



Heterogeneous effects of FDI, energy poverty, and resource rents on agricultural environmental degradation in Pakistan: Quantile regression evidence

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ABSTRACT

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The energy–environment nexus has received empirical attention; however, limited evidence explains how geographically contingent factors, including foreign direct investment, energy poverty, resource depletion, resource rents, and renewable energy, collectively shape agriculture-related environmental degradation. This research explores the heterogeneous impact of foreign direct investment, economic growth, traditional energy use, resource depletion, natural resource rents, renewable energy consumption, and renewable energy production on Pakistan's agricultural environmental degradation using annual data from 1990 to 2021 from the World Bank's World Development Indicators (WDI) database. Quantile regressions at the 25th, 50th, and 75th percentiles were used to examine heterogeneous impacts across low-, medium-, and high-emission regimes in Pakistan. The heterogeneous results indicate that foreign direct investment increases environmental degradation. Economic growth increases emissions across all quantiles, demonstrating that Pakistan's economic growth trajectory remains environmentally intensive. Environmental degradation in Pakistan increases with natural resource rents, suggesting that resource dependency and governance conditions affect environmental conditions. Energy poverty contributes to higher emissions by intensifying inefficient energy demand in agriculture. Renewable energy consumption and production mitigate emissions in Pakistan. The results underline the need for an integrated geospatial and sustainability framework to align green FDI reforms (Sustainable Development Goal 9), renewable energy expansion (SDG 7), responsible resource management (SDG 12), and climate action strategies (SDG 13) to reduce environmental degradation in Pakistan and advance progress toward the Sustainable Development Goals.

Contribution/Originality: This study uses quantile regression to examine the heterogeneous effect on environmental degradation in Pakistan as compared to traditional regression with implication for SDGs achievement and a sustainable environment.

1. INTRODUCTION

Sustainability faces hurdles due to environmental degradation across the globe. Environmental degradation damages ecosystems, climate stability, human health, and socioeconomic development. It is caused by an imbalance between anthropogenic pressures and the capacity of natural systems to recover. Across the globe, policymakers and scientific experts are confronting rising biodiversity loss, air and water pollution, resource depletion, and climate-related changes, which they consider global issues (Barkat, Alsamara, Al Kwifi, & Jarallah, 2025; Butty, Seraj, & Özdeşer, 2025; Najia, Taher, & Elkader, 2024; Wang, Gillani, Balsalobre-Lorente, Shafiq, & Khan, 2025). Existing literature shows that environmental degradation is shaped by multiple interacting drivers, including renewable and conventional energy use, natural resource depletion and rents, energy poverty, economic growth, and foreign direct investment. These factors may influence ecosystems and long-term environmental sustainability through different pathways, depending on the structure of energy systems, resource governance, and development trajectories.

However, among the various elements of environmental degradation, traditional energy sources, particularly the use of fossil fuels, have an acute impact because they directly contribute significantly to carbon emissions and climate change (Habib, Ali, Mehmood, & Abd Rahman, 2025). In contrast, emissions are mitigated by the crucial role of renewable energy consumption, which enhances environmental sustainability, particularly when renewable energy is supported by environmental technological innovation and effective institutional quality (Almulhim, Inuwa, Chaouachi, & Samour, 2025; Han, Peng, Guo, Aslam, & Xu, 2025). The environmental impacts of renewable energy consumption in the short run are context-dependent, whereas its long-run effectiveness in mitigating environmental degradation has been confirmed (Bashir, Pata, & Shahzad, 2025; Shah, Balsalobre-Lorente, Radulescu, Zhang, & Hussain, 2025). These findings highlight the critical importance of transitioning to cleaner energy systems and their impact on environmental quality. However, dependence on fossil fuels remains a key driver of environmental issues, while renewable energy infrastructure requires resource-intensive development that contributes to the depletion of natural resources. If not developed and utilized sustainably, it may exert additional environmental impacts. As a result, beyond energy consumption patterns, the excessive use and depletion of natural resources are also key reasons why environmental degradation increases.

A major driver of environmental degradation is the depletion of natural resources, particularly in resource-intensive countries that predominantly use unsustainable natural resource extraction practices. Carbon emissions, habitat loss, and biodiversity loss increase with the overexploitation of finite natural resources, including fossil fuels, minerals, and deforestation (Chen & Usman, 2025). Environmental degradation not only increases with the depletion of natural resources but also reduces the recovery capacity of ecosystems by increasing the environmental footprint (Guan, Wang, Mansoor, & Nadeem, 2025). Moreover, revenues from natural resource rents encourage overexploitation and increase corruption, which decreases the effectiveness of government institutions and leads to inefficient environmental management (Qamruzzaman, 2025). Ecological problems and carbon emissions increase environmental costs in resource-intensive economies as they pursue economic development. To ensure environmental sustainability, these economies require stronger and more effective environmental policies and sustainable natural resource management. In addition, natural resource depletion not only intensifies environmental problems but also reduces access to affordable and clean energy sources. This increases dependence on traditional energy sources, intensifies energy poverty, and exacerbates environmental degradation.

As a result, energy poverty poses both a social and environmental challenge in emerging economies. Environmental degradation increases with energy poverty due to heavy dependence on traditional energy sources, including carbon-intensive fuels such as wood, charcoal, and kerosene. This energy pattern is common among households in low- and middle-income economies and causes higher carbon emissions and increased climate-related risks (Butty et al., 2025; Ullah, Khan, & Ahmad, 2025). Socioeconomic development slows due to limited access to modern energy sources, which increases inequality and limits investment in sustainable infrastructure (Dudzińska, Baciór, & Prus, 2018; Zhiña et al., 2025). Policies aimed at reducing energy poverty and environmental degradation through the expansion of fossil fuel energy may conflict with environmental sustainability if they are not aligned with clean energy strategies for sustainable development (Kumara, Azam, Abbas, & Ullah, 2025). Increasing access to modern energy can help alleviate energy poverty and support environmental protection; however, energy poverty limits the development of energy infrastructure and reduces foreign direct investment (FDI). Investment in environmentally unsustainable projects increases environmental degradation in economies already affected by energy poverty.

The role of FDI is crucial in shaping environmental degradation. Environmental degradation is influenced by FDI, depending on the host country's regulatory framework and level of technological development. Strong environmental regulations and innovation-driven strategies can improve environmental quality by encouraging investment in environmentally friendly production practices and cleaner technologies (Gibbs, 2020; Xiao et al., 2026). Conversely, countries with relaxed environmental regulations for investors may experience increased environmental degradation due to the establishment of pollution-intensive industries, supporting the pollution haven hypothesis (Kumar & Wu, 2025). Although FDI contributes to economic growth, evidence from emerging economies shows that its environmental sustainability depends on the strength of regulatory policies and sustainable investment governance for reducing environmental degradation (Awan, Nawaz, & Razzaq, 2025; Salman, Xiang, & Naeem, 2025).

Although previous studies have examined the energy-environment relationship, important research gaps remain. First, the existing literature examines the impacts of energy consumption and economic growth on the environment while paying limited attention to the effects of energy poverty, natural-resource depletion and rents, traditional energy consumption, renewable energy consumption and production, economic growth, and FDI on both agricultural-sector and energy-related carbon emissions in Pakistan. These factors are rarely analysed within a single, integrated sustainability framework (Butty et al., 2025; Chen & Usman, 2025; Wang et al., 2025). This limitation is particularly important in Pakistan, where agriculture constitutes a major component of the economy and environment. The agricultural sector contributes around 23.5% of Pakistan's national GDP and employs 37% of the labour force, reflecting its central role in economic growth, food security, and rural livelihoods (Government of Pakistan, 2025). The agricultural sector is also environmentally significant. Pakistan's first Biennial Transparency Report indicates that the agriculture, forestry, and other land-use sector accounted for approximately 47% of national greenhouse-gas emissions (Ministry of Climate Change and Environmental Coordination, 2024). Livestock alone generated approximately 53% of these emissions, primarily through enteric fermentation and manure management (Food and Agriculture Organization of the United Nations, 2025). These economic and environmental characteristics justify examining how investment, energy poverty, resource dependence, conventional energy use, and the renewable-energy transition influence environmental degradation in Pakistan's agricultural economy. As a developing country, Pakistan remains heavily dependent on traditional energy resources, i.e., fossil fuels, to meet its energy demand for

economic development. To capture different dimensions of environmental degradation, this study estimates three separate quantile-regression models using three dependent variables obtained from the World Development Indicators database. The first is CO₂ emissions from gaseous-fuel consumption as a percentage of total fuel-related CO₂ emissions (DP1). The second is methane emissions from agriculture, measured in MtCO_{2e} (DP2), while the third is carbon dioxide emissions from agriculture, also measured in MtCO_{2e} (DP3). DP2 and DP3 directly capture agriculture-specific environmental pressures, whereas DP1 is an indicator of the broader energy-related carbon structure in Pakistan. In Pakistan, traditional energy sources, particularly oil, natural gas, and coal, are believed to be major drivers of environmental degradation. Achieving the Sustainable Development Goals (SDGs) by 2030, particularly those related to energy transition and sustainable development, is difficult because of continued dependence on traditional energy resources. This creates a research gap in the literature because of the fragmented approach and the lack of a comprehensive understanding of the structural drivers of environmental degradation. Measuring environmental degradation alongside socioeconomic factors presents challenges in developing a quantifiable and distribution-sensitive framework that accounts for different emission levels and development conditions. Existing literature indicates that statistical approaches enhance the diagnosis of structural disparities (Czapiewski & Janc, 2008; Noszczyk, Rutkowska, & Hernik, 2017). In this research, we used a structured quantitative design to identify the main drivers of environmental degradation in Pakistan and provide policy-relevant insights.

Second, although previous research has used traditional regression models, simple regression examines only the uniform effects of independent variables on the dependent variable. Traditional regression ignores variations in how economic, energy, and resource-related factors affect environmental degradation under low-, medium-, and high-emission conditions. To address this methodological gap, this research used quantile regression techniques to examine heterogeneous effects across the emissions distribution. Quantile regression provides a more nuanced and robust analysis than traditional regression by capturing distributional differences that were ignored in earlier studies (Barkat et al., 2025; Bashir et al., 2025).

Third, from a policy perspective, this integrated research approach, which considers differences across emission levels, provides clearer and more targeted guidance for sustainable development planning in Pakistan. The study directly contributes to SDG 7 (Affordable and Clean Energy) by examining renewable energy adoption and clean fuel access (Xiao et al., 2026); SDG 9 (Industry, Innovation, and Infrastructure) through the technological role of FDI inflows (Barkat et al., 2025); SDG 12 (Responsible Consumption and Production) by emphasizing sustainable natural resource management (Chen & Usman, 2025; Guan et al., 2025); and SDG 13 (Climate Action) by examining the drivers of CO₂ and CH₄ emissions across Pakistan's energy and agricultural sectors (Wang et al., 2025). This study addresses the following research question: How do FDI, energy poverty, resource depletion, resource rents, economic growth, and conventional and renewable energy use affect agricultural environmental degradation across different emission quantiles in Pakistan?

2. LITERATURE REVIEW

Empirical evidence demonstrates that carbon emissions are reduced by renewable energy consumption across developed and emerging economies, which supports environmental sustainability (Muhammad, Khan, Khan, & Khan, 2021; Naimoğlu & Akal, 2024). Renewable energy consumption lowers pollution levels in country-level studies,

particularly when supported by strong regulations and innovation frameworks (Adebayo & Kirikkaleli, 2021; Karasoy & Akçay, 2019). However, environmental sustainability remains conditional and gradual.

In contrast, the continued dependence on fossil fuels, which dominate the energy structure of developing countries, contributes significantly to environmental degradation (Appiah, Du, Yeboah, & Appiah, 2019; Solarin, 2020). Dependence on carbon-intensive energy resources increases alongside economic and population growth in emerging economies, thereby restricting the environmental benefits of renewable energy transitions (Li et al., 2023). Emerging economies face structural challenges in balancing clean energy implementation with persistent fossil fuel consumption, whereas renewable energy consumption helps mitigate environmental degradation and dependence on fossil fuels increases emissions.

Fossil fuel consumption is considered a central element of environmental degradation because of its strong relationship with greenhouse gas emissions. Empirical research shows that coal, oil, and natural gas consumption significantly increase carbon emissions across countries (Depren, Kartal, Çelikdemir, & Depren, 2022; Kartal, Kılıç Depren, Ayhan, & Depren, 2022). Continued reliance on fossil fuels undermines environmental sustainability (Das, Bhattacharya, & Sethi, 2011; Lim, Chang, & Holmes, 2014). In contrast to renewable energy, whose environmental benefits are well documented in the literature, fossil fuels continue to dominate the global energy mix and slow the transition toward a low-carbon economy, thereby intensifying ecological degradation (Mukhtarov, 2022; Oliveira & Moutinho, 2021). Dependence on fossil fuels not only increases emissions but also accelerates the depletion of natural resources, limiting long-term sustainability.

The depletion of natural resources is a major driver of environmental degradation. Empirical studies from Sub-Saharan Africa, Asia, and Latin America demonstrate that the overuse of forests, fossil fuels, and agricultural land increases carbon emissions, biodiversity loss, and water scarcity (Byaro, Nkonoki, & Mafwolo, 2023). In resource-rich developing countries, weak institutional quality and heavy dependence on resource rents further exacerbate environmental issues (Xie, Wang, Wang, & Zhang, 2023). Similarly, Duan, Wang, Wang, Wang, and Hou (2023) indicated that the interaction between rapid industrialization and resource depletion has been linked to land and ecological degradation in transition economies (Duan et al., 2023). However, although natural resources promote economic growth, their unsustainable depletion undermines long-term environmental stability. In contrast to conservation-based management, extractive growth strategies increase ecological degradation and weaken environmental sustainability (Duan et al., 2023; Xie et al., 2023). Moreover, high resource depletion restricts access to affordable and reliable energy, particularly in economies dependent on natural resources, thereby reinforcing energy poverty and environmental vulnerability (Byaro et al., 2023).

In developing economies, energy poverty contributes to environmental degradation. Households with limited access to modern energy depend on biomass and fossil-based fuels that increase deforestation, carbon emissions, and indoor air pollution (Batool, Zhao, Sun, & Irfan, 2023). Empirical evidence from Sub-Saharan African countries confirms that energy poverty reinforces the consumption of environmentally harmful fuels that reduce ecosystem stability and agricultural productivity (Dimnwobi, Okere, Onuoha, & Ekesiobi, 2023). These effects increase during crises, which further worsen environmental and health issues (Zafar, Shahbaz, Hou, & Sinha, 2022). However, foreign direct investment (FDI) helps reduce energy poverty by improving energy infrastructure and access to clean energy (Zafar et al., 2022), but its environmental impact depends on sectoral allocation and regulatory quality. While FDI

invested in green-oriented projects supports sustainability, investment in carbon-intensive sectors further increases environmental degradation (Batool et al., 2023; Dimnwobi et al., 2023).

Foreign direct investment (FDI) in BRICS economies is associated with higher carbon emissions due to increased industrial activity and high energy demand, particularly under relaxed environmental regulations (Pradhan, Sachan, Sahu, & Mohindra, 2022). This confirms the pollution haven hypothesis, which claims that polluting industries relocate to countries with relaxed environmental regulations (Yao, Zhang, & Zhang, 2020). However, the pollution halo hypothesis indicates that FDI improves environmental performance through investments in cleaner technologies and more efficient production methods that reduce environmental degradation (Zhang, Wang, & Liu, 2021). Findings from empirical studies remain mixed: some studies demonstrate that FDI increases emissions through fossil-fuel-intensive production, whereas others confirm that it reduces environmental degradation through technology transfer and energy-efficiency improvements (Yaqoob, Hussain, & Ahmed, 2021). These findings confirm that FDI's environmental impact is conditional on the host country's regulations and governance framework for investment.

3. DATA AND METHODS

3.1. Variables' Data Source and Description

This research used annual time-series data for Pakistan from 1990 to 2021. The study aims to examine the impacts of energy poverty, natural resource depletion and rents, traditional energy consumption, renewable energy consumption and production, economic growth, and FDI on environmental degradation in Pakistan. Variables were selected based on recent empirical literature. CO₂ emissions from fuel consumption, methane emissions, and CO₂ emissions from agriculture are used as indicators of environmental degradation in the agricultural sector (Butty et al., 2025; Wang et al., 2025). These studies stressed that fossil-fuel energy use in the agricultural sector increases emissions. Bashir et al. (2025) demonstrated that fossil-fuel consumption is associated with higher environmental degradation, while financial reliance on the extraction of natural resources through unsustainable methods decreases environmental sustainability (Chen & Usman, 2025; Guan et al., 2025). Energy poverty is measured by access to clean fuels and technologies for cooking, reflecting social and environmental disparities (Butty et al., 2025). The energy transition and decarbonization can be achieved through renewable energy consumption and renewable electricity production, which help reduce environmental issues (Xiao et al., 2026). The pollution haven and halo hypotheses depend on foreign direct investment (FDI) and its role in shaping environmental issues (Barkat et al., 2025). The Environmental Kuznets Curve (EKC) hypothesis demonstrates the nonlinear association between economic growth and environmental degradation (Barkat et al., 2025; Wang et al., 2025). The number of observations differs across variables due to the unavailability of data for certain series. As data were not available for the full sample period, no interpolation or imputation was performed for missing observations, resulting in an effective sample size of 15, despite the data range spanning 1990 to 2021 for Pakistan. Table 1 presents the variable descriptions.

Based on the above following three time series equations are used to examine the relationship in the study variables.

$$DP1_t^{Qi} = \beta_0 + \beta_1 ID1_t + \beta_2 ID2_t + \beta_3 ID3_t + \beta_4 ID4_t + \beta_5 ID5_t + \beta_6 ID6_t + \beta_7 ID7_t + \beta_8 ID8_t + \beta_9 ID9_t + \varepsilon_t \quad (1)$$

$$DP2_t^{Qi} = \beta_0 + \beta_1 ID1_t + \beta_2 ID2_t + \beta_3 ID3_t + \beta_4 ID4_t + \beta_5 ID5_t + \beta_6 ID6_t + \beta_7 ID7_t + \beta_8 ID8_t + \beta_9 ID9_t + \varepsilon_t \quad (2)$$

$$DP3_t^{Qi} = \beta_0 + \beta_1 ID1_t + \beta_2 ID2_t + \beta_3 ID3_t + \beta_4 ID4_t + \beta_5 ID5_t + \beta_6 ID6_t + \beta_7 ID7_t + \beta_8 ID8_t + \beta_9 ID9_t + \varepsilon_t \quad (3)$$

In the above three equations DP indicates the dependent variable that is environmental degradation while ID variable shows the independent variables, error term is represented by ε .

Table 1. Variable's description.

Variable Code	Full Variable Name	Data Source
DP1	Carbon dioxide (CO ₂) emissions from Agriculture (Mt CO ₂ e)	World Development Indicators (WDI) World Bank
DP2	Methane (CH ₄) emissions from Agriculture (Mt CO ₂ e)	
DP3	CO ₂ emissions from gaseous fuel consumption (% of total CO ₂ emissions)	
ID1	Foreign direct investment, net inflows (% of GDP)	
ID2	Energy use (kg of oil equivalent per capita)	
ID3	Fossil fuel energy consumption (% of total)	
ID4	GDP growth (Annual %)	
ID5	Adjusted savings: natural resources depletion (% of GNI)	
ID6	Total natural resources rents (% of GDP)	
ID7	Access to clean fuels and technologies for cooking (% of population) proxy used for energy poverty; higher values indicate lower energy poverty	
ID8	Renewable energy consumption (% of total final energy consumption)	
ID9	Renewable electricity output (% of total electricity output)	

3.2. Quantile Regression

To empirically examine the heterogeneous effects of renewable and traditional energy consumption, natural resource depletion and rents, FDI inflows, and economic growth on environmental degradation, this study employs quantile regression (QR) techniques. Unlike traditional mean-based estimators, such as ordinary least squares (OLS), which assume a uniform relationship across the conditional distribution and estimate the conditional mean, quantile regression allows the estimated coefficients to vary across different points of the dependent variable's distribution and estimates conditional quantiles (Koenker & Bassett, 1978).

In QR, the classical OLS minimization of squared residuals is replaced by the minimization of an asymmetric loss function based on absolute deviations, with error weights that depend on the quantile. The estimated 25th quantile (Q₂₅) from the QR model can be interpreted as follows: conditional on the explanatory variables, 25% of observations are expected to fall below the estimated value, while 75% are expected to fall above it. This approach is particularly relevant for environmental and energy studies (Aznarte, 2017; Kamińska & Kazak, 2023), where the impacts of macroeconomic and energy-related variables may differ across low-, medium-, and high-emission regimes (Bashir et al., 2025; Butty et al., 2025).

Table 2. Descriptive statistics results.

Variables	Obs.	Mean	Std. Dev.	Min.	Max.
DP1	32	4.016	1.054	2.182	5.585
DP2	32	118.861	33.969	74.326	186.41
DP3	27	43.59	7.02	34.006	56.015
ID1	32	0.955	0.669	0.31	3.036
ID2	25	416.932	23.624	369.031	461.601
ID3	25	58.109	2.818	52.305	62.476
ID4	32	4.115	2.026	-1.274	7.831
ID5	32	1.3	0.418	0.629	2.155
ID6	32	1.743	0.584	0.965	2.891
ID7	22	36.432	8.45	23.4	51.3
ID8	32	48.928	4.358	41.6	58.1
ID9	32	33.617	4.886	26.577	44.926

The Breusch–Godfrey Lagrange Multiplier (LM) test checks for serial correlation in regression models. It is well suited to time-series analysis because it can accommodate more complex autocorrelation structures and models that include lagged dependent variables (Breusch, 1978; Godfrey, 1978). Quantile regression provides a detailed

understanding of how economic and energy factors affect environmental degradation. By using quantile regression, this research addresses heteroskedasticity and non-normality issues that are common in time-series datasets. This method offers more robust and policy-relevant findings for Pakistan's progress towards the Sustainable Development Goals (SDGs 7, 9, 12, and 13).

4. RESULTS AND DISCUSSIONS

Findings from the descriptive statistics Table 2 show that methane emissions (DP2) have the highest mean (118.86 Mt CO_{2e}), while CO₂ emissions from gaseous fuel consumption (DP3) have a mean of 43.59%, reflecting continued dependence on fossil energy in Pakistan. Furthermore, the findings confirm that the mean values for energy use (ID2) and fossil fuel consumption (ID3) indicate Pakistan's dependence on non-renewable energy resources. The findings indicate that renewable energy consumption (ID8) and renewable electricity production (ID9) show gradual progress toward cleaner energy resources in Pakistan. Critically, the energy poverty measure for access to clean cooking fuels (ID7) has a mean value of 36.4%, underscoring persistent energy poverty and the significant challenge of achieving SDG 7 and SDG 13 goals.

Table 3. Unit root test results.

Variables	ADF (P-Values)	ADF (1st Diff) (P-Values)	PP (P-Values)	PP (1st Diff) (P-Values)
DP1	-1.299	-3.306 (0.0146)	-1.537	-3.368 (0.0121)
DP2	3.502	-4.750 (0.0001)	4.427	-4.867 (0.0000)
DP3	-1.359	-9.912 (0.0000)	-1.057	-12.774(0.0000)
ID1	-1.863	-3.686 (0.0043)	-2.264	-3.652 (0.0048)
ID2	-1.936	-3.792 (0.0030)	-1.919	-3.801 (0.0029)
ID3	-1.579	-3.691 (0.0042)	-1.583	-3.696 (0.0042)
ID4	-4.333	-6.510 (0.0000)	-4.275	-6.901 (0.0000)
ID5	-1.976	-5.126 (0.0000)	-2.284	-5.151 (0.0000)
ID6	-1.593	-5.062 (0.0000)	-1.871	-5.063 (0.0000)
ID7	3.623	-2.822 (0.0552)	4.384	-2.760 (0.0642)
ID8	-1.198	-5.455 (0.0000)	-1.118	-5.516 (0.0000)
ID9	-2.303	-5.240 (0.0000)	-2.300	-5.228 (0.0000)

The findings in Table 3 demonstrate that all variables are non-stationary at the level but become stationary at the first difference. These results confirm integration of order one, I(1). Both the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests demonstrate that variables such as DP1, DP2, DP3, ID1, ID2, ID3, ID5, ID6, ID8, and ID9 become stationary at the first difference ($p < 0.05$). These findings validate their appropriateness for quantile regression.

The findings indicate that GDP growth (ID4) is stationary at level, suggesting short-term stability in economic growth trends, while energy poverty (ID7) becomes weakly stationary at the first difference ($p \approx 0.06$), reflecting gradual but limited progress in energy access. Overall, the findings confirm a mixture of integration orders, I(0) and I(1).

Based on these results, the use of quantile regression models is most suitable for both stationary and non-stationary variables without the requirement of differencing, ensuring robust estimation of the energy-environment nexus in Pakistan.

Table 4. Quantile regression coefficients for carbon dioxide (CO₂) emissions from agriculture (Mt CO₂e).

Variables	DP1 _t ^{Q25}	DP1 _t ^{Q50}	DP1 _t ^{Q75}
ID1	0.482*** (20.41)	0.413* (2.84)	0.312 (2.47)
ID2	-0.0337*** (-16.19)	-0.0209 (-1.63)	0.00626 (0.56)
ID3	-0.184*** (-10.81)	-0.198 (-1.88)	-0.0698 (-0.77)
ID4	0.323*** (33.45)	0.309** (5.19)	0.277** (5.36)
ID5	-7.569*** (-34.79)	-7.061** (-5.26)	-7.085** (-6.09)
ID6	4.559*** (29.66)	4.151** (4.38)	4.593** (5.59)
ID7	0.140*** (37.62)	0.141** (6.13)	0.120** (6.02)
ID8	-0.268*** (-15.11)	-0.194 (-1.78)	0.0254 (0.27)
ID9	-0.135*** (-17.25)	-0.142* (-2.95)	-0.122* (-2.93)
_cons	42.72*** (20.48)	34.97* (2.72)	4.527 (0.41)
N	15	15	15
Pseudo R2	0.8732	0.7973	0.8128
Diagnostic Test			
Test	Statistic	P-value	Decision
Ramsey RESET	F(3, 2) = 0.18	0.899	No issue
Breusch–Pagan/Cook–Weisberg	$\chi^2(1) = 0.13$	0.721	No issue
White's test	$\chi^2(14) = 15.00$	0.378	No issue
Durbin–Watson (10, 15)	d = 2.70	—	No issue

Note: t statistics in parentheses. * p<0.05, ** p<0.01, *** p<0.001.

The findings of the quantile regression in Table 4 demonstrate heterogeneous effects of agricultural CO₂ emissions (DP3) across emission levels (Q25, Q50, and Q75) and offer nuanced policy recommendations for Pakistan's Sustainable Development Strategy Agenda 2030. The findings at the 25th quantile (Q25) show that FDI inflows (ID1) have a strong, positive, and significant effect ($\beta = 0.482$, $p < 0.001$) on environmental degradation, suggesting that foreign investment in Pakistan's agricultural sector causes higher emissions. The findings indicate that Pakistan is a haven for highly polluting industries, and that FDI increases carbon intensity (Barkat et al., 2025). However, research studies such as Xiao et al. (2026) highlight that when FDI is invested in green technologies, it helps enhance production efficiency and reduce emissions, contributing to SDG 9 (Industry, Innovation, and Infrastructure). Pakistan should therefore adopt green investment screening mechanisms and encourage eco-innovation and technology transfer through fiscal incentives for low-emission agricultural machinery and sustainable irrigation systems.

Energy use (ID2) and fossil fuel consumption (ID3) both exhibit negative and statistically significant coefficients at the 25th quantile ($\beta = -0.0337$ and -0.184 , respectively, $p < 0.001$), indicating an inverse association with agricultural CO₂ emissions at this quantile. As both variables are constructed as positive-intensity indicators, whereby higher values reflect greater energy consumption and fossil fuel dependence, the negative coefficients suggest that elevated energy use is associated with comparatively lower agricultural CO₂ emissions, the same effect observed by Butty et al. (2025) for African economies. In Pakistan, this underscores the need for comprehensive energy transition

policies (SDG 7: Affordable and Clean Energy) to promote environmental sustainability by incorporating renewable energy production and efficient energy consumption standards in Pakistan's agricultural sector.

Findings on GDP growth (ID4) show a significant positive impact on emissions across all quantiles ($\beta \approx 0.30$, $p < 0.01$). Barkat et al. (2025) and Wang et al. (2025) indicated that emissions initially increase with economic growth before declining after reaching a threshold. These findings demonstrate the need for green-growth frameworks that decouple agricultural productivity from carbon emissions through modern farming technologies, renewable-powered irrigation, and sustainable soil management in Pakistan.

Findings on natural resource depletion (ID5) indicate a significant reduction in emissions ($\beta \approx -7.5$, $p < 0.001$), suggesting that reduced natural resource depletion, together with improved resource management, helps improve environmental stability. Conversely, findings on natural resource rents (ID6) show a positive and significant effect on emissions ($\beta \approx 4.5$, $p < 0.001$), indicating that rent-seeking behaviour in natural resource extraction sectors increases unsustainable resource extraction in Pakistan. These findings are consistent with those of (Chen & Usman, 2025; Guan et al., 2025). In Pakistan, the effective implementation of SDG 12 (Responsible Consumption and Production) is required. Resource taxation reforms, reinvestment of natural resource rents in renewable energy infrastructure, and strict environmental governance can reduce unsustainable natural resource depletion in Pakistan.

Energy poverty (ID7) indicates a positive relationship with agricultural CO₂ emissions ($\beta \approx 0.14$, $p < 0.001$), owing to high energy demand in households and the agricultural sector, as well as a shift from biomass to commercial fuels, which increases environmental degradation. Similar results were reported by Butty et al. (2025), who indicated that energy access through renewable-based rural electrification and clean-cooking programs can help reduce fossil fuel use and environmental degradation.

Furthermore, the findings indicate that renewable energy consumption (ID8) and renewable electricity production (ID9) both have significant negative effects ($p < 0.05$) on environmental degradation, confirming the mitigation role of renewable energy in agricultural emissions. However, the diminishing influence at higher quantiles demonstrated by the findings indicates that renewable energy integration must be scaled up to offset growing energy intensity in Pakistan and support SDG 13 (Climate Action). Bashir et al. (2025) and Xiao et al. (2026) indicated that renewable energy consumption, when supported by stable financing and grid access, can help reduce environmental degradation and improve energy security in developing economies such as Pakistan.

Based on the findings, a multidimensional strategy aligned with the Sustainable Development Goals (SDGs) is recommended to promote environmental sustainability in Pakistan. To achieve SDG 9 (Industry, Innovation, and Infrastructure), the promotion of green FDI and innovation is needed through the introduction of environmental standards and tax incentives for investment. This will encourage foreign firms to invest in renewable technologies, sustainable fertilizers, and precision agriculture, transforming FDI from a "pollution haven" into a "pollution halo" in Pakistan. To achieve SDG 7 (Affordable and Clean Energy), it is recommended that Pakistan accelerate the clean-energy transition through renewable-based rural electrification to improve energy access and grid reliability. The government also needs to provide subsidies for biogas and solar-powered irrigation systems to replace fossil-fuel-intensive agricultural practices. To achieve SDG 12 (Responsible Consumption and Production), the government needs to reform resource management by establishing rent-redistribution mechanisms that redirect natural resource revenues toward renewable infrastructure and agricultural resilience initiatives. Furthermore, the government needs to foster sustainable production to reduce resource-depletion pressures. Finally, to achieve SDG 13 (Climate Action),

Pakistan needs to integrate climate action across the industrial and agricultural sectors by reinforcing emission standards for agricultural and industrial production. It is recommended that Pakistan adopt carbon-pricing mechanisms for resource-intensive activities and promote climate-smart agricultural practices over traditional practices to reduce both CO₂ and CH₄ emissions. Collectively, these connected policy recommendations offer a practical and evidence-based approach to steering Pakistan toward an inclusive, low-carbon, and resilient agricultural and industrial economy. The diagnostic tests fail to reject their null hypotheses, indicating no evidence of misspecification, heteroskedasticity, or autocorrelation. Figure 1 demonstrates the coefficients of the quantile regression reported in Table 4.

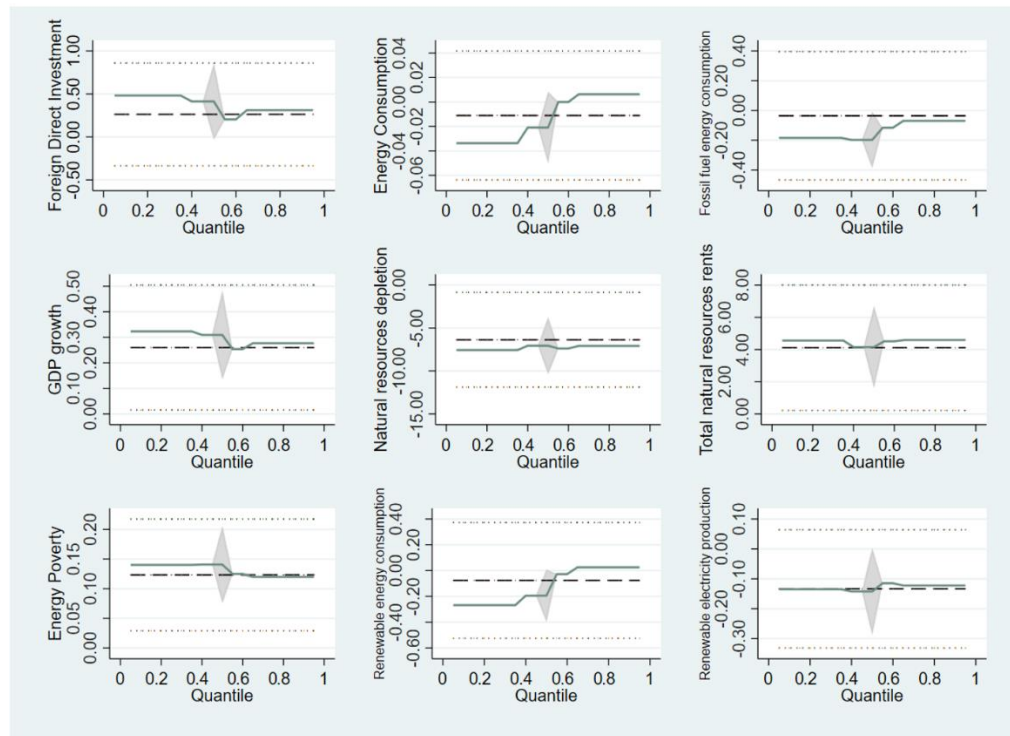


Figure 1. Quantile regression figure for carbon dioxide (CO₂) emissions from agriculture (Mt CO_{2e}).

Table 5 confirms that FDI inflows (ID1) have a positive and significant impact on methane emissions (DP2) at the 25th quantile (Q25), suggesting that foreign direct investment initially increases emissions in the agricultural sector. These results support the pollution haven hypothesis. Similar findings were reported by Barkat et al. (2025), who indicated that FDI initially boosts environmental degradation. However, this effect of FDI decreases emission levels through investment in sustainable and green technology adoption, supporting progress towards SDG 9 (Industry, Innovation, and Infrastructure). The effect of energy consumption (ID2) is negative, but it becomes positive at other quantiles, reflecting the high energy demand associated with agricultural production. This emphasises the need for SDG 7 (Affordable and Clean Energy) interventions to promote a sustainable environment through renewable-powered agricultural practices in Pakistan.

Furthermore, the findings indicate that natural resource depletion (ID5) positively affects methane emissions, while natural resource rents (ID6) significantly reduce emissions in Pakistan's agricultural sector. These findings demonstrate that revenues derived from natural resources, if efficiently managed to fund low-emission technologies, can support the achievement of SDG 12 (Responsible Consumption and Production). Notably, energy poverty (ID7) strongly exacerbates environmental issues across all quantiles because of the high demand for traditional energy resources in rural areas.

Table 5. Quantile regression coefficients for methane (CH₄) emissions from agriculture (Mt CO₂e).

Variables	DP2 _t ^{Q25}	DP2 _t ^{Q50}	DP2 _t ^{Q75}
ID1	1.499* (3.29)	2.259 (1.37)	-2.285 (-1.29)
ID2	-0.108* (-2.67)	-0.125 (-0.86)	0.413* (2.65)
ID3	0.0401 (0.12)	-0.289 (-0.24)	1.952 (1.53)
ID4	0.0410 (0.22)	-0.0560 (-0.08)	-0.113 (-0.16)
ID5	21.42** (5.10)	25.11 (1.65)	-19.62 (-1.20)
ID6	-20.64*** (-6.95)	-24.61 (-2.28)	15.10 (1.31)
ID7	3.380*** (46.97)	3.294*** (12.62)	3.282*** (11.75)
ID8	-0.683 (-1.99)	-1.419 (-1.14)	4.063* (3.06)
ID9	0.0889 (0.59)	0.0597 (0.11)	0.215 (0.37)
_cons	94.59 (2.35)	163.8 (1.12)	-479.2* (-3.06)
N	15	15	15
Pseudo R2	0.9524	0.9386	0.9326
Diagnostic Test			
Test	Statistic	P value	Decision
Ramsey RESET	F(3, 2) = 16.22	0.059	No issue of misspecification at 5%
Breusch–Pagan/Cook–Weisberg	$\chi^2(1) = 0.00$	0.974	No issue of heteroskedasticity
White's test	$\chi^2(14) = 15.00$	0.378	No issue of heteroskedasticity
Durbin–Watson (10, 15)	d = 3.01	—	No issue of autocorrelation

Note: t statistics in parentheses. * p<0.05, ** p<0.01, *** p<0.001.

The findings highlight a transitional phase in Pakistan, where clean energy expansion must be combined with renewable energy integration to ensure climate co-benefits under SDG 13 (Climate Action). Finally, the findings on renewable energy consumption (ID8) indicate mixed effects: environmental degradation is mitigated at lower quantiles, but emissions increase at higher quantiles. This suggests that renewable energy in the agricultural sector needs to be scaled up and strategically managed to ensure energy efficiency. To advance Pakistan's sustainable development toward the 2030 SDG Agenda, the government needs an integrated policy approach that combines clean energy access, responsible resource use, sustainable extraction of natural resources, and green investment to support the attainment of SDGs 7, 9, 12, and 13. All diagnostic tests fail to reject their null hypotheses, indicating no evidence of misspecification, heteroskedasticity, or autocorrelation. Figure 2 illustrates the coefficients from the quantile regression reported in Table 5.

Table 6 is used to assess the robustness of the results by using CO₂ emissions from gaseous fuel consumption (DP1) as the dependent variable. The findings demonstrate that FDI inflows (ID1) have a strong positive impact on environmental degradation in Pakistan, indicating that carbon emissions are increasing with industrial and energy-related investments. Based on the findings regarding FDI, the Government of Pakistan needs to promote green FDI with strict environmental compliance standards to align industrial growth with SDG 9 (Industry, Innovation, and Infrastructure) and support environmental sustainability. Energy consumption (ID2) and fossil fuel consumption (ID3) show significant negative coefficients, suggesting that improvements in energy efficiency and reduced reliance on fossil fuels help reduce CO₂ emissions. This is a key element in advancing SDG 7 (Affordable and Clean Energy).

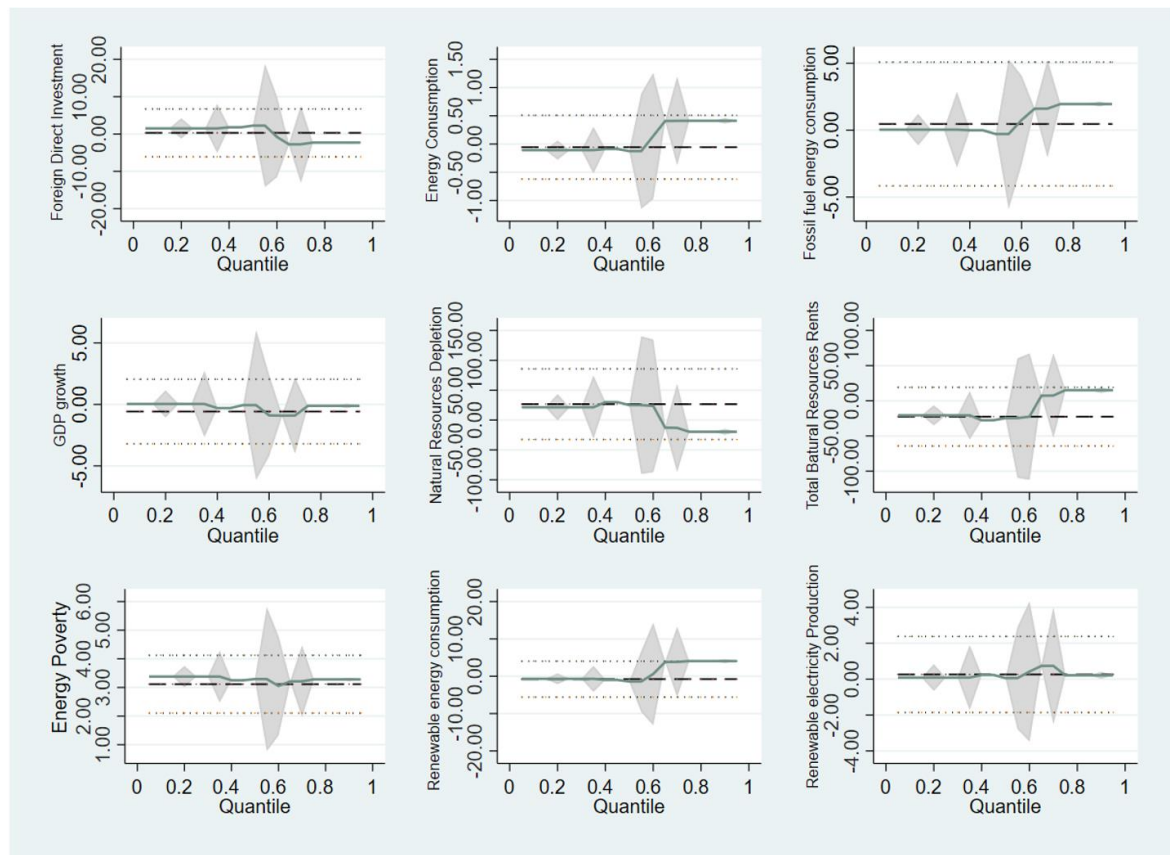


Figure 2. Quantile regression figure for methane (CH₄) emissions from Agriculture (Mt CO₂e).

Natural resource depletion (ID5) reduces emissions, while resource rents (ID6) have positive effects. This implies the need for sustainable resource management in Pakistan and for reinvesting natural resource rents in sustainable projects. These strategies are essential for achieving SDG 12 (Responsible Consumption and Production). The positive relationship between energy poverty (ID7) and emissions reflects the transitional stage of Pakistan's energy system; it is recommended that access to modern fuels supplied by renewable energy be expanded to reduce dependence on fossil energy in Pakistan. Furthermore, the negative coefficients for renewable energy consumption (ID8) confirm its mitigating role in environmental degradation. Renewable electricity production (ID9) shows a positive and significant coefficient across all quantiles ($\beta = 1.612, 0.697, \text{ and } 0.939$ at $Q25, Q50, \text{ and } Q75$; $p < 0.05$), indicating that higher renewable electricity output is associated with increased gaseous-fuel CO₂ emissions.

This may partly reflect limited grid efficiency and transmission losses. Renewable energy production captures broader demand-driven dynamics, whereby renewable output rises during periods of high overall energy demand that simultaneously increase gaseous-fuel consumption, rather than renewable expansion directly increasing emissions. Pakistan needs to implement decarbonization and energy-transition strategies, including targeted investment in green projects, incentives, greater integration of renewable energy projects, and sustainable resource governance.

Table 6. Quantile Regression coefficients for CO₂ emissions from gaseous fuel consumption (% of total).

Variables	DP3 _t ^{Q25}	DP3 _t ^{Q50}	DP3 _t ^{Q75}
ID1	1.520* (2.24)	1.962* (2.27)	2.441*** (9.34)
ID2	-0.203* (-3.40)	-0.0958 (-1.26)	-0.157** (-6.81)
ID3	-3.644*** (-7.45)	-2.746** (-4.40)	-3.023*** (-16.01)
ID4	1.135** (4.09)	1.726** (4.88)	1.878*** (17.54)

Variables	DP3 _t ^{Q25}	DP3 _t ^{Q50}	DP3 _t ^{Q75}
ID5	-16.33* (-2.61)	-39.46** (-4.95)	-40.15*** (-16.65)
ID6	11.88* (2.69)	33.90** (6.02)	33.66*** (19.76)
ID7	0.601** (5.62)	0.877** (6.43)	0.846*** (20.51)
ID8	-2.151** (-4.23)	-0.230 (-0.35)	-0.520* (-2.65)
ID9	1.612*** (7.19)	0.697* (2.44)	0.939*** (10.85)
_cons	380.2** (6.35)	194.2* (2.54)	245.3*** (10.61)
N	15	15	15
Pseudo R ²	0.8992	0.8860	0.8993
Diagnostic Statistics			
Test	Statistic	P-value	Decision
Ramsey RESET	F(3, 2) = 0.10	0.9533	No issue of misspecification
Breusch–Pagan/Cook–Weisberg	$\chi^2(1) = 0.24$	0.6252	No issue of heteroskedasticity
White's test	$\chi^2(14) = 15.00$	0.3782	No issue of heteroskedasticity
Durbin–Watson (10, 15)	d = 2.97	—	No issue of autocorrelation

Note: t statistics in parentheses. * p<0.05, ** p<0.01, *** p<0.001.

Furthermore, the government needs to implement a coherent national framework linking SDG 7, SDG 9, SDG 12, and SDG 13 (Climate Action) to reduce carbon emissions and increase low-carbon economic activities for sustainable economic growth. All diagnostic tests fail to reject their respective null hypotheses at the 5% significance level, demonstrating that the model is correctly specified, homoscedastic, and free from autocorrelation. Figure 3 presents the coefficients of the quantile regression in Table 6.

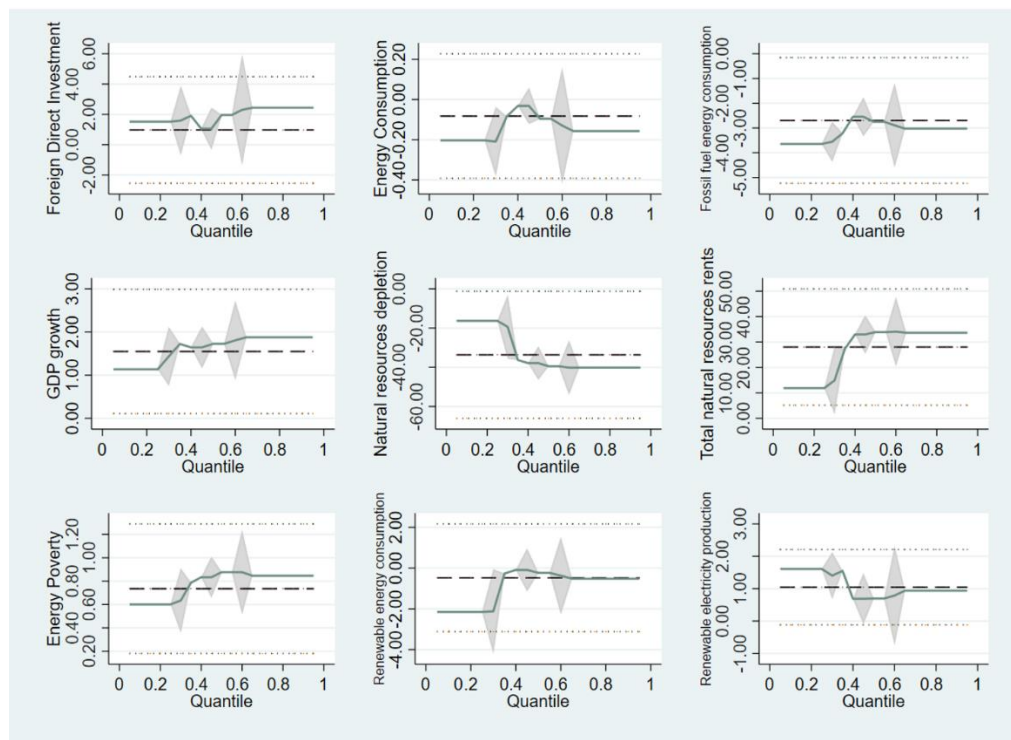


Figure 3. Quantile regression figure for CO₂ emissions from gaseous fuel consumption (% of total).

5. CONCLUSIONS AND RECOMMENDATIONS

This research study provides robust evidence on the key factors driving environmental degradation in Pakistan's agricultural sector using time-series data from 1990 to 2021. Unit root tests confirm that all variables are integrated of order one, justifying the use of quantile regression for heterogeneous analysis. Results from the three quantile models reveal that foreign direct investment (FDI), economic growth, and natural resource rents consistently increase CO₂ and CH₄ emissions across different quantiles, whereas renewable energy consumption, energy-efficiency improvements, and responsible resource management help mitigate environmental degradation. The findings demonstrate a significant impact of FDI on emissions at higher quantiles, confirming the persistence of the pollution haven effect in Pakistan, as foreign investments are concentrated in emission-intensive industries that increase environmental degradation. In contrast, renewable energy has a negative effect on carbon emissions, highlighting its essential role in reducing the carbon footprint and achieving long-term energy security in Pakistan. Furthermore, the positive association between energy poverty and emissions indicates a transitional energy phase in which greater fuel accessibility increases energy demand before full renewable-energy integration takes effect to support a sustainable environment. Robustness checks further confirm that Pakistan's environmental degradation is driven by both economic and energy dynamics. This research stresses that sustainable economic growth in Pakistan requires immediate policies to expand clean-energy projects, improve resource efficiency, promote the sustainable use of natural resources, and encourage environmentally friendly and responsible industrialization for sustainable economic growth.

To achieve Sustainable Development Goals (SDGs) 7, 9, 12, and 13 in Pakistan, policymakers need to adopt an integrated, multisectoral approach that harmonizes economic development with environmental stewardship. To achieve SDG 9 (Industry, Innovation, and Infrastructure), Pakistan needs to promote green foreign direct investment (FDI) and industrial transformation. This includes implementing green investment regulations to assess the environmental impact of significant foreign projects. Pakistan also needs to incentivize technology transfer in low-carbon agriculture, renewable energy systems, and eco-efficient manufacturing, as well as establish green industrial zones that align investment incentives with emissions-reduction commitments under the SDGs. To achieve SDG 7 (Affordable and Clean Energy), Pakistan needs to improve the integration of renewable energy, particularly solar, biogas, and micro-hydel systems, into rural and agricultural sectors to reduce reliance on fossil fuels. It should also strengthen industrial energy-efficiency programs and ensure equitable access to clean cooking fuels through renewable-based supply chains. To achieve SDG 12 (Responsible Consumption and Production), Pakistan should reinvest natural-resource rents in renewable infrastructure, sustainable irrigation, and environmental innovation funds. It should introduce resource-use efficiency rules to support circular-economy initiatives, supported by strong institutional governance to ensure the transparent allocation of resource revenues. To achieve SDG 13 (Climate Action), Pakistan needs a framework that links agricultural, industrial, and energy policies through climate-governance mechanisms. This should include carbon-pricing mechanisms for high-emission sectors, the advancement of climate-smart agricultural practices to reduce both CO₂ and CH₄ emissions, and enhanced emissions monitoring coupled with adaptive strategies to manage drought and resource stress in Pakistan. These strategies provide a sound policy framework for Pakistan to transition towards a resilient, inclusive, low-carbon economy and achieve sustainable development.

This research has several limitations. First, complete data for the variables used were not available from the WDI database for the entire period, reducing the sample to 15 observations. Second, the analysis relies solely on country-level data for Pakistan, which limits the generalizability of the findings to other developing or resource-dependent economies. Future research could include other Asian countries to broaden the scope of the study. Third, the study identifies associations rather than causal relationships, as potential endogeneity among FDI, resource rents, and environmental degradation was not formally addressed. Future studies could use dynamic panel data models to examine this issue and generate comparative evidence on the energy–environment nexus across countries facing similar environmental challenges.

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