

Trade Openness, Renewable Energy, and Environmental Outcomes: Evidence from Pakistan

Wasim Shahid Khawaja ¹ Azam Ali ² Saleem Raza Bhatti ³ Muhammad Mubashir Khan ⁴

ABSTRACT: This study examines the dynamic, long-run and short-run relationships between trade openness, renewable energy consumption, and environmental degradation in Pakistan from 1970 to 2023. Employing an autoregressive distributed lag (ARDL) bounds-testing approach, the study analyzes the key determinants of per-capita CO₂ emissions. Long-run findings indicate that trade openness reduces emissions significantly, whereas a greater share of renewable energy, unexpectedly, correlates with increased CO₂ emissions. This counterintuitive outcome is attributed to the inclusion of traditional biomass in renewable data and the carbon-intensive nature of new energy infrastructure development. Furthermore, economic growth and foreign direct investment both contribute to environmental degradation, supporting the presence of the Environmental Kuznets Curve and pollution-haven phenomena in their early phases. Short-run analysis indicates that the emission-reducing effects of trade liberalization are immediate, whereas the benefits of renewable energy exhibit a significant lag. The error correction model implies a fast, overshooting return to long run equilibrium. These findings highlight the complex, context-dependent nature of the environmental-economic nexus in a developing nation and underscore the necessity for nuanced policy that accounts for both immediate and delayed impacts. The analysis suggests a need to exploit effects of trade liberalization through stricter environmental standards, improve strategies for the use of renewable energy resources that actually reduce emissions, and carefully screen foreign investments to be consistent with 'green' needs, in order to reconcile tensions between economic prosperity and environmental protection.

KEYWORDS: Trade Openness, Renewable Energy, Environmental Damage, Pakistan, ARDL, CO₂ Emissions

JEL Classification: Q53, Q42, F18, C22

¹ HOD, Department of Business Administration, Emaan Institute of Management & Sciences, Karachi, Sindh, Pakistan. Email: wkhawaja@hotmail.com

² Dean, Emaan Institute of Management & Sciences, Karachi, Sindh, Pakistan. Email: drazam@emaan.edu.pk

³ Senior Lecturer, Department of Business Administration, Emaan Institute of Management & Sciences Karachi, Sindh, Pakistan. Email: engrsrbhatti12@gmail.com

⁴ Lecturer, Department of Business Administration, Emaan Institute of Management & Sciences, Karachi, Sindh, Pakistan. Email: 501mubashir@gmail.com

Corresponding Author:

Wasim Shahid Khawaja

✉ wkhawaja@hotmail.com

Introduction

Ensuring environmental sustainability has emerged as one of the biggest challenges of the 21st century, especially for less developed countries that have to manage the dual pressures of fast growth and rising environmental threats (Raza et al., 2022; Transparency, 2020). This predicament is exemplified by Pakistan,

listed as one of the countries that the climate crisis will hit the hardest. Its greenhouse gas emissions surged by 140% between 1990 and 2017 and may triple compared to 2015 levels by 2030 if current trends persist (Raihan, 2024).

The relationship between international trade and environmental health is a widely debated topic, with conflicting theories about how trade liberalization influences ecology (Ahmad et al., 2025; Iqbal et al., 2025). Trade can impact the environment through three main routes: the scale effect (where economic expansion leads to more pollution), the composition effect (where changes in industrial structure affect pollution levels), and the technique effect (which drives the spread of cleaner technologies) (Ahmad et al., 2025; Bernard & Mandal, 2016; Iqbal et al., 2025; Zaman et al., 2024). In Pakistan's case, empirical evidence remains inconclusive; some research indicates early trade liberalization phases increase pollution (Raza et al., 2022; Transparency, 2020; Zaman et al., 2025). while others argue it fosters environmental improvements through technology transfer and efficiency gains (Bernard & Mandal, 2016).

This paper is structured thus: Section 1 outlines the research problem and aims; Section 2 reviews existing literature on trade and energy; Section 3 details the methodological approach and data sources; Section 4 discusses the empirical results and their implications; and Section 5 provides policy suggestions and future research avenues.

Problem Statement

Globally, expanding renewable energy capacity is a key goal, with Pakistan aiming for renewables to supply 60% of its electricity by 2030 (Umar, 2024). However, the actual environmental benefits of renewable energy vary greatly in developing countries (Anwer et al., 2023; Rahman et al., 2024; Zaman et al., 2024). In Pakistan's context, the environmental advantages of renewable electricity generation may be negligible. Studies suggest that the environmental gains from increased renewables can be overestimated, especially when renewable sources constitute a small fraction of total energy supply (Rahman et al., 2024; Zafar et al., 2023; Zaman et al., 2025).

Although trade-environment and energy-environment linkages have been studied extensively worldwide, little research addresses the combined effects of trade liberalization and renewable energy deployment on Pakistan's environment. Diverse methodological approaches, particularly regarding time-series data that can be non-stationary or integrated of various orders, complicate analysis (Mahmood et al., 2022; Zaman et al., 2024). This study addresses these gaps using the ARDL bounds testing method, suitable for mixed integration orders, enabling robust analysis of both short- and long-term dynamics. Existing Pakistani studies remain few and present mixed findings, underscoring the need for focused, context-aware research.

Objective of the Study

This study aims to broaden the existing knowledge by analyzing five decades (1970–2023) of continuous data on Pakistan's trade-environment relationship. It provides a thorough evaluation of both long- and short-term interactions between trade openness, renewable energy use, and environmental performance, incorporating crucial economic and demographic factors. These insights are timely, as Pakistan has recently updated its Nationally Determined Contributions, committing to reduce emissions by 50% by 2030 (Ahmad et al., 2025; Hulo et al., 2022).

Literature Review

Trade Openness and Environmental Quality

Grossman and Krueger (1995) identify three fundamental mechanisms through which trade affects the environment: the scale effect (economic expansion increasing pollution), the composition effect (changes in industry structure affecting pollution), and the technique effect (trade advancing cleaner technologies and regulatory standards).

Bernard and Mandal (2016) examined 60 developing economies and reported that trade liberalization is accompanied by higher environmental performance index scores but also higher CO₂ emissions. This divergence underscores the multifaceted nature of the relationship and the necessity of distinguishing between pollution types and regulatory contexts (Bernard & Mandal, 2016).

Ahmad et al. (2020) analyzed Pakistan's trade-environment nexus from 1990 to 2021 and established that when trade openness rises, so do CO₂ emissions, consequently exacerbating environmental decline (Ahmad et al., 2025). In contrast, Khan et al. (2022) explored the country's macroeconomic fabric and concluded that greater trade openness exerts a long-run, significant destructive force on environmental quality, suggesting the possibility of future environmental improvements if specific policies are enacted. Such divergent findings highlight the pressing need for contemporary studies employing advanced econometric techniques (Khan et al., 2022).

Zahra et al. (2022) demonstrated that trade openness enlarges Pakistan's ecological footprint, with energy consumption and a rising gross domestic product (GDP) serving as the principal transmission mechanisms (Zahra et al., 2022). The interplay between trade and the environment exhibits considerable heterogeneity Across South Asia. Research on information and communication technology (ICT) trade among South Asian nations, including Pakistan, shows that deepening such trade channels elevates renewable energy usage and curtails CO₂ emissions, thus producing beneficial environmental externalities (Murshed et al., 2020; Zaman et al., 2024). The CPEC framework adds another layer of complexity to the nexus between trade and the environment in Pakistan. Ashraf (2023) demonstrated that the liberalization of trade, as articulated in CPEC agreements, correlates with rising pollutant loads; nevertheless, the authors argue that a persistent political order can attenuate the magnitude of such externalities (Ashraf, 2023). The findings underscore the mediating influence of institutional capabilities on the net environmental footprint of export-led growth.

Renewable Energy and Environmental Outcomes

Rahman et al. (2024) analyzed the time series data on sectoral consumption in Pakistan from 1980 to 2021, utilizing a nonlinear autoregressive distributed lag model. The authors concluded that increments in renewable generation exerted statistically insignificant pressure on the trajectory of CO₂ emissions (Rahman et al., 2024). They argue that this verdict is attributable to the nascent proportion of renewables within the overall generation matrix, as fossil contributors (both CO₂ and non-CO₂), such as coal and natural gas, retain a dominant role in pollutant release.

Anwer et al. explored the environmental consequences of renewable energy deployment in Pakistan over the period 1990–2020 (Anwer et al., 2023; Zaman et al., 2025). Their findings indicate that the diffusion of renewable energy technologies, alongside improvements in energy efficiency and increases in human capital per capita, is inversely correlated with carbon dioxide emissions. However, the magnitude of these

associations remains modest, compounded by the fact that renewable energy continues to be introduced at a constrained rate.

Zafar et al. (2023) found an unexpected relationship in Pakistan revealing that a higher share of renewable energy relates to a higher CO₂ emission (Zafar et al., 2023; Zaman et al., 2024). Such a contradiction may arise due to incorrect data reporting, the carbon footprint of renewable infrastructure construction, or other indirect consequences such as economic growth caused by renewable investment, which cancels emission reductions.

Ahmed et al. (2022) suggested that renewable energy consumption has a negative impact on economic growth in Pakistan over the short run, while a positive correlation was found for India (Ahmed et al., 2022; Ahmed et al., 2024; Zaman et al., 2025). The most important fact that these results illustrate here is the varying economic and environmental impacts of renewable energy across the country depending on its level of development, institutional frameworks and stages of the energy transition.

Huang et al. (2025) Using data for 1990–2022, investigates the effect of economic globalization on environmental degradation (CO₂ emissions) in Pakistan and finds that both FDI and trade openness increases pollution in the short and long run. This meaningfully demonstrates the direct pollution reduction based on renewable energy and that renewable energy can meaningfully offset the adverse effects of FDI and trade openness on the natural environment. These conclusions reinforce the Environmental Kuznets Curve and Pollution Halo Hypothesis and highlight the significance of synergy between the provision of renewable energy and economic growth in fostering sustainable development for Pakistan (Huang et al., 2025).

New policy priorities highlight the importance of exploring the relationship between renewable energy policy RE-ECO in the context of Pakistan. Under its renewable energy targets 20X25 and 30X30, the Government intends to achieve 20% renewable energy by 2025 and 30% by 2030. Reaching these objectives will require more than an initial outlay of about \$100 billion (Ahmad et al., 2025; Zaman et al., 2025).

Methodological Considerations

ARDL bounds testing is widely used in environmental time series analysis because it can handle variables that are integrated at different levels, including I(0) and I(1). Recent improvements, such as the augmented ARDL approach with extra F-tests introduced by McNown et al. (2018) (McNown et al., 2018), allow for better handling of I (2) variables. This study implements first differencing to address the I(2) series, focusing on growth rates for robust inference.

The Breusch–Godfrey test is utilized to identify serial correlation, the Breusch–Pagan–Godfrey test is employed to analyze heteroskedasticity, and model stability is regularly assessed through CUSUM and CUSUMQ techniques. Together, these methods bolster the resilience and dependability of empirical model evaluation.

Methodology and Data Description

Theoretical Framework

This analysis builds on the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) framework, which is an econometric extension of the IPAT that introduces stochastic terms and

flexible elasticities to examine environmental drivers (Xing et al., 2023; Zaman et al., 2024; Zaman et al., 2025). Per capita CO₂ emissions (lnCE) are affected by demographic, economic, and technological factors: population growth ($\Delta \ln(\text{PG})$) and urbanization ($\ln(\text{UR})$) represent the demographic pressure on CO₂ emissions; GDP per capita ($\ln(\text{GC})$) indicates levels of affluence. while trade openness ($\ln(\text{TO})$), renewable energy share ($\ln(\text{RS})$), energy use ($\ln(\text{EU})$), energy intensity ($\ln(\text{EI})$), and foreign direct investment ($\ln(\text{FD})$) reflect the technological dimension. Expressing the model in log-linear form facilitates interpreting coefficients as elasticities and reduces heteroscedasticity:

$$\ln(\text{CE}) = \beta_0 + \beta_1 \ln(\text{TO}) + \beta_2 \ln(\text{RS}) + \beta_3 \ln(\text{GC}) + \beta_4 \ln(\text{EU}) + \beta_5 \ln(\text{FD}) + \beta_6 \ln(\text{EI}) + \beta_7 \Delta \ln(\text{PG}) + \beta_8 \ln(\text{UR}) + \varepsilon$$

The ARDL bounds testing method by Pesaran et al. is employed to detect long-term equilibrium relationships, which is well-suited to small samples with mixed $I(0)$ and $I(1)$ integration orders. For $I(2)$ variables, first differencing is applied. Cointegration is established if the calculated F-statistic exceeds the critical upper bound, enabling simultaneous estimation of short-run and long-run effects.

The study uses annual data from 1970 to 2023, totaling 54 observations, sourced from the World Bank, Our World in Data, IEA, and national statistics (Ritchie, 2022; WDI, 2025). The dependent variable is per capita CO₂ emissions, and explanatory factors include trade openness, renewable energy share, GDP per capita, energy consumption, FDI inflows, energy intensity, population growth, and urbanization.

Diagnostic tests confirm model adequacy: the Breusch–Godfrey test indicates no serial correlation, the Breusch–Pagan–Godfrey test supports homoskedasticity, and CUSUM/CUSUMQ tests verify parameter stability, endorsing the reliability of ARDL results for policy analysis.

Data Sources and Variable Definitions

The empirical investigation draws upon annual time series data spanning 1970 to 2023, yielding 54 observations for Pakistan. Data were retrieved from established online repositories to guarantee uniformity and intertemporal comparability (Ritchie, 2022; WDI, 2025). The variables, along with their provenance, are enumerated below.

Dependent Variable

CE: CO₂ emissions per capita attributable to fossil fuel combustion and industrial processes (Ritchie, 2022).

Independent Variables

TO: Trade openness, measured as trading to GDP ratio (WDI, 2025)

RS: the share of renewable energy, which is the ratio of renewable to total primary energy supply (Ritchie, 2022)

Control Variables

GC: GDP per capita expressed in constant 2015 US dollars (WDI, 2025).

EU: per-capita energy consumption, reported in kilowatt-hours (WDI, 2025).

FD: net foreign direct investment inflows, expressed as a percentage of GDP (WDI, 2025).

EI: Energy intensity quantifies the energy required per unit of economic output, expressed in kilowatt-hours per dollar of GDP (Ritchie, 2022)

PG: percentage growth rate (population) (WDI, 2025).

UR: proportion of the population residing in urban areas, expressed as a percentage of the total population. (WDI, 2025)

Hypotheses for Cointegration Testing in the ARDL Bounds Test Framework

In implementing the bounds test for cointegration, the following hypotheses are proposed:

(Null Hypothesis H0) $\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = \lambda_6 = \lambda_7 = \lambda_8 = \lambda_9 = 0$

(Alternate Hypothesis H1) $\lambda_1 \neq \lambda_2 \neq \lambda_3 \neq \lambda_4 \neq \lambda_5 \neq \lambda_6 \neq \lambda_7 \neq \lambda_8 \neq \lambda_9 \neq 0$

The coefficients λ_1 to λ_9 in the ARDL bounds test for cointegration indicate the long-run relationship between the variables in the model. The joint significance of the lagged level terms in the error correction form of the ARDL equation is analyzed.

Each λ maps to one of the quantities under investigation:

λ_1 : Per capita CO₂ emissions (lnCE)

λ_2 : Trade openness (lnTO)

λ_3 : Renewable energy share (lnRS)

λ_4 : GDP per capita (lnGC)

λ_5 : Energy use per capita (lnEU)

λ_6 : Net foreign direct investment (lnFD)

λ_7 : Energy intensity (lnEI)

λ_8 : Population growth ($\Delta \ln(\text{PG})$)

λ_9 : Urbanization rate (lnUR)

The null hypothesis ($H_0: \lambda_1 = \lambda_2 = \dots = \lambda_9 = 0$) is that there exists no long-run relationship between these variables, which means there is no cointegration. The alternative hypothesis (H_1) is that one or more of these coefficients is non-zero, and that there is at least one long-run, equilibrium relationship.

Empirical Results and Discussion

Descriptive Statistics

Table 1

Descriptive Statistics of Environmental and Economic Data in Study

Variable	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis	J-B p-value	N
ln(CE)	-0.540	0.362	-1.213	0.035	-0.46	2.00	0.13	54
ln(TO)	3.398	0.191	2.761	3.651	-1.37	4.86	0.00	54
ln(RS)	2.597	0.263	1.463	2.927	-1.45	7.45	0.00	54
ln(GC)	6.917	0.296	6.406	7.404	-0.16	1.97	0.27	54
ln(EU)	7.934	0.343	7.267	8.452	-0.44	1.98	0.13	54
ln(FD)	-0.772	1.017	-4.670	1.110	-1.21	6.04	0.00	53
ln(EI)	-0.047	0.134	-0.671	0.154	-2.03	9.80	0.00	54
$\Delta \ln(\text{PG})$	-0.012	0.071	-0.160	0.165	-0.07	2.97	0.98	53
ln(UR)	3.454	0.121	3.212	3.639	-0.36	2.04	0.19	54

Table 1 provides a summary of the descriptive statistics from 1970 through 2023. Per capita CO₂ emissions (lnCE) demonstrate moderate variability with mean -0.54 and a standard deviation of 0.36, along with a near-

normal distribution (skewness -0.46, kurtosis 2.00, with Jarque-Bera p-value 0.13). Variables such as trade openness (lnTO) and the renewable energy share (lnRS) display strong skewness and leptokurtosis, reflecting the impact of policy changes, which causes their distributions to deviate from normality (JB p-values near zero). GDP per capita (lnGC) and energy use (lnEU) show symmetrical, mesokurtic distributions, supporting the appropriateness of log transformations. On the other hand, FDI inflows (lnFD) and energy intensity (lnEI) have pronounced kurtosis and negative skewness, reflecting episodic shocks. Population growth and urbanization variables approximate normal distributions.

Collectively, these patterns reveal a mixture of normal and non-normal data series, especially for variables sensitive to external shocks. Using logarithmic transformations helps alleviate heteroscedasticity and nonlinear relationships, reinforcing the suitability of the ARDL bounds testing method used subsequently, and enhances the robustness of the model estimates.

Unit Root Test Results

The Augmented Dickey-Fuller (ADF) test was conducted to assess whether each variable was stationary, categorizing them as I(0) if stationary in levels, I(1) if stationary after first differencing, or I(2) after second differencing, as displayed in Table 2.

Table 2

Augmented Dickey-Fuller (ADF) Unit Root Test Results

Variable	Level (I)	Level (T&I)	1st Diff (I)	2nd Diff (I)	Order
ln(CE)	-1.18 [0.68]	-1.32 [0.87]	-5.89*** [0.00]	-5.06*** [0.00]	I(1)
ln(TO)	-3.42** [0.01]	-3.35* [0.07]	-7.64*** [0.00]	-9.31*** [0.00]	I(1)
ln(RS)	-1.67 [0.44]	-5.29*** [0.00]	-8.45*** [0.00]	-6.35*** [0.00]	I(0)
ln(GC)	-0.22 [0.93]	-2.11 [0.53]	-6.10*** [0.00]	-8.65*** [0.00]	I(1)
ln(EU)	-1.26 [0.64]	-3.43* [0.06]	-10.69*** [0.00]	-9.96*** [0.00]	I(1)
ln(FD)	-3.54** [0.01]	-4.24*** [0.01]	-13.40*** [0.00]	-9.13*** [0.00]	I(0)
ln(EI)	-2.56 [0.11]	-2.96 [0.15]	-10.61*** [0.00]	-8.88*** [0.00]	I(1)
ln(PG)	0.18 [0.97]	-2.12 [0.52]	-2.38 [0.15]	-5.81*** [0.00]	I(2)
ln(UR)	-1.61 [0.47]	-4.90*** [0.00]	-1.53 [0.51]	-4.52*** [0.00]	I(0)
Δln(PG)	-2.38 [0.15]	-5.18*** [0.00]	-5.81*** [0.00]	-5.45*** [0.00]	I(0)

Notes: p-values in brackets; *, **, *** denote significance at 10%, 5%, 1%.

Several key variables including per capita CO₂ emissions (lnCE), trade openness (lnTO), GDP per capita (lnGC), energy use (lnEU), and energy intensity (lnEI) were identified as I(1), meaning they become stationary after differencing once.

In contrast, renewable energy share (lnRS), foreign direct investment (lnFD), and urbanization (lnUR) are stationary at levels (I(0)), as is population growth (lnPG). This mixture of integration orders supports the use of the ARDL method and guides the modeling approach.

These unit root findings indicate that classical Johansen cointegration methods are ill-suited here, whereas the ARDL approach provides a robust analytical framework.

ARDL Model Selection and Estimation

Applying the Akaike Information Criterion (AIC) for model selection determined the ARDL (1,3,3,2,0,3,3,1,3) as optimal, featuring a restricted constant term and no trend. The model uses the natural log of per capita CO₂ emissions (lnCE) as the dependent variable, with independent variables including logs of trade openness, renewable energy share, GDP per capita, energy use, FDI, energy intensity, changes in population growth, and urbanization rate. This ARDL setup allows simultaneous estimation of both the long-run equilibrium relationships and the dynamics of short-run fluctuations.

Table 3

Regression Results (Dependent Variable: ln(CE))

Variable	Coefficient (Std. Error)	Variable	Coefficient (Std. Error)
ln(CE-1)	-0.210 (0.153)	ln(FD)	0.037*** (0.011)
ln(TO)	-0.276*** (0.058)	ln(FD-1)	-0.015 (0.012)
ln(TO-1)	0.028 (0.052)	ln(FD-2)	0.016* (0.009)
ln(TO-2)	-0.059 (0.057)	ln(FD-3)	-0.008 (0.008)
ln(TO-3)	-0.091* (0.047)	ln(EI)	-0.520*** (0.062)
ln(RS)	0.011 (0.020)	ln(EI-1)	0.042 (0.053)
ln(RS-1)	0.119*** (0.022)	ln(EI-2)	0.064 (0.053)
ln(RS-2)	0.125*** (0.025)	ln(EI-3)	0.265*** (0.048)
ln(RS-3)	0.209*** (0.029)	(Δln(PG))	-0.077 (0.111)
ln(GC)	-0.336 (0.258)	(Δln(PG-1))	-0.126 (0.078)
ln(GC-1)	0.008 (0.251)	ln(UR)	20.129 (12.807)
ln(GC-2)	0.764*** (0.205)	ln(UR-1)	-41.095 (25.535)
ln(EU)	0.882*** (0.118)	ln(UR-2)	38.152* (21.885)
		ln(UR-3)	-16.553* (8.803)
Constant	-12.794*** (1.895)		

Cointegration and Long-Run Estimates

The ARDL bounds testing strongly confirms the existence of a long-run cointegrating relationship between trade openness, renewable energy share, economic growth, energy consumption, FDI, energy intensity, population growth, and urbanization in Pakistan. The reported F-statistic of 18.23 significantly surpasses the critical values, verifying a stable long-term equilibrium among these variables and supporting the estimation of long-run coefficients in the model (Table 4).

Table 4

ARDL Bounds Test for Cointegration

SIG.	F-STATISTIC	I(0)	I(1)
10%	18.23	1.85	2.85
5%	18.23	2.11	3.15
2.5%	18.23	2.33	3.42
1%	18.23	2.62	3.77

Long-Run Coefficient Estimates

Table 5 displays the normalized long-run coefficients derived from the ARDL framework, enabling the identification of the fundamental determinants of per-capita CO₂ emissions in Pakistan and illuminating intricate environmental-economic linkages that complicate prevailing theoretical paradigms.

Table 5

Long-Run Coefficient Estimates

Sig.	F-statistic	I(0)	I(1)
10%	18.23	1.85	2.85
5%	18.23	2.11	3.15
2.5%	18.23	2.33	3.42
1%	18.23	2.62	3.77

The long-run results indicate that a 1% increase in trade openness reduces per capita CO₂ emissions by approximately 0.33%, reflecting beneficial technology spillovers and cleaner production methods known as the technique effect. Conversely, the renewable energy share exhibits a positive association with emissions, a surprising outcome possibly linked to the measurement of traditional biomass as renewable energy and additional emissions tied to renewable infrastructure construction.

FDI emerges as a significant positive contributor to emissions, suggesting that current foreign investments may support pollution-intensive industries, aligning with the pollution haven hypothesis in early stages. Economic growth and energy consumption are positively correlated with emissions, fitting the Environmental Kuznets Curve theory, which posits that emissions rise during the early growth phase.

Short-Run Dynamics and Error Correction Model

The test statistic thus derived does not conform to any standard distribution, with critical values supplied by Pesaran et al. (2001). If the obtained F-statistic exceeds the upper-bound critical threshold, cointegration is affirmed. Conversely, a statistic below the lower bound threshold negates cointegrating relationships. An inconclusive outcome is recorded if the computed statistic occupies the interval between the two bounds (Pesaran et al., 2001).

Table 6

ARDL Error Correction Model

VARIABLE	COEF.	STD. ERR.	T	P
D(LN(TO))	-0.276	0.032	-8.69	0.000***
D(LN(RS-1))	-0.334	0.025	-13.34	0.000***
D(LN(GC))	-0.336	0.136	-2.47	0.023**
D(LN(FD))	0.037	0.007	5.28	0.000***
D(LN(EI))	-0.520	0.032	-16.38	0.000***
D(LN(UR))	20.129	6.415	3.14	0.005**
COINTEGRATION EQ (-1)	-1.210	0.074	-16.39	0.000***
R ² = 0.962, ADJ. R ² = 0.938, DW = 2.34				

Dependent Variable: ln(CE)

Chosen Model: ARDL(1, 3, 3, 2, 0, 3, 3, 1, 3) Time Period: 1970-2023

- ▶ In the short term, trade openness continues to significantly reduce emissions, indicating immediate environmental gains. However, positive coefficients on lagged trade variables imply adjustment costs that delay the realization of long-term benefits (according to Table 3).
- ▶ Increases in foreign direct investment in the short-run tend to raise emissions, highlighting the need for targeted investments in cleaner sectors.
- ▶ The highly significant and negative error correction term indicates that any short-term deviations from equilibrium are quickly rectified, with the system correcting over 100% of the disequilibrium within one period, signaling robust convergence.
- ▶ Explained Variance: The model shows strong explanatory power, with $R^2 = 0.962$ and Adjusted $R^2 = 0.938$, suggesting that over 93% of the variation is explained by the estimated ARDL–ECM specification.
- ▶ Durbin-Watson statistic: 2.34 (indicating no significant autocorrelation, and the residuals satisfy the assumption).

Diagnostic Test Results

Table 7

Diagnostic Tests for Model Adequacy

Test	H ₀	Stat	p-Value	Decision
Breusch–Godfrey (4 lags)	No serial correlation	F=2.17	0.12	No correlation
		$\chi^2=17.23$	0.002	Rejected
Breusch–Pagan–Godfrey	Heteroscedasticity	F=0.33	0.996	Homoskedastic
		0.037	$\chi^2=15.09$	0.968 Homoskedastic

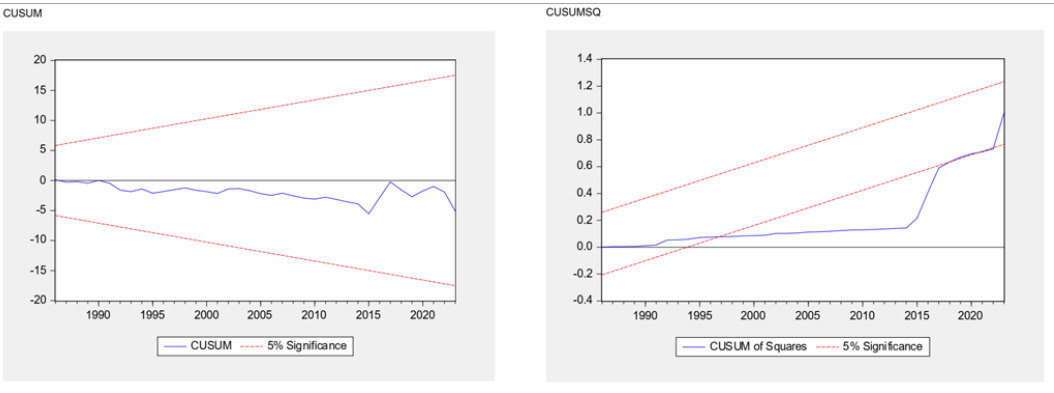
Overall, the ARDL model demonstrates strong fit, with homoskedastic and near-normally distributed residuals. While evidence of higher-order serial correlation is detected, it does not materially weaken the robustness of the long-run and short-run inferences.

Stability tests: CUSUM and CUSUM of Squares

Figure 1 displays the results of the CUSUM and CUSUM of Squares stability tests. Both assessments show that the model’s parameters and the variance of residuals remained stable throughout the entire sample period. The test statistics consistently stayed within the 5% significance limits, indicating no presence of structural breaks or fluctuations in variance. This evidence strongly supports the reliability and consistency of the estimated relationships across time.

Figure 1

Cumsum and Cumsum of Squares Test



Discussion

The ARDL results indicate:

- ▶ Findings suggest that trade liberalization consistently reduces emissions over both short and long horizons, supporting the prevalence of the pollution halo or technique effect rather than the pollution haven hypothesis in Pakistan (Ur Rahman et al., 2019).
- ▶ The positive link between renewable energy share and emissions may reflect the effects of traditional biomass usage and carbon emissions from renewable energy infrastructure development (Hussain et al., 2019).
- ▶ Economic growth and foreign direct investment contribute to rising emissions, with FDI notably promoting pollution-heavy industrial activities (Ahmad et al., 2020; Zaman et al., 2025).
- ▶ Energy consumption stands out as the strongest determinant of emissions, whereas improvements in energy intensity fail to meaningfully lower emissions, likely due to offsetting demand increases (Ahmad et al., 2020).
- ▶ Both population growth and urbanization show no significant impact on emissions during the study period, possibly reflecting Pakistan's economic and structural transition phase (Ahmad et al., 2020; Ur Rahman et al., 2019; Zaman et al., 2025).
- ▶ The coefficient of the error correction term is 1.21, suggesting rapid adjustment back to long-run equilibrium after short-run disturbances.
- ▶ The diagnostics and stability tests confirm the reliability of the ARDL framework, and the empirical conclusions drawn for policy and further research.

Conclusion

This study is unique in that it explores trade liberalization, renewable energy consumption, and environmental degradation over a full sample period from 1970 to 2023. The findings contribute significantly to the literature on environmental economics and policy-making.

The most important finding is the negative long-run association between trade openness and CO₂ emission growth, indicating that greater trade liberalization leads to environmental improvement in Pakistan. This effect aligns with the pollution halo hypothesis and counters concerns that trade liberalization leads to increased environmental degradation. The results suggest that Pakistan's integration into global markets has the potential to help achieve its environmental targets, including the NDC goal of a 50% reduction in emissions by the end of 2030 (Ahmad et al., 2025).

This surprising link between the share of renewable energy and CO₂ emissions raises important questions for both policy and research. This echoes recent studies that challenge the idea that expanding the renewable energy market in developing countries will automatically lead to environmental benefits (Rahman et al., 2024; Zafar et al., 2023). There are a few reasons this might be happening: for instance, traditional biomass is often counted as renewable energy, initial construction of renewable energy infrastructure can produce significant CO₂ emissions, and expanded access to energy may even lead to increased consumption overall.

The error correction model indicates a rapid adjustment toward long-term equilibrium, with disequilibrium adjustments occurring at a rate of approximately 121% per period. This quick response

suggests that Pakistan's environmental and energy systems are relatively flexible, indicating that policy interventions can influence emission pathways within a short timeframe.

Diagnostic tests validated the model fit, showing minimal concerns regarding serial correlation and homoscedastic residuals, and supported the substantive interpretations. The high explanatory power ($R^2 = 0.961$) implies that the model effectively accounts for the major factors affecting CO₂ emissions growth in Pakistan.

There are multiple policy implications of these results for the government. First, trade liberalization must continue and accelerate, particularly with respect to environmental standards and technology transfer clauses in trade agreements. Second, policies on renewable energy expansion must be reassessed to ensure that growth leads not only to increased capacity but also to real emission reductions. Third, foreign investment reviews should focus on green investments and mitigate the environmental risks associated with emission-intensive FDI. Fourth, upgrading energy efficiency is identified as an important short-term policy instrument for emission reduction.

Several limitations of the methodology should be noted, including the availability of information for renewable energy classification, details regarding trade composition, and a lack of comprehensive environmental indicators beyond CO₂ emissions. Future research should address these limitations by incorporating more disaggregated sectoral studies, alternative environmental metrics and international comparisons.

Despite these limitations, this study provides vital empirical evidence useful for environmental policymaking in Pakistan, especially as the country devises plans to meet its international climate obligations without sacrificing economic growth. Well-designed environmental policies that manage trade and energy can lead to conservation outcomes; however, successful promotion requires a strong focus on policy design and implementation.

This study contributes to the broader literature on trade-environment and energy-environment connections in developing countries by presenting a methodologically robust analysis based on long-term data and suggesting broader relevance to other developing economies facing similar challenges. As Pakistan and other developing countries strive to balance economic development and environmental sustainability, such empirical evidence is critically important for policy formulation and international cooperation.

Recommendations

Policy Research Needs

This study's findings carry important policy implications. Firstly, detailed sectoral analyses are necessary to identify the specific industries and trade activities most responsible for the trade-environment nexus, facilitating more precise policy interventions.

Secondly, firm-level studies examining technology adoption and behavioral patterns can illuminate how trade openness influences environmental outcomes, supporting the formulation of targeted industrial and environmental policies.

Lastly, comparisons of the costs and benefits among renewable energy technologies and policies are critical to optimize investment efficiency. The observed positive association between renewables and emissions indicates that renewable investments vary in their true emission reduction impact.

Trade Policy Recommendations

The inverse long-run relationship between trade openness and CO₂ growth suggests that trade liberalization may benefit environmental performance in Pakistan. This indicates that integration into the global market should continue, but with an emphasis on environmental standards in the trade agreements. Policymakers should:

1. Promote environmental goods and services trade by reducing tariffs and non-tariff barriers.
2. Enhance environmental regulations to ensure that growth from trade encourages cleaner technologies.
3. Foster participation in global value chains that uphold stringent environmental standards.
4. Integrate environmental protections and technology transfer provisions explicitly into trade agreements.

Renewable Energy Policy Concerns: The observed rise in emissions alongside growing renewable energy shares highlights a significant policy challenge. Rather than abandoning renewable energy initiatives, Pakistan must refine its renewable energy policies:

- ▶ Emphasize grid-connected centralized renewable systems over small-scale local projects to maximize impact (Raza et al., [2022](#)).
- ▶ Boost renewable energy production while minimizing carbon emissions during infrastructure construction.
- ▶ Improve accounting practices to ensure renewable energy statistics reflect truly clean sources (Rahman et al., [2024](#)).
- ▶ Pair renewable energy deployment with energy efficiency programs to achieve greater environmental gains.

Foreign Investment Management:

The positive association between FDI and emission growth underscores the importance of conducting environmental screenings for foreign investment. The policy recommendations are as follows:

1. Conduct Environmental Studies: Conduct environmental assessments for major FDI projects (Ashraf, [2023](#)).
2. Incentivizing Environmentally Friendly FDI: Promote environmentally friendly FDI while curbing eco-unfriendly investments.
3. Require Technology Transfer Obligations: Demand technology transfer obligations, especially for clean technologies, from foreign investors in proportion to their foreign direct investment (FDI).
4. Align Investment Promotion with Environmental Goals: Integrate investment promotion targeting FDI with environmental objectives and NDC targets.

Energy Efficiency Priority

Improving energy intensity presents certain short-term challenges; however, it underscores the critical importance of energy efficiency as a policy focus. The following actions are recommended to support energy efficiency efforts:

1. Set legally binding energy efficiency standards for industries and construction projects.
2. Encourage investments in energy-saving technologies by providing financial support options.
3. Promote energy management training programs to build expertise and improve practices.
4. Encourage Conservation: Provide tax credits and subsidies for conservation efforts.

Integrated Policy Framework

The intricate relationship between trade, energy, and environmental effects calls for a more holistic policy solution:

1. **Align Policies:** Align trade, energy, and environmental policies to maximize synergies (Ahmad et al., 2025).
2. **Create Green Industrial Zones:** Establish green industrial zones that integrate commercial promotion and environmental protection.
3. **Develop Holistic Regulatory Regimes:** Create regulatory frameworks that comprehensively address trade-environment-energy interfaces.
4. **Institute Monitoring Mechanisms:** Implement monitoring systems that simultaneously assess performance across multiple goals.

Limitations and Future Research Directions

This study is subject to several data limitations. First, the renewable energy category includes the traditional use of biomass, which is not necessarily a clean energy source and may help explain the paradoxical positive association with emissions (Rahman et al., 2024). In future research, differentiating between modern renewables (such as solar, wind, and hydropower) and traditional renewables (such as biomass) could provide deeper insights.

Second, the current measure of trade openness—trade as a share of GDP—does not capture what types of goods are traded or their environmental impacts. It would be useful for future studies to use more detailed trade indicators that reflect the environmental footprint of different sectors and trade flows.

Third, this study uses CO₂ emissions alone to represent environmental effects, which doesn't fully capture all environmental consequences of international trade and renewable energy. Broader measures, like ecological footprints, air quality indexes, or comprehensive environmental performance indicators, should be considered in future analyses for a more complete understanding.

References

- Ahmad, A. U., Ismail, S., Ahmad, I. M., Adamu, I. M., Jakada, A. H., Farouq, I. S.,...Fagge, A. (2020). Pollutant emissions, renewable energy consumption and economic growth: An empirical review from 2015-2019. *Journal of Environmental Treatment Techniques*, 8(1), 323-335.
- Ahmad, R., Liu, G., Rehman, S. A. U., Fazal, R., Gao, Y., Xu, D.,...Giannetti, B. F. (2025). Pakistan road towards Paris Agreement: Potential decarbonization pathways and future emissions reduction by A developing country. *Energy*, 314, 134075. <https://doi.org/10.1016/j.energy.2024.134075>
- Ahmed, S.M.M., Zaman, S.U., & Alam, S. H. (2024). The Effect of Green Branding on Consumer Beliefs and Attitudes Toward Eco-Conscious Purchases. *Journal of Social Sciences Review*, 4(4), 281–299. <https://doi.org/10.62843/jssr.v4i4.477>
- Ahmed, Z., Ahmad, M., Rjoub, H., Kalugina, O. A., & Hussain, N. (2022). Economic growth, renewable energy consumption, and ecological footprint: Exploring the role of environmental regulations and democracy in sustainable development. *Sustainable Development*, 30(4), 595-605. <https://doi.org/10.1002/sd.2251>
- Anwer, M. A., Farooq, F., Faheem, M., & Yousuf, M. (2023). Assessing the Environmental Impact of Energy Efficiency and Renewable Energy: Evidence from Pakistan. *Review of Applied Management and Social Sciences*, 6(1), 117-129. <https://doi.org/10.47067/ramss.v6i1.305>
- Ashraf, J. (2023). Does political risk undermine environment and economic development in Pakistan? Empirical evidence from China–Pakistan economic corridor. *Economic Change and Restructuring*, 56(1), 581-608. <https://doi.org/10.1007/s10644-022-09434-z>
- Bernard, J., & Mandal, S. (2016). The impact of trade openness on environmental quality: an empirical analysis of emerging and developing economies. *WIT Transactions on Ecology and the Environment*, 203, 195-208. <https://doi.org/10.2495/EID160181>
- Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *The Quarterly Journal of Economics*, 110(2), 353–377. <https://doi.org/10.2307/2118443>
- Huang, X., Ahmad, W., Umair, M., Antohi, V. M., Fortea, C., & Cristache, N. (2025). Foreign direct investment, trade openness and environmental pollution in Pakistan: does renewable energy mitigate environmental degradation? *Frontiers in Environmental Science*, 13(1618767). <https://doi.org/10.3389/fenvs.2025.1618767>
- Hulio, Z. H., Jiang, W., & Chandio, G. S. (2022). Power policies, challenges, and recommendations of renewable resource assessment in Pakistan. *Energy Exploration & Exploitation*, 40(3), 947–976. <https://doi.org/10.1177/01445987211064678>
- Hussain, M., Butt, A. R., Uzma, F., Ahmed, R., Islam, T., & Yousaf, B. (2019). A comprehensive review of sectorial contribution towards greenhouse gas emissions and progress in carbon capture and storage in Pakistan. *Greenhouse Gases Science and Technology*, 9(4), 617–636. <https://doi.org/10.1002/ghg.1890>
- Iqbal, F, a Nakhoda, I Nabi, E Arshad, and H Aziz. "Trade Policy Measure to Encourage a Shift towards Green Technologies." CDPR, June 2, 2025. <https://www.cdpr.org.pk/projects/trade-policy-measure-to-encourage-a-shift-towards-green-technologies/>.
- Khan, H., Weili, L., & Khan, I. (2022). Environmental innovation, trade openness and quality institutions: an integrated investigation about environmental sustainability. *Environment Development and Sustainability*, 24(3), 3832–3862. <https://doi.org/10.1007/s10668-021-01590-y>

- Mahmood, H., Hassan, S., Tanveer, M., & Ahmad, A.-R. (2022). The effects of rule of law, regulatory quality, and renewable energy on CO2 emissions in South Asia. *International Journal of Energy Economics and Policy*, 12(6), 16-21. <https://doi.org/10.32479/ijee.13468>
- McNown, R., Sam, C. Y., & Goh, S. K. (2018). Bootstrapping the autoregressive distributed lag test for cointegration. *Applied Economics*, 50(13), 1509–1521. <https://doi.org/10.1080/00036846.2017.1366643>
- Murshed, M., Chadni, M. H., & Ferdaus, J. (2020). Does ICT trade facilitate renewable energy transition and environmental sustainability? Evidence from Bangladesh, India, Pakistan, Sri Lanka, Nepal and Maldives. *Energy, Ecology & Environment*, 5(6), 470–495. <https://doi.org/10.1007/s40974-020-00190-2>
- Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics* (Chichester, England), 16(3), 289–326. <https://doi.org/10.1002/jae.616>
- Rahman, M. R., Rahman, M. M., & Akter, R. (2024). Renewable energy development, unemployment and GDP growth: South Asian evidence. *Arab Gulf Journal of Scientific Research*, 42(3), 1044–1059. <https://doi.org/10.1108/agjsr-04-2023-0152>
- Raihan, A. (2024). The interrelationship amid carbon emissions, tourism, economy, and energy use in Brazil. *Carbon Research*, 3(1). <https://doi.org/10.1007/s44246-023-00084-y>
- Raza, M. A., Aman, M. M., Rajpar, A. H., Bashir, M. B. A., & Jumani, T. A. (2022). Towards achieving 100% renewable energy supply for sustainable climate change in Pakistan. *Sustainability*, 14(24), 16547. <https://doi.org/10.3390/su142416547>
- Ritchie, H. R., Max; Rosado, Pablo. (2022). *Energy*. Our World in Data. <https://ourworldindata.org/energy>
- Transparency, C. (2020). Climate transparency report 2022. *Climate Transparency*. <https://www.climate-transparency.org/en/g20-climate-performance/g20report2022>
- Umar, H. (2024). Comparative Dynamics of the Belt and Road Initiative: Unveiling the Unique Position and Implications of the China-Pakistan Economic Corridor. *Indus Journal of Social Sciences*, 2(2), 1-18. <https://doi.org/10.59075/ijss.v2i2.93>
- Ur Rahman, Z., Chongbo, W., & Ahmad, M. (2019). An (a) symmetric analysis of the pollution haven hypothesis in the context of Pakistan: a non-linear approach. *Carbon Management*, 10(3), 227-239. <https://doi.org/10.1080/17583004.2019.1577179>
- WDI. (2025). *World Development Indicators*. <https://databank.worldbank.org/source/world-development-indicators>
- Xing, L., Khan, Y. A., Arshed, N., & Iqbal, M. (2023). Investigating the impact of economic growth on environment degradation in developing economies through STIRPAT model approach. *Renewable and Sustainable Energy Reviews*, 182(113365), 113365. <https://doi.org/10.1016/j.rser.2023.113365>
- Zafar, M. A., Bhatti, M. A., Nawaz, M. A., & Ahmad, T. I. (2023). Assessing the influence of renewable energy sources on CO2 emissions: New insights from Pakistan. *iRASD Journal of Economics*, 5(3), 825–844. <https://doi.org/10.52131/joe.2023.0503.0164>
- Zahra, S., Khan, D., Gupta, R., Popp, J., & Oláh, J. (2022). Assessing the asymmetric impact of physical infrastructure and trade openness on ecological footprint: An empirical evidence from Pakistan. *PloS One*, 17(5), e0262782. <https://doi.org/10.1371/journal.pone.0262782>

- Zaman, S. U., Sabih, A., Alam, S.H., & Shahzad, K. (2025). User Acceptance of Social Media-Backed Digital Detox Apps: Exploring the Role of Personality Traits in Pakistan's Digital Landscape. *Annual Methodological Archive Research Review*, 3(4), 97-124. <https://doi.org/10.63075/1nfx8d75>
- Zaman, S. U., Hasan, S. M. Y., Alam, S.H., & Abbasi, B. A. (2025). Effect of Client Satisfaction on Developing CRM, Trust, and Quality. *Annual Methodological Archive Research Review*, 3(3), 76-100. <https://doi.org/10.63075/b3523c23>
- Zaman, S. U., Ahmed, W., & Alam, S. H. (2025). How Brand Experience Builds Loyalty: The Roles of Trust, Association, Word-of-Mouth, and Credibility. *The Critical Review of Social Sciences Studies*, 3(1), 3744-3762. <https://doi.org/10.59075/s1b55795>
- Zaman, S. U., Ali, S. M. O., Alam, S. H., & Ahmed, J. (2024). Factors Influencing the Purchase Intention Towards Electronic Vehicle and Impact on Individual's Pro-Environmental Future Intentions. *Journal of Asian Development Studies*, 13(4), 1175-1192. <https://doi.org/10.62345/jads.2024.13.4.96>
- Zaman, S. U., Khalid, M.U.I., Alam, S. H., & Hunain, M. (2025). Investigating the Factors Influencing the Acceptance of Islamic Mobile Banking Services. *The Asian Bulletin of Green Management and Circular Economy*, 5(1), 99-126. <https://doi.org/10.62019/abgmce.v5i1.129>
- Zaman, S. U., Kumar, L., & Alam, S. H. (2024). The role of Financial Literacy and challenges Faced by Rural Communities in Adoption of Digital Tools: An Empirical study on District Tharparkar. *Journal of Social & Organizational Matters*, 3(4), 663-680. <https://doi.org/10.56976/jsom.v3i4.220>
- Zaman, S. U., Kunbher, A., & Alam, S.H. (2024). From Awareness to Investment: Unpacking the Risk-Based Pathway in Financing Decisions. *Advance Journal of Econometrics and Finance*, 2(4), 27-42. <https://doi.org/10.63075/1e69yt28>
- Zaman, S. U., Mohtashim, M., & Alam, S. H. (2024). Private Finance as Public Planner: A Channel-Based Framework for Equitable and Strategic Climate Transitions. *Research Journal of Psychology*, 2(3), 279-299. <https://doi.org/10.59075/rjs.v2i3.121>
- Zaman, S. U., Siddiqui, A., Alam, S.H., & Khan, A. W. (2025). Strategic Resource Integration: Exploring the Role of Business Model Design, Human Capital, and Financial Capital in Startup Performance. *Annual Methodological Archive Research Review*, 3(1), 98-116. <https://doi.org/10.63075/pe18t314>
- Zaman, S. U., Tahir, M., Alam, S.H., & Furqan, M. (2024). Impact of Sensory Branding and Brand Awareness on Consumer Buying Behavior. *The Asian Bulletin of Big Data Management*, 4(4), 90-113. <https://doi.org/10.62019/vsk6m466>
- Zaman, S. U., Yousfi, F. A., & Alam, S. H. (2025). Consumer Behavior in Choosing Shopping Malls versus Local Traditional Markets. *ACADEMIA International Journal for Social Sciences*, 4(1), 461-483. <https://doi.org/10.63056/ACAD.004.01.0090>
- Zaman, S. U., Zubairi, S. A., Zubairi, N. A., & Alam, S.H. (2024). Consumer Adoption of Livestream Shopping: A Technology and Service Quality Perspective. *Qlantic Journal of Social Sciences and Humanities*, 5(4), 358-371. <https://doi.org/10.55737/qjssh.v-iv.24322>
- Zaman, S.uz, Alam, J, S.H., Khan, U. A., & Kamal, M. H. (2025). Exploring the Role of Livestream Shopping and M-Commerce in Enhancing Humanitarian Logistics. *Pakistan Journal of Humanities and Social Sciences*, 13(2), 21-34. <https://doi.org/10.52131/pjhss.2025.v13i2.2693>