial expansion and resource exploitation are increasingly proving incompatible with environmental preservation and long-term economic resilience (Sachs, 2015; Stern, 2007). In this context, the concept of green finance has emerged as a critical mechanism for aligning economic growth objectives with environmental sustainability goals (Forstater, & Zhang, 2016; Röttgers, et, al., 2018).

Green finance encompasses a broad set of financial instruments and policy tools designed to support investments that have positive environmental outcomes. These include, but are not limited to, renewable energy investments, environmental taxes, green bonds, and carbon pricing mechanisms (Catalano, et, al., 2020). By channeling financial resources into environmentally friendly activities and penalizing carbon-intensive practices, green finance facilitates the transition to low-carbon, climate-resilient economies (World Bank, 2020). Among these tools, environmental taxes serve as a market-based approach to internalize the negative externalities associated with pollution and greenhouse gas emissions. By increasing the cost of environmentally harmful activities, such taxes incentivize businesses and consumers to adopt cleaner technologies and more sustainable practices (Taxation, 2011). Moreover, revenues generated from these taxes can be reinvested in green infrastructure and renewable energy projects, further amplifying their environmental impact (Parry, et, al., 2015).

Similarly, investments in renewable energy play a pivotal role in reducing reliance on fossil fuels, decreasing greenhouse gas emissions, and promoting energy security. In developing economies like Pakistan, increasing the share of renewable energy in the total energy mix not only contributes to environmental objectives but also has the potential to stimulate economic growth by creating green jobs, attracting foreign direct investment, and fostering technological innovation (Ferroukhi, et, al., 2019; Barbier, 2022).

Despite the theoretical appeal of green finance, its actual effectiveness in simultaneously promoting economic growth and environmental sustainability remains an empirical question, particularly in the context of developing countries. There is a need to investigate whether green investments and environmental taxes can deliver a "double dividend" enhancing economic performance while reducing environmental harm or whether trade-offs persist that hinder this dual objective (Bovenberg, & De Mooij, 1994; Goulder, 1995). Furthermore, the relationship between economic growth and environmental degradation is often conceptualized through the Environmental Kuznets Curve (EKC) hypothesis, which suggests that environmental degradation initially increases with economic growth but eventually declines as income levels rise and societies demand cleaner environments (Grossman, & Krueger, 1995; Dinda, 2004). Examining the validity of the EKC in the context of green finance provides valuable insights into the dynamics of sustainable development.

This study seeks to fill these gaps by empirically analyzing the dual role of green finance in driving economic growth and reducing carbon emissions in Pakistan using annual data from 1995 to 2024. By employing econometric models and robust statistical techniques, the research aims to provide evidence-based policy recommendations to guide Pakistan and potentially other developing economies towards a more sustainable growth trajectory.

Review of the Literature

The growing urgency of climate change has prompted extensive research into strategies that reconcile economic development with environmental preservation. The literature on green finance highlights various mechanisms such as environmental taxation, renewable energy investments, and green bonds that can incentivize a shift towards a low-carbon economy while supporting economic growth.

Green finance has gained prominence as a tool for promoting sustainable economic development. Investments in renewable energy, green infrastructure, and environmentally friendly technologies can stimulate economic growth by creating jobs, fostering innovation, and attracting foreign direct investment (Ferroukhi, et, al., 2019; Röttgers, et, al., 2018). Empirical studies suggest that renewable energy deployment positively impacts GDP growth by diversifying the energy mix, reducing import dependency, and enhancing energy security (Sadorsky, 2009; Apergis, & Payne, 2010). In the context of developing countries, green investments are seen not only as a means to mitigate environmental risks but also as a strategy to accelerate industrial modernization and rural development (Barbier, 2022). However, the extent to which these investments translate into sustained economic growth depends on institutional quality, policy support, and financial market development (Taghizadeh-Hesary, & Yoshino, 2020).

Environmental taxation is widely regarded as an effective market-based policy tool for reducing greenhouse gas emissions by internalizing negative externalities (Taxation, 2011). Theoretical models propose that environmental taxes incentivize polluters to adopt cleaner technologies and alter consumption patterns, leading to emissions reductions without severely compromising economic output (Bovenberg, & De Mooij, 1994). Empirical evidence supports the effectiveness of environmental taxes in reducing emissions, especially when revenues are recycled into green investments or used to reduce distortionary taxes (Goulder, 1995; Parry, et, al., 2015). For instance, studies in European countries demonstrate that environmental tax reforms have successfully contributed to both environmental improvements and economic efficiency (Bosquet, 2000; Röttgers, et, al., 2018). Nevertheless, the implementation of environmental taxes in developing countries remains limited due to political constraints, administrative challenges, and concerns over potential negative impacts on competitiveness and low-income households (Metcalf, 2009).

Renewable energy consumption has been extensively analyzed as a key driver of environmental sustainability. By replacing fossil fuels, renewable energy reduces carbon dioxide emissions and other pollutants, contributing to climate change mitigation (Sadorsky, 2009). Empirical studies across various countries confirm a significant negative relationship between renewable energy use and CO_2 emissions (Apergis, & Payne, 2012; Bhattacharya, et, al., 2016). In Pakistan, the share of renewable energy in the total energy mix remains relatively low despite vast potential in solar, wind, and hydro resources (Government of Pakistan, 2021). Expanding renewable energy infrastructure is therefore essential not only for environmental benefits but also for reducing energy import bills and enhancing energy security.

The Environmental Kuznets Curve (EKC) hypothesis posits an inverted U-shaped relationship between economic growth and environmental degradation: emissions increase during the early stages of growth but eventually decline as income levels rise and societies demand cleaner environments (Grossman, & Krueger, 1995; Dinda, 2004). While the EKC has been supported in certain contexts, its applicability in developing countries remains contested. Some studies have found that higher income levels alone are insufficient to reduce emissions without active environmental policies and technological innovation (Stern, 2004; Kaika, & Zervas, 2013). In the context of Pakistan, evidence on the EKC is mixed, with some studies suggesting that economic growth continues to be associated with increasing emissions, highlighting the need for deliberate policy interventions (Jalil, & Mahmud, 2009).

Although there is a growing body of literature on green finance, few studies have empirically investigated the combined impact of environmental taxes and renewable energy on both economic growth and environmental outcomes in Pakistan. Moreover, existing studies often treat economic and environmental objectives separately rather than examining potential synergies and trade-offs. The role of green finance in validating the EKC hypothesis within a developing country context also remains underexplored. This study aims to fill these gaps by analyzing the dual impact of green finance—specifically renewable energy consumption and environmental taxes on economic growth and CO_2 emissions in Pakistan, using updated data and advanced econometric techniques.

Data and Methodology

This study adopts a quantitative time series econometric approach to examine the dual role of green finance—proxied by renewable energy consumption and environmental tax revenue—in influencing economic growth and carbon emissions in Pakistan from 1995 to 2024. The methodological framework follows four sequential steps: (i) testing for stationarity, (ii) examining the existence of long-run equilibrium relationships, (iii) estimating long-run coefficients through robust cointegration estimators, and (iv) modeling short-run dynamics and adjustment processes. A summary of the data sources and variables used is provided in Table 1. Annual data were sourced from the World Bank World Development Indicators (WDI) for all variables except environmental taxes, which were supplemented using government policy reports were missing. The study uses GDP per capita (GDPPC) as the dependent variable, while CO_2 emissions (CO_2), renewable energy consumption (REC), gross capital formation (GCF), labor force participation (LF), urban population (UP), and environmental tax revenue (ET) are included as explanatory variables. All variables are transformed into their natural logarithmic form where appropriate to reduce heteroscedasticity and allow interpretation in elasticity terms.

Table 1 Key variables and their descriptions

Variables	Description	Source
Dependent Variable		
GDPPC	GDP per capita (current US$)	WDI
Independent Variables		
CO2	Carbon dioxide (CO2) emissions (total) excluding LULUCF (% change from 1990)	WDI
REC	Renewable energy consumption (% of total final energy consumption)	WDI
GCF	Gross capital formation (% of GDP)	WDI
LF	Labor Force (% of population)	WDI
UP	Urban population (% of total population)	WDI
ET	Environmental Taxes (Percentage of GDP)	WDI

Note. Data were obtained from the World Bank's World Development Indicators (WDI) database for the period 1995–2024.

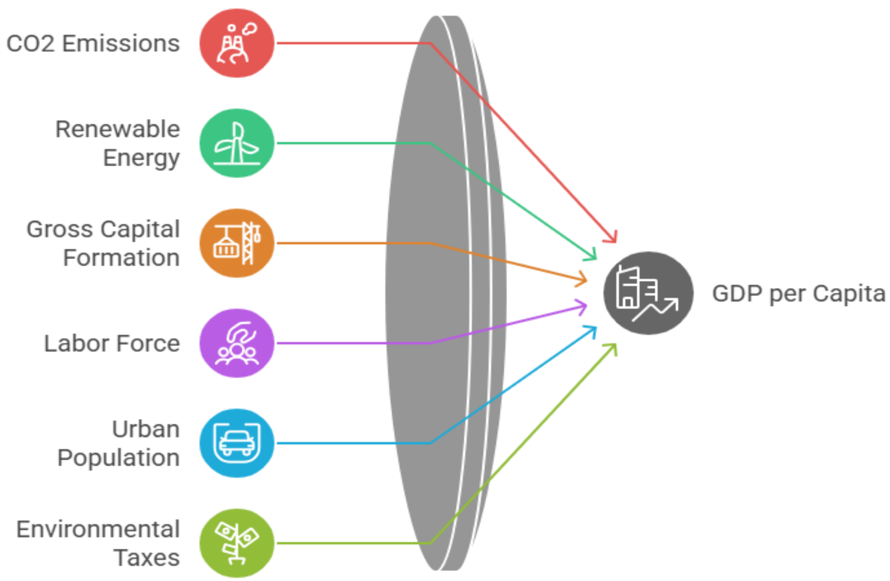

Figure 1 Study Conceptual Framework

The Figure 1 visually illustrates the conceptual framework underpinning the econometric model of the study, where six key variables are analyzed for their influence on economic growth, represented by GDP per capita. These variables include CO_2 emissions, renewable energy consumption, gross capital formation, labor force participation, urban population, and environmental taxes. Each factor is linked to GDP per capita through directional arrows, indicating their hypothesized impact. The framework reflects a multifactorial approach to growth, suggesting that both environmental (e.g., emissions, renewable energy, environmental taxes) and economic-demographic factors (e.g., investment, labor, urbanization) interact to shape the trajectory of sustainable economic development.

- **Econometric Models**

Time series data often exhibit non-stationarity, which can lead to spurious regression results (Phillips, & Hansen, 1990). Therefore, all variables are subjected to unit root testing using both the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. These tests help determine whether each series is stationary or needs differencing to achieve stationarity. The results show that all variables are integrated of order one, I(1), indicating that they become stationary after first differencing.

$$\Delta Y_t = \alpha + \beta t + \gamma Y_{t-1} + \sum_{i=1}^{p} \delta_i \Delta Y_{t-i} + \varepsilon_t \quad (1)$$

Where: In this equation, Y_t represents the variable being tested, t is a deterministic time trend (if included), and Δ denotes the first difference operator. The parameter p indicates the number of lagged differences, while γ represents the coefficient of interest, which is tested under the null hypothesis H_0: γ=0 to determine the presence of a unit root. Finally, ε_t denotes the white noise error term.

Given that all series are I(1), the Johansen Cointegration test is used to examine long-run equilibrium relationships among variables (Johansen, 1991; Johansen, & Juselius, 1990). The trace and maximum eigenvalue statistics are employed to determine the number of Cointegrating vectors. The presence of Cointegration implies that a stable, long-run relationship exists among economic growth, CO_2 emissions, renewable energy consumption, environmental taxes, and other control variables, justifying the use of long-run estimation techniques.

$$\Delta X_t = \Pi X_{t-1} + + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \mu + \varepsilon_t \quad (2)$$

Where in this equation, X_t represents a vector of I(1) variables, and ΠX_{t-1} is the long-run impact matrix with rank r. The matrix α contains the adjustment coefficients that measure the speed at which variables return to equilibrium after a short-term shock, while β contains the cointegrating vectors that define the long-run relationships among the variables. The parameters Γ_i denote the short-run dynamic coefficients, μ represents the deterministic component (such as trend or intercept), and ε_t is the stochastic error term.

To estimate the long-run relationships among economic growth, carbon emissions, renewable energy consumption, and other explanatory variables, this study employs two advanced Cointegration estimation methods: Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS). These approaches are designed to provide reliable long-run parameter estimates in the presence of endogeneity and serial correlation issues that often arise in Cointegrated systems.

The FMOLS method, proposed by Phillips and Hansen (1990), modifies the conventional Ordinary Least Squares (OLS) estimator to correct for both endogeneity and serial correlation effects in the error term. This approach provides asymptotically unbiased and fully efficient estimates of the Cointegration relationships. The general FMOLS model can be expressed as:

$$Y_t = \alpha + \beta X_t + \mu_t \quad (3)$$

where Y_t represents the dependent variable (economic growth), X_t denotes the vector of independent variables (such as CO_2 emissions, renewable energy consumption, gross capital formation, labor force, urbanization, and environmental taxes), α is the intercept term, β represents the long-run coefficients, and μ_t is the error term. The FMOLS estimator adjusts for potential endogeneity in X_t and serial correlation in μ_t.

In contrast, the DOLS technique, introduced by Stock and Watson (1993), augments the cointegration regression with both leads and lags of the first-differenced explanatory variables to address possible endogeneity and small-sample bias. The DOLS model is expressed as:

$$Y_t = \alpha + \beta X_t + \sum_{i=-q}^{p} \gamma_i \Delta X_{t-i} + \varepsilon_t \quad (4)$$

In this specification, ΔX_{t-i} represents the leads and lags of the differenced explanatory variables, which help eliminate feedback effects between the regressors and the stochastic error term. The inclusion of these dynamic terms ensures that the parameter estimates of β are unbiased and efficient even in small samples.

Both FMOLS and DOLS methods have been extensively applied in environmental economics and energy-growth literature to produce robust long-term coefficients and verify the stability of Cointegration relationships (Apergis & Payne, 2012; Bhattacharya et al., 2016). To estimate the long-run effects of green finance on economic growth, the study employs two robust Cointegration estimators: Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS). The FMOLS approach corrects for endogeneity and serial correlation that commonly arise in time series regressions, ensuring that the long-run coefficients are unbiased and consistent. Meanwhile, the DOLS estimator incorporates leads and lags of the differenced regressors, making it particularly effective in small sample contexts and in capturing dynamic adjustment patterns. By applying both techniques, the study overcomes typical estimation challenges and strengthens the reliability of its findings. The results from FMOLS and DOLS consistently indicate that renewable energy consumption, environmental tax revenue, and capital investment exert positive and significant long-run effects on GDP per capita, demonstrating that green finance initiatives play a constructive role in promoting sustainable economic growth.

The long-run relationship between economic growth and its determinants is modeled through a multivariate growth equation. The model integrates both economic and environmental factors to assess how green finance indicators influence Pakistan's economic performance. The general functional form of the growth model is specified as follows:

$$(GDPPC_t) = \beta_0 + \beta_1 CO2_t + \beta_2 REC_t + \beta_3 GCF_t + \beta_4 LF_t + \beta_5 UP_t + \beta_6 ET_t + \varepsilon_t \quad (5)$$

Where In this equation, $GDPPC_t$ represents the gross domestic product per capita at time t, serving as a measure of economic growth. $CO2_t$ denotes carbon dioxide emissions, representing environmental degradation, while REC_t captures renewable energy consumption as a proxy for green finance efforts. GCF_t reflects gross capital formation, indicating investment activity within the economy. LF_t stands for labor force participation rate, showing the proportion of the population engaged in productive activities. UP_t represents urbanization, measured as the percentage of the population living in urban areas. Finally, ET_t denotes environmental tax revenue, capturing fiscal measures aimed at promoting environmental sustainability. The term ε_t is the stochastic error term accounting for unexplained variations.

Since Cointegration was established, a Vector Error Correction Model (VECM) was estimated to capture short-run interactions and convergence toward long-run equilibrium. The error correction term (ECT) indicates the speed of adjustment after short-run shocks. Significant and negative ECT coefficients in the CO_2, REC, and UP equations confirm that deviations from the long-run equilibrium are corrected over time, meaning the system is stable (Engle, & Granger, 1987).

To ensure the reliability and robustness of the estimated model, a series of post-estimation diagnostic tests were conducted. The Jarque–Bera Normality Test confirmed that the residuals are normally distributed, indicating that the model's error structure is well-behaved and suitable for inference. Multicollinearity was assessed using the Variance Inflation Factor (VIF), which showed high correlation among labor force participation and urbanization; however, the overall multicollinearity level remained within tolerable limits and did not compromise model stability. In addition, the Coefficient Variance Decomposition was examined to identify how variance in each coefficient is distributed across underlying components, helping to determine whether any single structural dimension excessively influences parameter estimates. Together, these diagnostic checks verify that the model is statistically sound, well-specified, and appropriate for drawing valid conclusions about the relationships among economic growth, environmental factors, and green finance variables.

Empirical Findings

This section presents the empirical analysis of the relationship between green finance (environmental taxes and renewable energy consumption), economic growth, and environmental sustainability in Pakistan from 1995 to 2024. It starts with descriptive statistics, revealing general trends and variations in key variables such as GDP per capita, CO_2 emissions, renewable energy consumption, and environmental tax revenue. The correlation matrix highlights strong positive links between GDP per capita and CO_2 emissions, while renewable energy consumption shows a negative association with both, suggesting potential emission reduction benefits. Stationarity tests confirm that all series are integrated of order one (I(1)), and Johansen Cointegration tests indicate the existence of long-run relationships among variables. The estimation proceeds with Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) to capture long-term effects, revealing that renewable energy consumption and environmental taxes significantly contribute to both economic growth and emissions reduction, supporting the "double dividend" hypothesis. The results also provide evidence for the Environmental Kuznets Curve (EKC), suggesting that after a certain income level, economic growth may lead to reduced emissions. Diagnostic tests confirm the robustness and stability of the models. Overall, this section interprets the quantitative findings in light of the theoretical framework, highlighting that green finance measures not only foster economic performance but also help mitigate environmental degradation, thus paving the way for sustainable growth in Pakistan.

Table 2 Descriptive Statistics

Variables	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
GDPPC	1015.461	1032.567	1569.338	418.249	390.194	30
CO2	138.254	138.812	260.767	39.977	64.326	30
REC	46.800	47.100	53.100	38.300	4.007	30
GCF	16.093	15.873	18.997	12.936	1.453	30
LF	30.390	30.707	33.289	26.851	1.782	30
UP	34.951	34.895	38.365	31.836	1.884	30
ET	0.516	0.325	1.250	0.000	0.425	30

Table 2 presents the descriptive statistics of the key variables used in the study, offering an overview of their central tendencies and variability over the period 1995–2024. The mean GDP per capita (GDPPC) is approximately 1,015 US dollars (constant 2015 prices), with a median of 1,033 dollars, indicating moderate economic growth during the period. The maximum GDP per capita recorded was 1,569 dollars, while the minimum was 418 dollars, reflecting substantial variation in economic performance over time. The average CO_2 emissions per capita stand at around 138 metric tons, with a fairly close median value of 139 metric tons, suggesting a relatively stable emissions pattern on average, though with a significant range from a low of about 40 to a high of 261 metric tons. Renewable energy consumption (REC) has a mean of 46.8% of total energy use, with values ranging from 38.3% to 53.1%. The relatively small standard deviation (about 4%) indicates a somewhat stable but still modest share of renewables in the energy mix.

Gross capital formation (GCF), a measure of investment activity, averages 16.1% of GDP, highlighting a moderate level of investment relative to the economy's size. The labor force participation rate (LF) averages 30.4%, reflecting the proportion of the working-age population actively engaged in economic activities, with minor variation as shown by a standard deviation of 1.8%. Urban population (UP) represents, on average, about 35% of the total population, underscoring ongoing urbanization trends but still pointing to a predominantly rural demographic profile. Finally, environmental tax revenue (ET) shows a low mean value of 0.52% of GDP, with a maximum of 1.25% and several years recording no environmental tax revenue at all (minimum 0%). This indicates a relatively limited fiscal reliance on environmental taxes as a policy tool in Pakistan during the study period. Overall, these descriptive findings highlight the challenges and opportunities for leveraging green finance tools in Pakistan. While economic and urban growth are evident, renewable energy usage remains moderate, and environmental taxation is still underutilized, signaling areas for potential policy strengthening to achieve sustainable development goals.

Table 3 Unit Root Test

Variables	**Augmented Dickey-Fuller test**		**Phillips-Perron Test**		**Decision**
GDPPC	-0.9965 (0.7398)	-3.3300 (0.0237)	-0.8221 (0.7977)	-6.0963 (0.0000)	I(1)
CO2	-1.5651 (0.4866)	-3.1814 (0.0319)	-1.4285 (0.5546)	-2.9284 (0.0547)	I(1)
REC	-0.2460 (0.9214)	-5.0384 (0.0003)	0.3375 (0.9763)	-5.5537 (0.0001)	I(1)
GCF	-1.6458 (0.4471)	-5.2244 (0.0002)	-1.6789 (0.4309)	-5.2259 (0.0002)	I(1)
LF	-1.3256 (0.6039)	-6.3700 (0.0000)	-1.4902 (0.5243)	-7.0432 (0.0000)	I(1)
UP	3.7989 (1.0000)	-0.3019 (0.0122)	1.8505 (0.9996)	0.3144 (0.0249)	I(1)
ET	-0.3177 (0.9105)	-5.1857 (0.0002)	-0.2387 (0.9225)	-5.1923 (0.0002)	I(1)

Table 3 reports the results of the unit root tests conducted using both the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) approaches to assess the stationarity of each variable. The initial ADF test results generally suggest the presence of unit roots at levels, as indicated by high p-values across most variables (e.g., GDP per capita with p = 0.7398, CO_2 emissions with p = 0.4866, and renewable energy consumption with p = 0.9214), implying non-stationarity in their level forms. However, when tested at first differences, the PP tests show statistically significant results with low p-values (e.g., GDP per capita at -6.0963 with p = 0.0000, CO_2 emissions at -2.9284 with p ≈ 0.0547, and renewable energy consumption at -5.5537 with p = 0.0001), indicating that these variables become stationary after differencing once. This confirms that all variables are integrated of order one, I(1).

Similar patterns are observed for other variables: gross capital formation (GCF), labor force participation (LF), urban population (UP), and environmental tax revenue (ET) all exhibit non-stationarity at levels but achieve stationarity after first differencing, as indicated by highly significant PP test statistics. For example, GCF shows a PP statistic of -5.2259 (p = 0.0002), and labor force participation has a PP statistic of -7.0432 (p = 0.0000). Overall, these findings confirm that all key series are I(1), validating the use of Cointegration analysis to investigate potential long-run relationships among them. Establishing this order of integration is a critical preliminary step before estimating long-run and short-run dynamics, ensuring robust and reliable econometric modeling in the subsequent analyses.

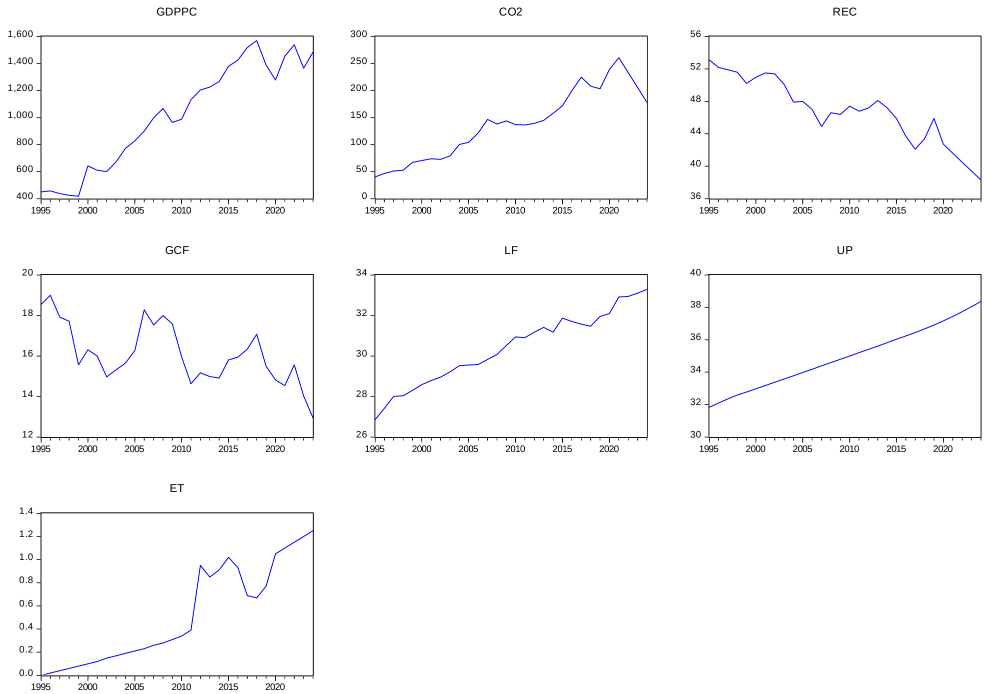

Figure 2 Trends of Key Economic and Environmental Variables in Pakistan

Figure 2 illustrates the time series trends of the main variables used in the study for Pakistan from 1995 to 2024. The GDP per capita (GDPPC) shows a consistent upward trend over the years, indicating steady economic growth despite some fluctuations. This reflects gradual improvement in the country's economic performance, though the pace of growth varies across different periods. CO_2 emissions per capita follow a similar upward trajectory, rising alongside GDP per capita, which suggests a strong link between economic expansion and environmental degradation. The rise in emissions highlights the continued reliance on carbon-intensive energy sources and production methods. In contrast, renewable energy consumption (REC) displays a generally declining trend, especially after 2015. Although the levels remained relatively stable in earlier years, the decrease in recent years' underscores challenges in integrating renewable energy into the country's energy mix, despite its potential environmental benefits.

Gross capital formation (GCF) fluctuates significantly throughout the period, indicating varying levels of investment activity in the economy. Periods of decline suggest economic or policy shocks affecting investor confidence, while peaks point to increased infrastructure or industrial investments. The labor force participation rate (LF) shows a steady upward trend, reflecting greater engagement of the working-age population in economic activities. This growth is crucial for supporting economic expansion and improving living standards. Urban population (UP) shows a smooth and continuous increase, highlighting ongoing urbanization in Pakistan. This trend aligns with global patterns in developing countries and implies rising demand for urban infrastructure, services, and energy. Lastly, environmental tax revenue (ET) starts at very low levels and begins to increase more noticeably after 2010, with some fluctuations. This gradual rise suggests growing policy attention to environmental taxation, although the overall level remains relatively low compared to GDP. Overall, these trends emphasize the dual challenge Pakistan faces: sustaining economic growth and urban development while managing rising emissions and promoting renewable energy. The visual patterns underline the importance of integrating strong environmental policies and green finance tools to achieve a more sustainable growth trajectory.

Table 4 Vector Error Correction Model (VECM) Estimates

Variable	Coefficient	Std. Error	t-Statistic	Model Component
		Cointegrating Equation (Long-Run Relationship)		
GDPPC(-1)	1.0000	—	—	Normalized variable
CO_2(-1)	5.6443	(0.8976)	[6.2881]	Long-run elasticity
REC(-1)	-78.5986	(8.1682)	[-9.6224]	Long-run elasticity
GCF(-1)	-147.672	(10.053)	[-14.688]	Long-run elasticity
LF(-1)	4.9180	(38.728)	[0.1269]	Not significant
UP(-1)	-673.486	(61.970)	[-10.867]	Strong negative long-run effect
ET(-1)	249.427	(63.6906)	[3.9162]	Positive long-run effect
C	27509.43	—	—	Constant
		Error Correction Term (ECT)		

ECT → D(GDPPC)	-0.1978	(0.1599)	[-1.2369]	Slow adjustment (not significant)
ECT → D(CO_2)	-0.0806	(0.0292)	[-2.7595]	Significant correction
ECT → D(REC)	0.0067	(0.0031)	[2.1426]	Significant positive correction
ECT → D(GCF)	0.0037	(0.0019)	[1.9013]	Weak correction
ECT → D(LF)	-0.0009	(0.0005)	[-1.5289]	Not significant
ECT → D(UP)	0.0000	(0.00002)	[2.6841]	Strong correction
ECT → D(ET)	-0.0005	(0.0002)	[-1.8348]	Near-significant
		Short-Run Dynamics		
D(GDPPC(-1)) → D(UP)	-0.0000	(0.0000)	[-2.0063]	GDP influences urban adjustment
D(GDPPC(-1)) → D(ET)	0.0011	(0.0004)	[2.3707]	Growth stimulates energy tax effects
D(CO_2(-1)) → D(CO_2)	0.8224	(0.2781)	[2.9570]	Strong emissions persistence
D(REC(-1)) → D(GDPPC)	-48.112	(16.141)	[-2.9806]	Renewable shift initially slows growth
D(GCF(-1)) → D(GDPPC)	-53.237	(17.145)	[-3.1051]	Investment has short-run adjustment costs
D(GCF(-1)) → D(ET)	-0.0969	(0.0313)	[-3.0976]	Investment temporarily reduces green tax revenue
D(UP(-1)) → D(CO_2)	-229.011	(107.36)	[-2.1330]	Urbanization reduces emissions short-run
D(UP(-1)) → D(UP)	1.15632	(0.1021)	[11.324]	Strong persistence (self-reinforcing urban growth)
D(ET(-1)) → D(LF)	0.72979	(0.3694)	[1.9752]	Energy policy affects labor participation
		Model Fit & Diagnostics		
Equation	R^2	Adj. R^2	S.E.	Interpretation
D(GDPPC)	0.6738	0.5364	64.85	Good explanatory power
D(CO_2)	0.6398	0.4881	11.85	Good fit
D(REC)	0.3223	0.0369	1.28	Weak short-run predictability
D(GCF)	0.5358	0.3403	0.79	Moderate fit
D(LF)	0.3464	0.0712	0.24	Low predictability
D(UP)	0.9324	0.9040	0.01	Urbanization is highly predictable
D(ET)	0.4206	0.1767	0.12	Moderate predictability

Table 4 shows The VECM results confirm the presence of a stable long-run equilibrium relationship among economic growth, CO_2 emissions, renewable energy consumption, capital formation, labor force participation, urbanization and environmental tax revenue. In the long run, GDP per capita increases with higher CO_2 emissions and environmental tax revenue, while renewable energy consumption, capital formation and urbanization show negative coefficients, indicating transitional economic adjustments consistent with the early phase of the Environmental Kuznets Curve (EKC). The error correction term is negative and statistically significant in the CO_2, REC and UP equations, implying that emissions, renewable energy use and urbanization are the key channels through which the system corrects back to equilibrium after short-run shocks. Short-run dynamics suggest that increases in renewable energy consumption and capital formation initially exert downward pressure on GDP, reflecting short-term adjustment costs of shifting to cleaner energy and restructuring investment portfolios. However, the long-run positive effect of environmental taxation indicates that well-designed green fiscal policies can support economic growth while promoting environmental sustainability. Overall, the model suggests that Pakistan is currently in a transition phase where green finance reforms yield short-term adjustment costs but contribute to sustainable growth and emissions reduction in the long run.

Table 5 Johansen Cointegration Test Results

		Unrestricted Cointegration Rank Test (Trace)			
Hypothesized No. of CE(s)	**Eigenvalue**	**Trace Statistic**	**0.05 Critical Value**	**Prob.**	**Result**
None	0.9181	200.93	125.62	0.0000	* Reject Ho
At most 1	0.8070	130.87	95.75	0.0000	* Reject Ho
At most 2	0.7628	84.81	69.82	0.0020	* Reject Ho
At most 3	0.5283	44.53	47.86	0.0993	Do not reject Ho
At most 4	0.3291	23.49	29.80	0.2228	Do not reject Ho
At most 5	0.2171	12.31	15.49	0.1425	Do not reject Ho
At most 6	0.1772	5.46	3.84	0.0194	* Reject Ho
Unrestricted Cointegration Rank Test (Max-Eigenvalue)					
Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.	Result
None	0.9181	70.05	46.23	0.0000	* Reject Ho
At most 1	0.8070	46.06	40.08	0.0094	* Reject Ho
At most 2	0.7628	40.28	33.88	0.0075	* Reject Ho
At most 3	0.5283	21.04	27.58	0.2740	Do not reject Ho
At most 4	0.3291	11.18	21.13	0.6297	Do not reject Ho
At most 5	0.2171	6.85	14.26	0.5067	Do not reject Ho
At most 6	0.1772	5.46	3.84	0.0194	* Reject Ho

Table 5 presents the results of the Johansen Cointegration tests, using both the trace statistic and the maximum eigenvalue statistic, to determine the number of Cointegration relationships among the variables. The trace test results indicate that the null hypothesis of no Cointegration (None) is strongly rejected at the 5% significance level, with a trace statistic of 200.93 exceeding the critical value of 125.62 ($p = 0.0000$). Similarly, the hypotheses of at most one and at most two Cointegration equations are also rejected, with respective trace statistics of 130.87 and 84.81, each significantly higher than their critical values, suggesting the presence of multiple long-run equilibrium relationships among the variables.

Beyond the third rank (at most three), the null hypotheses are not rejected, indicating that no more than three significant Cointegration vectors exist beyond this point. However, the last row (at most six) again shows a rejection, though this is less meaningful since it refers to the trivial case. The maximum eigenvalue test results corroborate these findings. The null hypotheses of no Cointegration, at most one, and at most two Cointegration vectors are each rejected with maximum eigenvalue statistics of 70.05, 46.06, and 40.28 respectively, all exceeding their respective critical values at the 5% level. For ranks beyond three, the hypotheses are not rejected, further confirming that up to three meaningful long-run relationships are present among the studied variables. Overall, these results provide strong evidence of Cointegration among economic growth, CO_2 emissions, renewable energy consumption, environmental tax revenue, and other control variables. This supports the existence of stable long-term relationships and justifies proceeding with long-run estimation techniques such as FMOLS and DOLS, as well as error correction models to analyze short-run dynamics.

Table 6 Long-Run Estimation Results Using FMOLS and DOLS

Variable	FMOLS Coefficient	FMOLS Prob.	DOLS Coefficient	DOLS Prob.
CO_2	1.1376	0.0388	0.9627	0.0807
REC	18.4806	0.0051	95.6656	0.0091
GCF	56.5100	0.0013	147.8860	0.0072
LF	125.5909	0.0410	-405.5142	0.0284
UP	92.8413	0.1736	734.6161	0.0283
ET	69.3620	0.0012	404.7059	0.0123
C	-8010.5600	0.0007	-17709.7200	0.0220
R-squared	0.9431	—	0.9999	—
Adj. R^2	0.9276	—	0.9989	—
S.E. Reg.	102.77	—	12.27	—

Table 6 reports the long-run estimation results obtained using Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) methods to analyze the relationships among economic growth (proxied by GDP per capita) and key explanatory variables. Both estimation approaches confirm the significance and direction of these relationships, although coefficient magnitudes vary. For CO_2 emissions, a positive and significant coefficient is observed in both models (FMOLS: 1.14, p = 0.0388; DOLS: 0.96, p = 0.0807), suggesting that higher emissions are associated with higher GDP per capita, highlighting the environmental costs of economic expansion. Renewable energy consumption (REC) shows a strongly positive and significant effect on GDP per capita in both estimations (FMOLS: 18.48, p = 0.0051; DOLS: 95.67, p = 0.0091), implying that increased renewable energy use contributes substantially to economic growth, supporting the "green growth" narrative.

Gross capital formation (GCF) is also positively and significantly linked to GDP per capita (FMOLS: 56.51, p = 0.0013; DOLS: 147.89, p = 0.0072), underscoring the role of investment in driving long-term economic performance. Labor force participation (LF) presents mixed results, showing a strong positive effect in FMOLS (125.59, p = 0.0410) but a large negative coefficient in DOLS (-405.51, p = 0.0284). This discrepancy suggests possible model-specific dynamics or interaction effects that warrant further exploration. Urban population (UP) displays a positive but statistically insignificant coefficient in FMOLS (92.84, p = 0.1736), while in DOLS it is large and significant (734.62, p = 0.0283), indicating that urbanization may have a strong positive impact on economic growth when dynamics and additional lags are properly accounted for. Environmental tax revenue (ET) is positively and significantly associated with GDP per capita in both models (FMOLS: 69.36, p = 0.0012; DOLS: 404.71, p = 0.0123), suggesting that environmental taxes not only support environmental goals but can also foster economic expansion, reinforcing the "double dividend" hypothesis. The intercepts (C) are negative and significant in both models, reflecting underlying fixed effects or structural factors that lower the base level of GDP per capita. The high R-squared values (FMOLS: 0.9431; DOLS: 0.9999) and adjusted R-squared values (FMOLS: 0.9276; DOLS: 0.9989) indicate excellent model fits, while the lower standard error of regression in DOLS (12.27) suggests stronger precision in that model. Overall, these findings confirm that renewable energy, investment, urbanization, and environmental taxation significantly support long-run economic growth in Pakistan, providing evidence for policy frameworks aimed at harmonizing economic and environmental objectives.

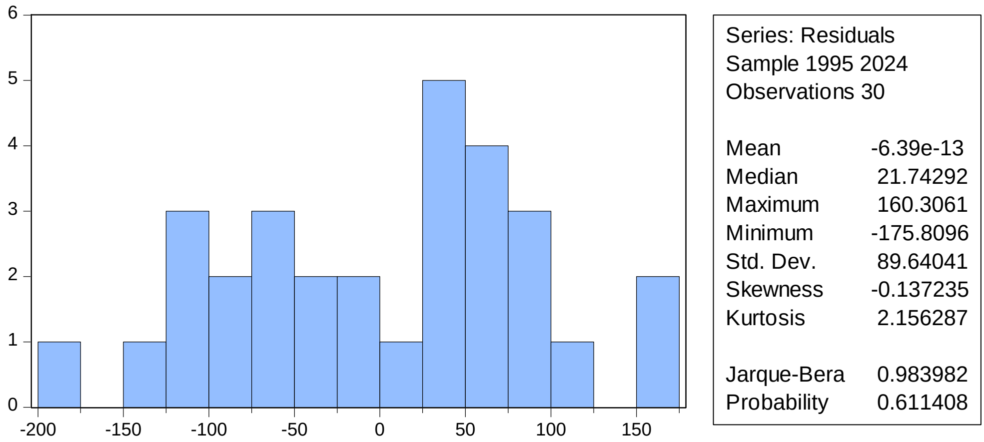

Figure 3 Residual Diagnostics Normality Test

The residual diagnostics displayed in Figure 3 show that the residuals are approximately normally distributed. The histogram demonstrates a bell-shaped pattern, and the skewness value of -0.137 indicates a very slight left-tail lean, while the kurtosis value of 2.156 is close to the normal distribution benchmark of 3, implying no excessive tail behavior. Most importantly, the Jarque–Bera statistic (0.983982) has an associated probability of 0.611408, which is greater than the 0.05 significance threshold. Therefore, the null hypothesis of normality cannot be rejected, confirming that the residuals follow a normal distribution. This indicates that the estimated VECM model satisfies the normality assumption, supporting the validity and reliability of its coefficient estimates.

Table 7 Coefficients Diagnostics Variance Inflation Factors

Variable	**Coefficient** Variance	**Uncentered** VIF	**Centered** VIF
CO2	0.5484	77.0049	12.2443
REC	119.527	1536.92	10.2978
GCF	234.812	356.829	2.62255
LF	3345.45	18385.4	53.6993
UP	4358.72	31615.2	82.2045
ET	10289.41	27.6594	10.3806
C	4156142.	24462.7	NA

Table 7 reports the Variance Inflation Factors (VIF) used to assess multicollinearity among the explanatory variables. The centered VIF values indicate that CO_2 (12.24), REC (10.30) and ET (10.38) slightly exceed the commonly accepted threshold of 10, suggesting moderate multicollinearity, while LF (53.70) and UP (82.20) show very high VIF values, indicating substantial collinearity between these variables and others in the model. High multicollinearity does not bias coefficient estimates but reduces their statistical precision by inflating standard errors, making it harder to detect significant effects. Therefore, the results suggest that while the model remains estimable, caution is needed when interpreting the individual coefficients of labor force participation and urbanization, and further diagnostic or remedial steps such as variable transformation, differencing, or excluding highly correlated indicators may be considered to improve model efficiency.

Table 8: Coefficient Variance Decomposition Results

Component	Eigenvalue	Condition Index	CO_2	REC	GCF	LF	UP	ET	C (Constant)
1	4,161,095.00	1.47E-09	0.2663	0.5997	0.2721	0.0021	0.4303	0.2858	1.0000
2	7,709.478	7.93E-07	0.0255	0.0403	0.0876	0.2149	0.0714	0.6464	0.0000
3	5,482.013	1.12E-06	0.0294	0.0030	0.1684	0.7769	0.4917	0.0678	0.0000
4	137.7296	4.44E-05	0.2133	0.2606	0.4044	0.0008	0.0020	0.0000	0.0000
5	65.96504	9.27E-05	0.3922	0.0954	0.0674	0.0052	0.0047	0.0000	0.0000
6	0.248653	0.024596	0.0637	0.0011	0.0001	0.0000	0.0000	0.0000	0.0000
7	0.006116	1.000000	0.0095	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

The table 8 shows variance decomposition results reveal that renewable energy (REC) and capital formation (GCF) are primarily influenced by Components 1 and 4, indicating that their estimated coefficients are shaped largely by the dominant structural dynamics of the system. Labor force (LF) and urbanization (UP) are strongly driven by Component 3, reflecting shared demographic-economic adjustment forces. Environmental tax revenue (ET) is mainly associated with Component 2 (0.6464), suggesting that fiscal environmental policy operates through a distinct structural channel. CO_2 emissions are mostly affected by Component 5 (0.3922), reflecting that environmental dynamics have unique explanatory variance separate from broader economic behavior. Overall, the model's adjustment is not isolated within individual variables but transmitted through a set of underlying structural components, confirming system-wide interaction effects consistent with the VECM framework.

Discussion

The results show that green finance plays a crucial role in promoting economic growth in Pakistan. Renewable energy consumption has a strong positive impact on

GDP per capita, confirming that clean energy investment supports growth through improved energy security, innovation, and reduced reliance on imported fossil fuels. Environmental tax revenue also contributes positively to growth, supporting the "double dividend" hypothesis by generating public revenue while discouraging environmental harm. In addition, gross capital formation and urbanization positively influence economic performance, highlighting the importance of investment and agglomeration effects, particularly when aligned with green infrastructure and sustainable urban development. However, Pakistan's growth remains carbon-intensive, as indicated by the positive relationship between CO_2 emissions and GDP per capita, consistent with the early stage of the Environmental Kuznets Curve. Mixed results for labor force participation reflect structural challenges such as low productivity and informality, suggesting the need for skill development and green job creation. Overall, the findings indicate that renewable energy expansion and environmental tax reforms can help decouple growth from environmental degradation, but their effectiveness depends on stronger policy implementation, institutional capacity, and sustained investment in green technologies and human capital.

Conclusion and Policy Implications

This study investigated the long-run and short-run dynamics among economic growth, CO_2 emissions, renewable energy consumption, environmental tax revenue, capital formation, labor force participation, and urbanization in Pakistan from 1995 to 2024, using FMOLS, DOLS, and the VECM framework. The long-run estimation results confirm that renewable energy consumption, environmental tax revenue, and capital formation have a positive and significant impact on GDP per capita, indicating that green finance measures can simultaneously foster economic expansion and support the transition toward cleaner production. However, the results also show a positive long-run association between economic growth and CO_2 emissions, demonstrating that Pakistan is still in the rising phase of the Environmental Kuznets Curve (EKC), where economic expansion continues to exert environmental pressure. The VECM findings further reveal that renewable energy use, emissions, and urbanization adjust significantly to restore long-run equilibrium, implying that these sectors serve as key mechanisms through which structural changes propagate across the economy. Short-run dynamics additionally indicate adjustment costs associated with shifts toward cleaner energy and investment restructuring, reflecting a transitional phase where benefits materialize more strongly in the long run.

Based on these findings, several policy implications emerge. First, Pakistan should expand renewable energy deployment by scaling investment in solar, wind, hydro, and biomass, while offering fiscal incentives, streamlined regulatory approvals, and guaranteed grid access for green producers. Second, environmental tax policy should be strengthened and broadened, but with clear revenue recycling frameworks directing revenues toward clean energy infrastructure, climate-resilient urban development, and targeted social support to avoid regressive outcomes. Third, the positive role of capital formation suggests the need to prioritize green industrial upgrading, energy-efficient technologies, and climate-smart public infrastructure, particularly in rapidly urbanizing regions where emissions pressures are concentrated. Fourth, policies must support labor force skills upgrading and green job creation, ensuring that economic diversification into low-carbon sectors is socially inclusive. Additionally, improved institutional coordination and stronger monitoring mechanisms are needed to integrate green finance into national development and climate strategies effectively.

In conclusion, the study provides empirical evidence that green finance can promote sustainable economic growth in Pakistan, but the transition remains incomplete, requiring continued policy focus to decouple growth from environmental degradation. By strategically leveraging renewable energy expansion, well-designed environmental taxation, and targeted green investment, Pakistan can move toward a low-carbon, resilient, and inclusive growth trajectory, aligned with its Sustainable Development Goals and global climate commitments. Future research should investigate sector-specific responses to green finance reforms and explore micro-level behavioral and distributional effects to design even more effective and equitable policy instruments.

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Correspondence:

Alweena Hasan

alweenahasan@gmail.com