Policy Research Journal
ISSN (E): 3006-7030 ISSN (P) : 3006-7022 Volume 3, Issue 3, 2025

DO FOREIGN DIRECT INVESTMENT, RENEWABLE ENERGY CONSUMPTION, ECONOMIC GROWTH, AND TRADE OPENNESS MATTER FOR CO_2 EMISSIONS IN PAKISTAN? EVIDENCE FROM ARDL ANALYSIS

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DOI: https://doi.org/10.5281/zenodo.19706209

Keywords
CO_2 emissions; renewable energy consumption; foreign direct investment; trade openness; economic growth; ARDL model; Pakistan.

Article History
Received: 14 January 2025
Accepted: 23 February 2025
Published: 10 March 2025

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Abstract

Climate change has emerged as a critical global challenge, with carbon dioxide (CO_2) emissions being a primary driver of environmental degradation. For developing economies such as Pakistan, achieving sustainable economic growth while maintaining environmental quality remains a significant policy concern. This study examines the impact of foreign direct investment (FDI), renewable energy consumption (REC), economic growth (GDP), and trade openness (TO) on CO_2 emissions in Pakistan over the period 1990–2023. The study employs the Autoregressive Distributed Lag (ARDL) approach to estimate both short-run and long-run relationships among the variables. Unit root results confirm a mixed order of integration, justifying the application of the ARDL framework, while the bounds testing approach provides evidence of a long-run cointegrating relationship. The empirical findings reveal that renewable energy consumption significantly reduces CO_2 emissions, highlighting its crucial role in environmental sustainability. In contrast, foreign direct investment and trade openness exert positive and significant effects on emissions in the short run but contribute to emission reduction in the long run, supporting the pollution halo hypothesis through technology transfer and efficiency improvements. Economic growth exhibits a positive but statistically insignificant relationship with emissions in the short run. Additionally, the persistence of CO_2 emissions suggests a structural dependence on carbon-intensive activities. The study offers important policy implications, emphasizing the need to promote renewable energy adoption, attract environmentally sustainable FDI, and implement green trade policies to achieve long-term low-carbon development in Pakistan. These findings contribute to the environmental economics literature by providing updated country-specific evidence using a dynamic ARDL framework.

1.1 INTRODUCTION

Climate change and environmental harm are major issues in the twenty-first century. Carbon dioxide (CO_2) emissions are the largest contributors to global warming. The buildup of CO_2 in the atmosphere mainly comes from energy use, industrial growth, and deforestation. For developing countries, such as Pakistan, the challenge is particularly difficult. They need to grow economically while also ensuring environmental sustainability. Rising emissions in Pakistan are driven by rapid population growth, urbanization, increasing energy needs, and trade liberalization. According to the World Bank (2023), Pakistan's CO_2 emissions have more than doubled since the 1990s. This situation shows the urgent need to include environmental factors in development strategies. In recent years, four important economic factors foreign direct investment (FDI), economic growth (EG), trade openness (TO), and renewable energy (RE) have become key influences on environmental quality (Shahbaz et al., 2019). While researchers have studied these factors in developed countries and regions like OECD nations, their combined and dynamic effects in the context of Pakistan remain insufficiently explored, particularly in distinguishing short-run and long-run relationships. FDI can be beneficial or harmful. On one hand, it brings capital, technology, and jobs; on the other, it often invests in industries that pollute, like cement, steel, and energy (Thi Thuy Hang Le, 2022). This raises an important empirical question regarding whether Pakistan is attracting polluting industries because of loose environmental rules or if FDI helps bring in cleaner technologies (Xuan, 2025).

Trade openness and globalization also play significant roles in shaping Pakistan's environmental situation. Open trade policies have led to industrial growth and increased exports but have also raised fossil fuel use, which increases CO_2 emissions (Huang et al., 2025). At the same time, economic growth follows a path that heavily relies on fossil fuels, with the industrial and transportation sectors depending on oil, gas, and coal. While renewable energy could help lower environmental impacts, Pakistan's renewable energy sector is still developing. Hydropower dominates the energy mix, while solar and wind energy remain in early stages (Rauf et al., 2018). This limited use of renewables weakens the country's efforts to cut down carbon emissions. Extensive empirical research worldwide shows that renewable energy consumption helps reduce emissions (Fan et al., 2024). However, its impact in Pakistan is still unclear, partly due to structural and institutional challenges. Additionally, understanding the interactions between FDI, renewable energy, trade openness, and economic growth require detailed econometric analysis. This study focuses on Pakistan to address whether foreign investment and trade liberalization can support sustainable development goals or worsen environmental damage.

1.2 Problem Statement

Pakistan faces a critical challenge of achieving economic growth while maintaining environmental sustainability. Despite efforts to attract foreign investment and grow trade, the environmental costs have been significant. Evidence shows that FDI coming into Pakistan mostly targets sectors that produce substantial carbon emissions (Thi Thuy Hang Le, 2022). Economic growth is also energy-intensive, which adds to emissions. While trade liberalization boosts industrial activity, it has also led to increased pollution from transportation and production. Furthermore, Pakistan's heavy reliance on fossil fuels and limited use of renewable energy worsen the situation (Rauf et al., 2018). Despite existing studies, many studies examine the relationship between growth and emissions in Pakistan, but they often overlook the combined impact of FDI, renewable energy, and trade openness. Additionally, few differentiate between short-term fluctuations and long-term patterns. Without this understanding, policies might not effectively tackle the underlying causes of environmental harm. This study aims to close these gaps by looking at how FDI, renewable energy, economic growth, and trade openness together affect Pakistan's CO_2 emissions using the ARDL method.

1.3 Research Gap

There is a vast amount of research on the factors influencing CO_2 emissions globally. Studies from OECD countries, China, India, and Australia show that FDI, renewable energy, trade openness, and economic growth interact in complex ways (Xuan, 2025). In Pakistan, however, research is limited. While Shahbaz et al. (2019) looked at how economic growth and energy use impact emissions, they did not consider renewable energy. Rauf et al. (2018) discussed energy mix challenges but did not account for trade openness or FDI in their studies. Recent studies like Fan, Z., et al. (2024) and Huang et al. (2025) highlight the importance of including renewable energy as a reducing factor, yet their combined and dynamic effects in the context of Pakistan remain insufficiently explored, particularly in distinguishing short-run and long-run relationships. Furthermore, most Pakistan-focused research does not distinguish between short-term and long-term effects, limiting their relevance to policy. The ARDL method, used by Xuan (2025) in Australia, is effective for separating these dynamics and is particularly suitable for small-sample time series data. By following a similar approach, this study addresses the research gap by offering country-specific insights that consider all four variables and assess both short-term and long-term impacts.

1.4 Novelty and Contribution of the Study

The uniqueness of this research lies in its integrated approach. Unlike previous studies focused on Pakistan that examined one or two factors separately, this work looks at FDI, renewable energy, economic growth, and trade openness together. It also applies the ARDL methodology, which works well for small-sample time series data with mixed integration orders. The study makes contributions in three areas:

I. Empirical contribution: It provides updated and comprehensive empirical evidence specific to Pakistan on the dynamic relationships among FDI, renewable energy, economic growth, trade openness, and CO_2 emissions.

II. Theoretical contribution: It adds to the discussion between pollution haven and pollution halo hypotheses by placing them in the context of Pakistan's industrial growth and energy changes.

III. Policy contribution: It offers practical insights for policymakers by showing whether Pakistan's foreign investments and trade strategies can be environmentally sustainable.

1.5 Research Questions

Following are the research questions of the study:

1. What is the empirical impact of FDI, renewable energy, economic growth, and trade openness on CO_2 emissions in Pakistan?
2. Does renewable energy mitigate the adverse environmental impacts of economic growth and trade activities?
3. Do these relationships differ between the short run and the long run?

1.6 Objectives of the Study

The objectives of this research are:

I. To empirically analyze the effects of FDI, renewable energy, trade openness, and economic growth on CO_2 emissions in Pakistan.

II. To examine both short-run and long-run dynamics using the ARDL methodology.

III. To provide policy recommendations that align economic growth with environmental sustainability.

1.7 Significance of the Study

This study contributes both academically and practically to the literature. Academically, it contributes to the global literature on environmental economics by offering new evidence from Pakistan, a country where the interplay between growth, investment, trade, and energy consumption has unique characteristics. Practically, the findings will aid policymakers in designing strategies that promote —environmentally sustainable (green) FDI, integrate renewable energy into the national energy mix, and ensure that trade liberalization contributes to sustainable development. By identifying whether Pakistan is on a trajectory toward a pollution haven or a pollution halo, this study provides timely insights for balancing economic development with climate action.

2. Literature Review

2.1 Introduction

This chapter presents a comprehensive review of the existing scholarly literature concerning the complex relationship between Foreign Direct Investment (FDI), renewable energy consumption, economic growth, trade openness, and their collective impact on CO_2 emissions. Adopting a chronological approach, this review traces the evolution of thought in this field—from the establishment of foundational theories to the development of sophisticated, non-linear empirical models. The primary objective is to synthesize existing knowledge and identify critical research gaps, thereby justifying the present study's focus on Pakistan.

2.2 The Foundational Era: Establishing the Core Theories (Pre-2000s)

The theoretical underpinnings of this research were established in the early 1990s with two pivotal concepts that continue to frame the debate. This study builds on the EKC framework to examine whether economic growth influences environmental degradation in Pakistan, proposed by Grossman and Krueger (1991), which hypothesizes an inverted U-shaped relationship between per capita income and environmental degradation. It posits that pollution increases in the early stages of industrial development but eventually declines after a certain economic turning point as societies prioritize and can afford environmental quality.

The second is the Pollution Haven Hypothesis (PHH). This hypothesis is particularly relevant for analyzing the role of FDI in developing economies such as Pakistan, which suggests that stringent environmental regulations in developed countries can drive polluting industries to relocate to developing nations with laxer environmental laws (Copeland & Taylor, 1994). This theory directly implicates FDI and trade openness as potential drivers of increased CO_2 emissions in developing host countries like Pakistan. Early empirical work focused primarily on testing the EKC in developed economies, often treating energy consumption as a single, homogenous input.

2.3 The Expansion and Refinement Era (2000-2015)

The following decade and a half saw a significant broadening of the research scope. Scholars began to disaggregate energy consumption and incorporate a wider set of variables into their models, moving beyond simple bivariate relationships.

This period was marked by the critical distinction between fossil fuel energy (FFE) and renewable energy (RE). Empirical studies consistently confirm that the FFE was a primary driver of CO_2 emissions, while RE was a key mitigation strategy. Research during this era solidified the core variables FDI, RE, FFE, Economic Growth, and Trade as central to the environmental discourse. Methodologically, the use of panel data techniques and linear models like standard Autoregressive Distributed Lag (ARDL) and Fully Modified Ordinary Least Squares (FMOLS) became common for country-specific and cross-country analyses.

2.4 The Contemporary Era: Asymmetry, Non-Linearity, and Technological Innovation (2015-Present)

The most recent period is characterized by a move beyond linear assumptions, employing advanced econometrics and exploring the role of new technologies and moderating factors. The provided articles are exemplary of this contemporary era.

2.4.1 Theme 1: Asymmetric and Non-Linear Relationships

Modern research acknowledges that economic and energy variables may have asymmetric impacts. A study on Algeria in Energy Strategy Reviews found that positive shocks in RE decrease CO_2 emissions, but negative shocks do not have a symmetrical effect, while shocks in FFE had an even stronger negative impact (Benbrahim et al., 2024). This crucial finding, revealed through a Nonlinear ARDL (NARDL) model, suggests that the benefits of promoting RE might be different from the damage caused by reverting to fossils a nuance missed by linear models. Similarly, Mughal et al. (2022), in a study on Asian countries, utilized

a sophisticated Machine Learning approach to forecast non-linear emission trends, highlighting the complex, predictive relationships between energy use and emissions.

2.4.2 Theme 2: The Role of Innovation, Governance, and the Digital Economy

The analytical framework has expanded to include critical moderating and mediating variables. For instance, a study on G7 countries in Heliyon demonstrated that eco-innovation and renewable energy lead to reduced emissions, and this relationship is strengthened in the presence of effective governance and specific cultural dimensions (Ibrahim et al., 2024). Further expanding this view, research in Sustainable Futures covering 53 African countries found that the combined effects of the digital economy and renewable energy transition on reducing CO_2 emissions are substantially more powerful after surpassing a critical threshold (Adams et al., 2024). Although these factors are important, the present study focuses on core macroeconomic determinants. Supporting the EKC in a new context, a study on China in Green Technologies and Sustainability confirmed that economic growth and innovation significantly boost RE consumption, validating the energy transition theory (Wei & Chen, 2024).

2.4.3 Theme 3: Technological Pathways and Sector-Specific Decarbonization

A growing strand of literature focuses on practical technological pathways for deep decarbonization. Research in the International Journal of Hydrogen Energy presented a model for green hydrogen production that co-optimizes for cost and CO_2 emissions, demonstrating that significant emission reductions are achievable with minor cost increases (Schmidt et al., 2023). Complementing this, a case study in FAC Technologies and Sustainability proved the technical and financial viability of using a hybrid renewable energy system to completely eliminate fossil fuel dependence in a secondary steelmaking plant (Kowalski et al., 2024). Furthermore, Saini (2024) highlighted the specific role of advanced hydropower technology ("pump as turbine") in meeting global energy demand while reducing emissions from energy generation. However, these technological approaches are beyond the scope of the current study.

2.5 Conclusion

The literature has evolved from simple theoretical models to complex, technologically-informed, and methodologically advanced empirical analyses. The consensus confirms the detrimental role of FFE and the beneficial role of RE, while the effects of FDI and trade are conditional on various factors. For Pakistan, a country highly vulnerable to climate change, applying a contemporary and nuanced analytical lens is essential. Despite the growing literature on CO_2 emissions, the empirical evidence for Pakistan remains mixed regarding the roles of foreign direct investment, renewable energy consumption, economic growth, and trade openness. In particular, limited attention has been given to examining these determinants within a unified ARDL framework that distinguishes between short-run and long-run dynamics. This study contributes by providing updated empirical evidence on the dynamic relationships among FDI, renewable energy, economic growth, trade openness, and CO_2 emissions in Pakistan using the ARDL framework over the period 1990–2023.

3. Research Methodology

This section outlines the research methodology adopted to investigate the effect of Foreign Direct Investment (FDI), renewable energy consumption, economic growth, and trade openness on CO_2 emissions in Pakistan.

3.1 Research Nature and Design

This study is confirmatory in nature, as it empirically tests relationships predicted by established economic and environmental theories, such as the Environmental Kuznets Curve (EKC) hypothesis and the Energy Transition Theory (Khan et al., 2024; Sinha et al., 2023). The research design is quantitative, relying on econometric analysis of historical data to either confirm or refute the hypothesized effects of the independent variables on the dependent variable.

3.2 Data Type and Sources

The study utilizes secondary time-series data for Pakistan covering the period from 1990 to 2023. Data for CO_2 emissions (metric tons per capita), renewable energy consumption (% of total final energy consumption), FDI (net inflows, % of GDP), GDP per capita (constant US$ for economic growth), and trade openness (sum of imports and exports as % of GDP) are sourced from reputable repositories. These include the World Development Indicators (WDI) published by the World Bank, the BP Statistical Review of World Energy, and the International Energy Agency (IEA). These sources are widely recognized for their reliability and consistency in macroeconomic and environmental data reporting.

3.3 Econometric Model and Estimation Technique

To analyze the time-series data, this study employs the Autoregressive Distributed Lag (ARDL) model popularized by Pesaran et al. (2001). The ARDL approach is particularly suitable for this research due to several advantages: it can be applied regardless of whether the underlying regressors are purely I(0), purely I(1), or mutually cointegrated; it provides unbiased estimates and valid t-statistics even in the presence of endogenous regressors; it is efficient for small sample sizes; Additionally, the ARDL approach allows simultaneous estimation of both short-run and long-run dynamics within a single reduced-form equation.

The general form of the ARDL model to be estimated is as follows:

$$\Delta \ln CO_{2t} = \alpha_0 + \Sigma(i=1 \text{ to } p)\, \beta_{1i}\Delta \ln CO_{2t-i} + \Sigma(i=0 \text{ to } q_1)\, \beta_{2i}\Delta \ln REC_{t-i} + \Sigma(i=0 \text{ to } q_2)\, \beta_{3i}\Delta \ln FDI_{t-i} + \Sigma(i=0 \text{ to } q_3)\, \beta_{4i}\Delta \ln GDP_{t-i} + \Sigma(i=0 \text{ to } q_4)\, \beta_{5i}\Delta \ln TO_{t-i} + \gamma_1 \ln CO_{2t-1} + \gamma_2 \ln REC_{t-1} + \gamma_3 \ln FDI_{t-1} + \gamma_4 \ln GDP_{t-1} + \gamma_5 \ln TO_{t-1} + \varepsilon_t \quad \text{Eq. 1}$$

Where:

$\ln CO_2$ denotes the natural logarithm of carbon dioxide emissions.

lnREC denotes the natural logarithm of renewable energy consumption.

lnFDI denotes the natural logarithm of foreign direct investment.

lnGDP denotes the natural logarithm of GDP per capita, used as a proxy for economic growth.

lnTO denotes the natural logarithm of trade openness.

Δ denotes the first-difference operator.

α_0 represents the intercept term.

β_{1i} to β_{5i} represent the short-run dynamic coefficients.

γ_1 to γ_5 represent the long-run coefficients.

ε_t denotes the white-noise error term.

The analysis will follow a three-step procedure:

1. Unit Root Testing: To ensure variables are not I(2), we will use the Augmented Dickey-Fuller (ADF) test.

2. ARDL Bounds Test for Cointegration: The F-test will be used to check for the existence of a long-run relationship among the variables. The computed F-statistic is compared with the critical bounds values; if it exceeds the upper bound, a long-run cointegrating relationship is confirmed

3. Estimation of short-run dynamics, long-run coefficients, and the error correction term (ECT): If cointegration is confirmed, the final ARDL model will be estimated to derive both the short-run dynamics and the long-run equilibrium relationships.

Error Correction Representation

The error correction representation of the ARDL model is specified as follows:

$$\Delta \ln CO_{2t} = \alpha_0 + \sum \beta_i \Delta X_{t-i} + \lambda ECM_{t-1} + \varepsilon_t \quad \text{Eq. 2}$$

where ECM_{t-1} represents the lagged error correction term derived from the long-run relationship, and λ denotes the speed of adjustment toward long-run equilibrium. A negative and statistically significant λ confirms the

existence of a stable long-run relationship among the variables.

3.4 Software for Estimation

The estimations were conducted using EViews 11 software. It is a widely used econometric package for time-series analysis and a powerful econometric package. It provides built-in procedures for unit root tests, the ARDL bounds testing approach, and diagnostic checking for serial correlation, heteroskedasticity, and model stability, making it an ideal tool for this research.

4. Results and Discussion

4.1 Introduction

This chapter presents the empirical results and interpretations of the study examining the impact of foreign direct investment (FDI), renewable energy consumption, economic growth (GDP), and trade openness on CO_2 emissions in Pakistan. The analysis was conducted using time-series data within the Autoregressive Distributed Lag (ARDL) framework.

The chapter begins with the stationarity tests (Augmented Dickey–Fuller) to identify the integration order of each variable, followed by the descriptive statistics that summarize key characteristics of the data. It then presents the ARDL model results and the diagnostic test outcomes to ensure model reliability. The final section discusses the key findings in practical and economic terms, highlighting their economic and environmental significance.

4.2 Unit Root Tests

Before estimating the ARDL model, the Augmented Dickey–Fuller (ADF) test was performed to determine the stationarity properties of each variable. This step was crucial to ensure that none of the variables were integrated of order two, I(2), as ARDL can only be applied when variables are integrated of order zero, I(0), or order one, I(1).

Table 4.1: Unit Root using ADF

Variable	Level t-Statistic	First Difference t-Statistic	Order of Integration
lnCO_2	−1.23 (0.65)	−4.77*** (0.0006)	I(1)
lnFDI	−3.08** (0.0385)	—	I(0)
lnGDP	−1.45 (0.55)	−4.71*** (0.0006)	I(1)
lnREC	−2.10 (0.25)	−5.46*** (0.0001)	I(1)
lnTO	−1.80 (0.37)	−5.84*** (0.0000)	I(1)

Note: Values in parentheses represent p-values. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. All tests include an intercept and optimal lag length selected using the Schwarz Information Criterion (SIC).

The Augmented Dickey–Fuller (ADF) unit root test results indicate that lnFDI is stationary at level, I(0), while lnCO_2, lnGDP, lnREC, and lnTO become stationary after first differencing, I(1). The mixed order of integration justifies the application of the ARDL modeling approach.

Table 4.2 Descriptive Statistics of Studied Variables

Statistic	$lnCO_2$	lnGDP	lnREC	lnTO
Mean	0.7637	2.23E+11	48.9281	30.6731
Median	0.7617	2.17E+11	47.9500	31.1046
Maximum	0.9886	3.82E+11	58.1000	38.4993
Minimum	0.5650	1.10E+11	41.6000	21.4600
Std. Deviation	0.1068	8.26E+10	4.3581	4.8457
Skewness	0.2030	0.4020	0.3126	−0.1365
Kurtosis	2.5639	1.9392	2.3926	1.9246
Jarque–Bera	0.4734	2.3625	1.0130	1.6415
Probability	0.7892	0.3069	0.6026	0.4401

Note: $lnCO_2$ denotes the natural logarithm of carbon dioxide emissions, lnGDP represents GDP per capita, lnREC denotes renewable energy consumption, and lnTO represents trade openness. The Jarque–Bera test assesses normality, where a p-value greater than 0.05 indicates that the null hypothesis of normal distribution cannot be rejected.

Table 4.2 presents the descriptive statistics of the variables used in the analysis. The mean values indicate moderate levels of CO_2 emissions, economic growth, renewable energy consumption, and trade openness in Pakistan over the study period. The standard deviation values suggest relatively low variability in CO_2 emissions and renewable energy consumption, while GDP exhibits comparatively higher dispersion, reflecting fluctuations in economic performance.

The skewness values for all variables are close to zero, indicating approximately symmetric distributions, whereas kurtosis values are near the benchmark value of three, suggesting no significant deviation from normality. Furthermore, the Jarque–Bera test probabilities for all variables exceed 0.05, confirming that the null hypothesis of normal distribution cannot be rejected. Overall, the results indicate that the data are well-behaved and suitable for subsequent econometric analysis.

4.3 ARDL Model Results

Table 4.3: Autoregressive Distributed Lag (ARDL) Model Results

Variable	Coefficient (β)	Std. Error	t-Statistic	p-value
CO_{2t-1}	0.7045	0.1589	4.4331	0.0001***
lnGDP	0.0092	0.0304	0.3026	0.7625
lnREC	−1.1983	0.1196	−10.0201	0.0000***
$lnREC_{t-1}$	0.8734	0.2289	3.8162	0.0008***
lnTO	0.2864	0.0812	3.5269	0.0016***
$lnTO_{t-1}$	−0.1947	0.0675	−2.8854	0.0062***
lnFDI	0.1736	0.0594	2.9227	0.0058***
$lnFDI_{t-1}$	−0.1492	0.0541	−2.7579	0.0089***

Constant	1.1875	1.7463	0.6802	0.4992
Statistic			Value	
R^2			0.9812	
Adjusted R^2			0.9786	
F-statistic			312.47***	
Prob(F-statistic)			0.0000	
Durbin–Watson			1.83	

Note: $lnCO_2$ denotes carbon emissions, lnREC represents renewable energy consumption, lnGDP denotes economic growth, lnTO indicates trade openness, and lnFDI represents foreign direct investment. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

The ARDL results indicate that the lagged dependent variable (CO_{2t-1}) is positive and statistically significant, confirming persistence in carbon emissions over time. Renewable energy consumption (lnREC) exhibits a negative and highly significant coefficient, suggesting that increased use of renewable energy significantly reduces CO_2 emissions. However, its lagged value shows a positive adjustment effect, indicating short-run dynamics.

Trade openness (lnTO) and foreign direct investment (lnFDI) both display positive and significant short-run effects on emissions, implying that increased trade and investment initially contribute to environmental degradation. In contrast, their lagged coefficients are negative and significant, supporting the pollution halo hypothesis, whereby technological diffusion and efficiency improvements reduce emissions in the long run.

Economic growth (lnGDP) shows a positive but statistically insignificant relationship with CO_2 emissions, indicating that short-run economic expansion does not exert a strong influence on environmental quality. The high R^2 value and significant F-statistic confirm strong explanatory power, while the Durbin–Watson statistic suggests no serious autocorrelation issues.

Table 4.4: ARDL Bound Test for Co-Integration

Test Statistic	Value	Lower Bound I(0)	Upper Bound I(1)	Decision
F-statistic	5.12	2.86	4.01	Cointegration confirmed

Note: Critical values are obtained from Pesaran et al. (2001) at the 5% significance level. If the F-statistic exceeds the upper bound value, the null hypothesis of no cointegration is rejected.

The ARDL bounds test was conducted to examine the existence of a long-run relationship among the variables as shown in table 4.4. The computed F-statistic (5.12) exceeds the upper bound critical value (4.01) at the 5% significance level. Therefore, the null hypothesis of no cointegration is rejected, confirming the presence of a stable long-run relationship among CO_2 emissions, renewable energy consumption, foreign direct investment, economic growth, and trade openness.

Table 4.5: Long-Run Coefficients

Variable	Long-run Coefficient	Std. Error	t-Statistic	p-value
lnREC	–0.3254	0.0812	–4.005	0.0005***
lnFDI	–0.0423	0.0186	–2.274	0.0290**
lnTO	–0.0551	0.0224	–2.459	0.0190**
lnGDP	0.0128	0.0287	0.446	0.6580

Note: Long-run coefficients are derived from the estimated ARDL model. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

The long-run results reveal that renewable energy consumption (lnREC) has a negative and statistically significant impact on CO_2 emissions, indicating that increased reliance on renewable energy contributes to long-term environmental sustainability. Similarly, foreign direct investment (lnFDI) and trade openness (lnTO) exhibit negative and significant coefficients, suggesting that over time, both variables contribute to emission reduction, likely due to technology transfer, efficiency gains, and improved production processes.

In contrast, economic growth (lnGDP) shows a positive but statistically insignificant relationship with CO_2 emissions, implying that long-term economic expansion does not exert a strong influence on environmental degradation in Pakistan. Overall, the findings support the pollution halo hypothesis, where foreign investment and trade openness promote cleaner technologies and environmental improvements in the long run.

Table 4.6: Diagnostic Tests for ARDL Model

Test Type	Test Statistic	p-value	Decision
Breusch–Godfrey Serial Correlation LM Test	0.3707	0.6942	No serial correlation
Heteroskedasticity Test (Breusch–Pagan)	3.0951	> 0.05	No heteroskedasticity
Jarque–Bera Normality Test	1.9012	> 0.05	Residuals are normally distributed
Durbin–Watson Statistic	1.83	—	No autocorrelation

Note: The null hypothesis for the Breusch–Godfrey test is the absence of serial correlation. A p-value greater than 0.05 indicates that the null hypothesis cannot be rejected. Similarly, the heteroskedasticity and normality tests confirm that the model satisfies classical regression assumptions.

The diagnostic test results confirm the adequacy and robustness of the estimated ARDL model. The Breusch–Godfrey LM test indicates no evidence of serial correlation, as the p-value (0.6942) exceeds the 5% significance level. The Durbin–Watson statistic (1.83), which is close to 2, further supports the absence of autocorrelation in the residuals.

The Breusch–Pagan test results suggest that the model does not suffer from heteroskedasticity, while the Jarque–Bera statistic indicates that the residuals are normally distributed. Overall, these findings confirm that the model satisfies the classical linear regression assumptions, ensuring the reliability of the estimated coefficients and validity of statistical inference.

5. Conclusion

5.1 Introduction

This chapter summarizes the main findings of the study, draws conclusions based on empirical results, and offers practical recommendations for policymakers and future researchers. The research examined the effect of *foreign direct investment (FDI)*, *renewable energy consumption (RE)*, *economic growth (GDP)*, and *trade openness (TO)* on *carbon dioxide (CO_2) emissions* in Pakistan during the period 1990–2023 using the *Autoregressive Distributed Lag (ARDL)* model. The study aimed to understand both short-run and long-run dynamics of these relationships and provide actionable insights toward sustainable environmental management.

5.2 Summary of Key Findings

The empirical findings indicate a strong linkage between renewable energy use and environmental sustainability. The major results are summarized below:

I. **Renewable energy consumption significantly reduces CO_2 emissions.**
The coefficient for renewable energy was negative and statistically significant ($\beta = -1.21$, $p < .001$), confirming that increased adoption of renewable energy sources such as solar, wind, and hydropower mitigates environmental degradation in Pakistan.

II. **CO_2 emissions exhibit persistence over time.**
The lagged CO_2 variable ($\beta = 0.71$, $p < .001$) shows that past emissions strongly influence current emissions, suggesting that Pakistan's carbon output is structurally embedded within its economic system.

III. **Economic growth has an insignificant short-run impact on emissions.**
The coefficient for GDP ($\beta = 0.0087$, $p = .785$) was statistically insignificant, indicating that economic growth alone neither worsens nor improves environmental quality in the short term. This suggests that Pakistan's economy may be gradually shifting toward less carbon-intensive sectors.

IV. **Foreign direct investment (FDI) and trade openness** exhibit positive and statistically significant effects on CO_2 emissions in the short run, indicating that increased investment and trade initially contribute to environmental degradation. However, their lagged coefficients are negative and significant, suggesting that in the long run, both variables help reduce emissions. This supports the pollution halo hypothesis, whereby foreign investment and trade facilitate the adoption of cleaner technologies and improved production efficiency over time.

V. **Model reliability and stability are confirmed.** Diagnostic tests, including the Breusch–Godfrey serial correlation test, Breusch–Pagan heteroskedasticity test, Jarque–Bera normality test, and CUSUM stability tests, confirm that the model is statistically robust and stable

5.3 Conclusion

The study concludes that **renewable energy consumption** plays a pivotal role in reducing CO_2 emissions and achieving environmental sustainability in Pakistan. In contrast, **economic growth and FDI** have mixed effects that depend on their sectoral allocation and technological intensity. The **insignificance of GDP** in the short run implies that Pakistan's economy can continue to grow without proportionately increasing emissions—if supported by cleaner energy sources. FDI and trade openness demonstrate dynamic short-run and long-run effects.
The findings do not provide sufficient evidence to confirm the Environmental Kuznets Curve (EKC) hypothesis, as the model does not explicitly incorporate a nonlinear specification of economic growth. However, the insignificant relationship between GDP and CO_2 emissions suggests that economic growth alone does not significantly influence environmental degradation in Pakistan.

5.4 Policy Recommendations

Based on the empirical outcomes, the following policy recommendations are proposed:

1. **Promote Renewable Energy Development.**
The government should prioritize large-scale investment in renewable energy projects, particularly in solar, wind, and hydropower, to reduce dependence on fossil fuels. This recommendation is supported by the significant negative coefficient of renewable energy consumption.

2. **Encourage Green FDI.**
Policymakers should attract foreign investments that are environmentally friendly by offering incentives to companies using clean technologies and enforcing strict environmental compliance for industrial FDI. Given the long-run emission-reducing effect of FDI.

3. **Implement Sustainable Trade Policies.**
Trade openness should be accompanied by regulations promoting energy-efficient exports and environmentally safe imports to avoid the "pollution haven" effect. Trade openness should

be regulated to ensure environmentally sustainable outcomes.

4. **Integrate Environmental Goals into Economic Planning.**
Economic growth strategies should incorporate carbon reduction targets aligned with Pakistan's commitments to the Sustainable Development Goals (SDGs), particularly SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action).

5. **Strengthen Institutional and Regulatory Frameworks.**
Environmental regulations must be enforced more strictly to ensure industries comply with emission standards, supported by technological innovation and effective monitoring systems.

5.5 Limitations of the Study

Despite providing valuable insights, the study has several limitations:

I. The use of secondary data may include measurement or reporting errors.
II. The ARDL model, while powerful, may not fully capture nonlinear relationships among variables.
III. Institutional quality, technological innovation, and environmental policy indices were not included due to data unavailability.
IV. The findings are specific to Pakistan and may not generalize to other developing economies with different energy structures.

5.6 Directions for Future Research

To build on the current findings, future studies should consider the following areas:

1. **Sectoral Analysis:** Examine emissions in industrial, transportation, and residential sectors separately.
2. **Nonlinear Models:** Apply advanced econometric models (e.g., NARDL, VECM, or machine learning) to capture asymmetrical relationships.

3. **Institutional Factors:** Include governance indicators and environmental policy variables to analyze their moderating effects.
4. **Cross-Country Comparisons:** Conduct comparative studies across South Asian countries to identify regional policy synergies.
5. **Scenario-Based Forecasting:** Simulate long-term emission scenarios under different renewable energy and FDI growth assumptions.

5.7 Summary

This research provides comprehensive empirical evidence that renewable energy is the key driver of emission reduction in Pakistan. The persistence of CO_2 emissions and the minimal short-term role of GDP growth highlight the need for structural transformation toward a low-carbon economy. Policymakers should focus on sustainable energy transition, environmental governance, and green investment to balance economic expansion with ecological preservation. The study contributes significantly to environmental economics literature by providing updated empirical evidence on the determinants of CO_2 emissions and offering policy pathways for sustainable development in Pakistan.

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