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Research Article

Impact of Renewable and Non-renewable energy consumption on Environmental Quality: Evidence from Pakistan

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Abstract

This research examines the interplay between renewable energy consumption and environmental quality in Pakistan, emphasizing sustainable development strategies. Using an empirical framework that combines a Correlation Matrix and the Auto-regressive Distributed Lag (ARDL) model, the study used annual time series data from 1991 to 2023. Carbon dioxide (CO_2) emissions are the key environmental quality indicator, with independent variables comprising renewable and non-renewable energy consumption, foreign direct investment (FDI), GDP per capita, and inflation. The key findings indicate a significant long-term inverse relationship between renewable energy consumption and CO_2 emissions. In contrast, non-renewable energy consumption shows a strong positive association with CO_2 emissions. FDI marginally worsens environmental quality, whereas GDP per capita and inflation exhibit negative correlations with CO_2 emissions, reflecting intricate economic-environmental dynamics.

Key words: Renewable Energy; Non-renewable energy; Inflation; GDP per capita; CO_2 emissions.
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1. Introduction

Energy serves as the cornerstone of economic progress and societal well-being, yet its production and consumption patterns—particularly reliance on non-renewable sources—pose significant environmental and health risks (Jin & Kim, 2018; Baranes et al., 2021). Globally, energy systems are broadly categorized into renewable (e.g., solar, wind, biomass) and non-renewable sources (e.g., coal, oil, gas), with the latter dominating due to their accessibility despite severe ecological consequences (Salman, Marek Jaszczur, 2024). Fossil fuels, finite in quantity and carbon-intensive, release greenhouse gases (GHGs) when burned, exacerbating climate hazardous and public health crises, such as respiratory diseases (Dolf Gielen, et aal., (2019; Akhtar & Rehmani, 2020). Developing nations like Pakistan exemplify this challenge because fossil fuels account for 60% of its energy mix, accelerating natural resource depletion (Ray, 2019) and exposing vulnerable populations to habitat destruction, soil degradation, and long-term air pollution (Rehman et al., 2022). While renewable energy sources offer a cleaner alternative with minimal carbon emissions, their adoption remains limited in Pakistan due to infrastructural and economic barriers as well as high cost. This imbalance depicts a pressing contradiction in policy framework. Some countries like Pakistan favor immediate energy availability at the expense of long-term environmental degradation, leading to irreversible ecological harm (Nizam et al., 2020; Anwar et al., 2021). In this challenging scenario, the study explores Pakistan's energy-environment relationship to determine viable strategies for balancing economic development with environmental conservation.

1.1 Background of the Study

Excessive dependence on non-renewable energy sources has led to severe environmental consequences. In Pakistan, coal mining—a major energy drivers—not only releases CO_2 but also causes underground fires and land subsidence, leaving vast areas barren for years (Akhtar & Rehmani, 2020). Fossil fuel combustion accounts for approximately 75% of

global greenhouse gas emissions, exacerbating climate-related disasters such as severe flooding, prolonged droughts, and ecosystem degradation (Rehman et al., 2023). Meanwhile, renewable energy—including wind and solar—generates minimal emissions. Despite this benefit, renewable constitute less than 5% of Pakistan's energy mix. (Anwar et al., 2021). The urgency of transitioning to renewable is amplified by projections: without policy intervention, global CO_2 emissions from energy could double by 2050 (Nizam et al., 2020; Yao, Zhang & Zhang, 2019) Pakistan's reliance on imported fossil fuels further strains its economy, diverting resources from poverty alleviation and healthcare (Ray, 2019). Despite international calls for sustainable energy frameworks, empirical evidence on Pakistan's renewable adoption barriers and their socio-environmental implications remains sparse. Hence, this study addresses this gap by analyzing historical data to inform context-specific strategies. The primary question of the study is as follows: -

What is the relationship between renewable and non-renewable energy consumption, economic variables (FDI, GDP per capita, inflation), and environmental quality (CO_2 emissions) in Pakistan, and how can policy frameworks align energy transitions with sustainable development goals? Hence, this study explores the following objectives:

- To assess the long- and short-term impacts of renewable and non-renewable energy consumption on CO_2 emissions in Pakistan.
- To evaluate the role of economic variables —foreign direct investment (FDI), GDP per capita, and inflation—in shaping environmental quality.
- To identify policy interventions that promote renewable energy adoption while mitigating ecological and socioeconomic trade-offs.

This study contributes to the energy-environment discourse in three keyways. First, it provides empirical evidence from Pakistan—a developing economy heavily reliant on fossil fuels—using advanced econometric techniques (ARDL model) to capture dynamic relationships between energy types, economic variables, and CO_2 emissions. Second, it

bridges a critical literature gap by integrating FDI and inflation into the analysis, offering insights into how macroeconomic stability influences sustainability. Third, the findings advocate for context-driven policies, such as incentivizing renewable infrastructure investments and aligning fiscal policies with ecological goals, which can serve as a blueprint for nations facing similar energy transitions. By linking theoretical frameworks with actionable strategies, this research advances global efforts to balance economic development with planetary constraints.

The rest of the paper is divided into the following sections. Section 2 reviews relevant studies. Section 3 illustrates research methodology. Section 4 describes empirical results. Section 5 concludes the paper with deeper discussion of the findings, theoretical contribution, limitations and suggestions for further research.

2. Literature Review

Recent research underscores the complex relationship between energy consumption, economic growth, and environmental sustainability, particularly in fossil fuel-dependent economies. Zaidi, Danish, Hou, and Mirza (2023) highlight renewable energy as a key driver of environmental improvement, contrasting sharply with fossil fuels, which exacerbate carbon emissions. Their analysis of Pakistan's energy dynamics (2004–2021) employs advanced econometric methods, such as the Two-Step System Generalized Method of Moments; to demonstrate how human capital, digitalization, and technology further reduce emissions. Sarkodie et al. (2020) expand on this by examining Pakistan's carbon-intensive growth trajectory, linking emissions to fossil fuel reliance, industrialization, and natural resource exploitation. Their policy-focused framework, which integrates neural networks and auto-regressive models, reveals that renewable energy consumption and income growth can slow environmental degradation, though challenges like fossil fuel dependency and human capital limitations persist. Saidi and Omri (2020) reinforce renewable energy's dual role in emissions reduction and economic growth across 15 countries, including Pakistan. Using Vector Error Correction Models,

they identify bidirectional causality between renewable energy adoption and GDP growth, though long-term de-carbonization strategies remain hindered by weak structural linkages. Kartal (2022) corroborates these findings, showing coal consumption as the primary predictor of emissions in fossil fuel-reliant nations. While renewable and nuclear energy contribute marginally to mitigation their impact against non-renewable, emphasizing the need for urgent policy shifts. Ali, Audi, and Roussel (2021) caution that economic development in emerging economies often prioritizes fossil fuels, creating unavoidable short-term environmental trade-offs. Their work stresses the necessity of transitioning to renewable to balance growth with sustainability. Arshad et al. (2020) add nuance by noting Southeast Asia's paradoxical relationship with natural resources: while renewable lower emissions, non-renewable and GDP growth elevate them, and certain natural resource practices unexpectedly improve environmental quality.

2.1 Research gap

Despite these voluble insights, academic literature has significant gaps. First, most of the studies mainly focus on CO_2 emissions as the sole environmental culprit, ignoring broader environmental impacts like biodiversity loss or soil degradation. Second, the nonlinear effects of renewable adoption—particularly the minimum thresholds required to significantly reduce emissions—remain unexplored, especially in developing nations like Pakistan where energy landscape is fragmented. Third, the effect of macroeconomic instability (including high inflation, fiscal deficits, and debt crises) on energy transition policies has received low attention, despite its crucial implications for economically volatile regions. Fourth, institutional weaknesses—such as weak enforcement of renewable energy policies and continued fossil fuel subsidies—are often overlooked, even though they fundamentally shape policy implementation. Finally, regional disparities in energy access (e.g., urban-rural divides) need deeper analysis to build equitable transition strategies. These gaps can be addressed by integrating environmental, economic, and governance factors to deliver context-specific solutions in a sustainable way.

2.2 Hypothesis of study

In this uncertain scenario, we developed the following hypotheses for empirical analysis of the nexus between environmental and economic variables using time-series data and robust econometric methods:

H_1: Renewable energy consumption shows a negative relationship with CO_2 emissions in both the short and long term, thereby improving environmental quality in Pakistan.

H_2: Non-renewable energy consumption demonstrates a strong positive association with CO_2 emissions, adversely affecting environmental quality over time.

H_3: GDP per capita shows a dual correlation—initially increasing CO_2 emissions due to industrialization but potentially improving environmental quality at higher income levels through cleaner technologies.

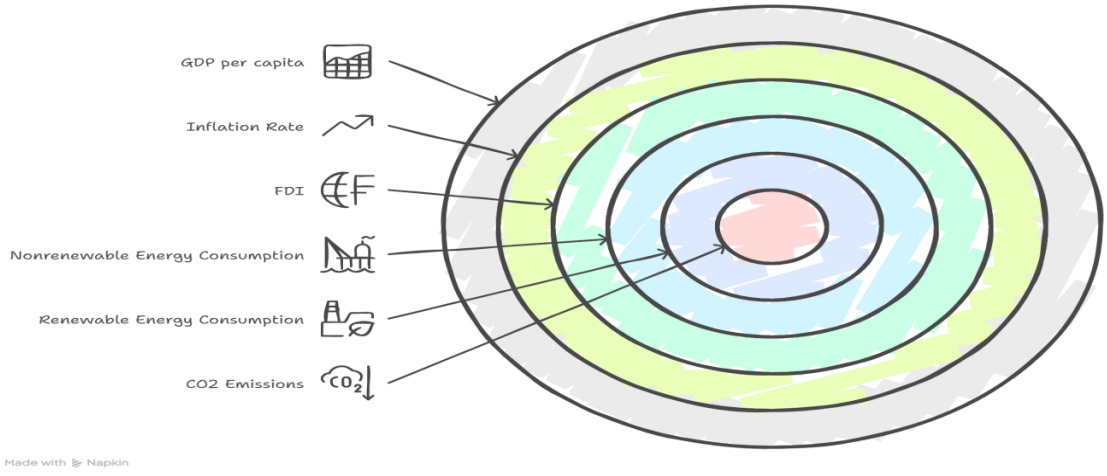
H_4: Inflation rate positively correlates with CO_2 emission and environmental quality in Pakistan.

H_5: Foreign Direct Investment (FDI) positively correlates with CO_2 emissions and environmental quality in Pakistan.

2.3 Conceptual Model

Keeping in view the variables, hypotheses and objectives of the study, we constructed a conceptual model having CO_2 emissions as dependent variable, while Renewable energy consumption, nonrenewable energy consumption, FDI, Inflation Rate and GDP per capita as independent variables to test their statistical short-and-long-term relationships.

Fig1: Research Model



Source: Author draws this image by Napkin.

3. Research Methodology

This study employs time series data spanning from 1991 to 2023, sourced from the World Bank's World Development Indicators, to investigate the relationship between energy consumption patterns and environmental quality in Pakistan. The dependent variable, CO_2 emissions, serves as a proxy for environmental quality, capturing the volume of carbon dioxide released into the atmosphere annually. Independent variables include renewable energy consumption (measured as the share of wind, solar, and hydro energy in total final energy consumption), non-renewable energy consumption (percentage from fossil fuels such as coal, oil, and natural gas), foreign direct investment (FDI), GDP per capita (economic output per person), and inflation rate (annual percentage change in consumer prices). Various econometric techniques were used to manipulate data and draw the results.

3.1 Specification of Model

The functional form of the study's model is shown in the following equation:

$$CO2t=\beta_1+\beta_2REt+\beta_3NREt+\beta_4FDIt+\beta_5INFt+\beta_6GDPPCt+\mu t \quad (1)$$

where CO_2 represents emissions, RERE and NRENRE denote renewable and non-renewable energy consumption, FDI is foreign direct investment, INF is inflation, GDPPC is GDP per capita, and μt is an error term.

For short-run dynamics, the Error Correction Model (ECM) was integrated into the ARDL framework:

$$\Delta CO_2t=\alpha+\sum i=1q\lambda 1\Delta REt-i+\sum i=1q\lambda 2\Delta NREt-i+\sum i=1q\lambda 3\Delta FDIt-i+\sum i=1q\lambda 4\Delta INFt-i+\sum i=1q\lambda 5\Delta GDPPCt-i+\omega ECMt-1+\epsilon t \quad (2)$$

Here, Δ indicates first differences, $\omega\omega$ is the error correction term coefficient (expected to be negative and significant for convergence to equilibrium), and ϵt is the residual. Unit root tests (e.g., Augmented Dickey-Fuller) were conducted to assess stationarity, ensuring variables did not exceed I (1) integration. While the methodology robustly addresses linear relationships, it does not explore nonlinear thresholds (e.g., minimum renewable energy adoption required for measurable emission reductions) or regional disparities in energy access within Pakistan due to lack of the availability of data.

3.2 Analytical techniques:

Descriptive statistics were first applied to summarize trends in energy use and environmental metrics, followed by a correlation matrix to identify pairwise relationships among variables. The Autoregressive Distributed Lag (ARDL) model, developed by Pesaran et al. (1999), was selected to analyze short- and long-term dynamics between CO_2 emissions and the predictors, accommodating variables with mixed orders of integration (I (0) or I (1)). The ARDL framework is particularly suited for small sample sizes and allows simultaneous estimation of equilibrium relationships and transient adjustments. The bound test was used to confirm co-integration, comparing the computed F-statistic against critical values to distinguish between short- and long-term effects. The study's variables are briefly described as below:

3.3 Description of variables:

- **CO2 Emission:**

CO_2 Emission is defined as the quantity of carbon dioxide emitted into the atmosphere over a specific time period and is expressed in metric tons per person (Rehman, Ozturk, & Ulucak, 2022; Zaidi,(2023) . The increase in volume of CO_2 emissions in atmosphere have significant negative impact on human health, soil fertility and plant growth. This variable also prefects environmental quality.

- **Renewable energy consumption**

Renewable energy consumption is referred to energy produced by Wind, Solar and Hydro system and is used as % of total final energy consumption (Kartal, 2022;Salman, Marek Jaszczur, (2024) . These renewable sources are environmentally friendly and have minimum impact on human beings, soil and plants.

- **Non-renewable energy Consumption**

The percentage of final energy consumption comes from using fossil fuels (coal, oil, and natural gas) and energy supplies that are limited and cannot be replenished naturally on a human timetable (Baranes, .Jacqmin,. & Poudou, 2021; Tze-Zhang Ang, 2022). These resources have negative impact on human health, soil fertility and plant growth (Dolf Gielen, 2019).

- **Foreign Direct Investment**

This is amount of capital which is invested by foreigners in a host country as equity investment, for establishing a new industry and for transfer of technology. It expedites capital formation and triggers economic growth in host country (Fariea Nazim et al., (2024). It is very beneficial for the developing countries if it is accompanied by transfer of technology on long-term basis (N. Abdul Rehman, et al., 2021; Islam & Beloucif, 2023).

- **GDP Per capita**

GDP per capita (Gross Domestic Product per capita) is a measure of a country's economic output divided by its population (Fariea Nazim et al., (2024). It reflects the average

economic value (goods and services produced) per person and is often used to gauge living standards or economic well-being in a nation. The formula is as follows:

GDP per capita = Total GDP/ Population.

This helps compare prosperity across countries but does not account for income inequality, non-market activities (e.g., unpaid work), or environmental/social factors (Islam & Beloucif, 2023)..

● **Inflation rate**

The inflation rate measures how quickly the average prices of goods and services in an economy rise over time, typically expressed as an annual percentage. It indicates the erosion of purchasing power, as higher prices mean each unit of currency buys fewer goods (C.R. Amitrano, Vasconcelos (2019). Central banks and governments track inflation using tools like the Consumer Price Index (CPI), which monitors price changes in a representative basket of household items, or the GDP deflator, which assesses broader economic price shifts (D. Van Dinh (2020). While moderate inflation is a sign of a growing economy, extreme inflation (hyperinflation) or sustained price declines (deflation) can disrupt economic stability. Policymakers often aim to manage inflation through measures like interest rate adjustments to balance economic growth and price stability.

4. Results and discussion

4.1 Descriptive Statistics of variables

The Jarque- Bera test (1987) is powerful tool to check normal distribution of data before starting formal statistical analysis. The outcomes of this analysis of variables are presented in Table 1.

Table 1:

Descriptive statistics outcomes

	LCO2	LRENEW	LNON-RENEW	FDI	LINF	LNGDPC
Mean	0.712116	3.879024	4.099969	3.545483	2.088096	11.75136
Median	0.711122	3.870158	4.090292	3.520330	2.227565	11.77426
Maximum	0.918473	4.062166	4.338538	4.023517	3.426479	12.06516
Minimum	0.505906	3.654844	3.957097	3.147434	0.927954	11.49236
Std. Dev.	0.114054	0.099007	0.086396	0.303765	0.585353	0.181873
Skewness	0.164526	-0.298507	0.788802	0.259681	-0.159113	0.299387
Kurtosis	2.182255	2.803861	3.503856	1.659680	2.691022	1.738036
Jarque-Bera	1.100726	0.559437	3.885497	2.927109	0.278708	2.764032
Probability	0.576740	0.755997	0.143309	0.231412	0.869920	0.251072
Sum	24.21193	131.8868	139.3990	120.5464	70.99525	399.5462
Sum Sq. Dev.	0.429275	0.323478	0.246321	3.045015	11.30707	1.091564
Observations	34	34	34	34	34	34

Source: Author owns calculation by E-view software.

Table 1 shows that each independent variable has a probability value greater than 0.05, indicating a stable model with a normal distribution of data. The CO_2 average has been 0.712 and it increased from its minimum value 0.50 to its maximum value 0.91 in the period 1990 to 2023. Kurtosis value 2.18 and Jorq-Bera value 1.10 shows its bearable and CO2 is normal emissions. Renewable Energy average is 3.879 in the last 34 years. Renewable energy increases from its minimum value 3.654 to its maximum value 4.062 in this period. Kurtosis value 2.803 and Jarque-Berra value 0.559 show that emission is normal. Non-renewable energy mean value is 4.099 in Pakistan in this duration 1991 to 2023. Non-Renewable energy emission increases from its minimum point 3.957 to its maximum level 4.338. Kurtosis and Jarque Berra values shows that its bearable emission in this duration in Pakistan. FDI is 3.545 and also increases from its minimum value 3.147 to its maximum

value 4.023. Kurtosis 1.659 and Jarque-Bera Value 2.927 which shows that FDI also bearable and normal emission. Average value of inflation is 2.088 in the last 34 years in Pakistan 1999-2024.Inflation increases from its minimum value 0.927 to its maximum value3.426. Kurtosis value 2.691 and Jarque-Bera value 0.278 shows that it's also normal in Pakistan in the last 34 years. Mean value of GDP per capita is 11.751 in Pakistan from 1991-2023. GDP per capita increases from its minimum value 11.492 to its maximum value 12.065. Kurtosis value 1.738 and Jarque-Bera value 2.764 show that controlled variable GDP per capita is distribution in normal in this time period 1991-2023. Overall, the results indicate normal distribution of data.

4.2 Correlation Analysis

Correlation matrix is mostly used to examine the correlation between a pair of variables and to determine when a variable increases upward, other variable also moves in the same direction or it moves to opposite direction. This tool also uses to check multi-collinearity among variables. When the value of correlation coefficient exceeds 80% it creates multi-collinearity, likely to produce spurious results. Table 2 presents the outcomes of correlation matrix.

Table 2:

Correlation Matrix Result

	LCO2	**LRENEW**	**LNONRENEW**	**FDI**	**LINF**	**LNGDPC**
LCO2	1					
LRENEW	-0.865	1				
LNONRENEW	0.907	-0.748	1			
LEFDI	-0.605	0.575	-0.453	1		
LINF	0.112	0.061	0.247	0.166	1	
LNGDPC	0.954	-0.852	0.908	-0.592	0.165	1

Source: Author own calculation by E-view software.

The correlation matrix results reveal that Renewable energy value is -0.865, indicating negative and strong correlation with CO_2 Emissions and positive correlation with

Environmental quality. Non-renewable energy value 0.907, indicating high and positive correlation with CO_2 emissions and negative correlation with environmental quality. FDI value -0.605, showing negative correlation with CO_2 and positive association with environmental quality. Inflation value is 0.112, which shows positive but very weak correlation with CO2 but negative correlation with environmental quality. GDP per capita value 0.954 shows very strong and positive correlation with CO2 and negative association with environmental quality. The correlation analysis results are displayed in Figure 2, highlighting positive and negative correlation.

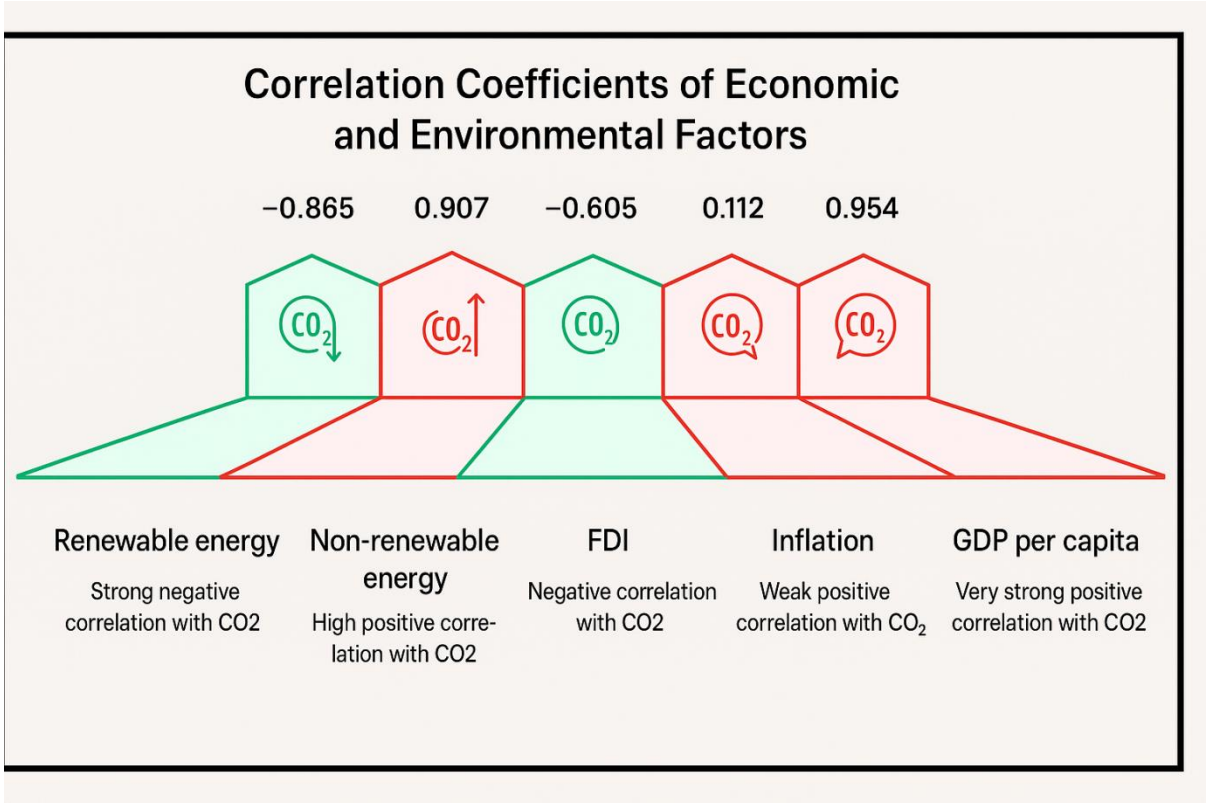


Fig. 2: Correlation between environmental and economic variables

Source: The Author draws this diagram by Napkin.

4.3 Unit Root Tests

This test is used to check stationarity among variables in order to decide which model is fit to the data. To check the stationarity, we used DF and PP unit root tests. Table 3 presents the estimated results of DF and PP tests.

Table 3:

Unit Root tests outcomes

	Augmented Ducky-fuller (ADF)		**Phillips Perron (PP)**	
Variable	**Level**	**First Difference**	**Level**	**First Difference**
CO2	0.792	0.000	0.857	0.000
RENEW	0.260	0.000	0.323	0.000
NONRENEW	0.994	0.000	0.997	0.000
FDI	0.467	0.000	0.438	0.001
INF	0.529	0.000	0.368	0.000
GDPPC	0.962	0.004	0.953	0.003

Source: Author own calculation by E-view software.

The rebuts reveal that our data is stable, and no variable has a unit root. The results also demonstrate that the probability value of each variable is at either level or first difference is substantial. Importantly, only when certain variables remain constant and others are at the initial difference, can the ARDL model be used for further analysis.

4.4 Bound Test

This test is commonly used to confirm long-term reparations between variables by comparing given statistics and calculated value at significant levels. Table 4 exhibits the estimated results of Bound Test.

Table 4:

Bound Test Results

Test Statistic	Value	Significance	I(0)	I(1)
F-statistic	19.62792	10%	2.75	3.79
		5%	3.12	4.25
		2.5%	3.49	4.67
		1%	3.93	5.23

Source: Author owns calculation using E-view software.

The bound test outcomes confirm a robust long-term relationship among variables. The F-statistics (19.62792) exceed all critical values at 1% (I(1) = 5.23), rejecting the null hypothesis of no co-integration. This validates the ARDL model's suitability for analyzing equilibrium dynamics.

4.5 ARDL long-run estimation

The Auto-regressive Distributed Lag (ARDL) model, developed by Pesaran et al. (1999), was used to examine short- and long-term relationship between CO_2 emissions and the predictors, with mixed orders of integration (I (0) or I (1)). This model is suitable for a small sample and allows simultaneous estimation of linear relationships of constructs. Table 4 demonstrates estimated long-term results of ARDL model.

Table 5:

Long-Run ARDL outcomes

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LRENEW	-0.205528	0.053181	-14.94022	0.0001
LNONRENEW	0.794538	0.038109	5.393140	0.0057
LFDI	0.069346	0.009763	7.103178	0.0021
LINF	0.015316	0.001624	9.430302	0.0007
LNGDPC	-0.121804	0.022472	-5.420363	0.0056

* Dependent variable: CO2 emissions.

Source: Author owns calculation by E-View software.

The long-run results of ARDL Model predicts a paradoxical relationship between renewable energy (LRENEW) and CO_2 emissions. A 1% increase in renewable energy consumption corresponds to a 20.55% decrease in emissions (coefficient = -0.2055, p=0.0001) in the long term, supporting environmental theories. Converse, Non-renewable energy (LNONRENEW) shows a positive coefficient (0.7945, p=0.0057). The Model predicts that Foreign direct investment (LFDI) exhibits a positive impact (0.0693, p=0.0021) on CI=O2 emissions, reflecting pollution-intensive industries attracting foreign capital. Inflation (LINF) marginally increases emissions (0.0153, p=0.0007), while GDP per capita (LNGDPC) reduces them (-0.1218, p=0.0056) in the long-term, aligning with the Kuznets'(1955)'*Environmental Curve Hypothesis*. The results predicted by **A**RDL Model are displayed in Figure 3 to observe impact of renewable and non-renewable impact of independent variables on CO_2 emissions in the long-term.

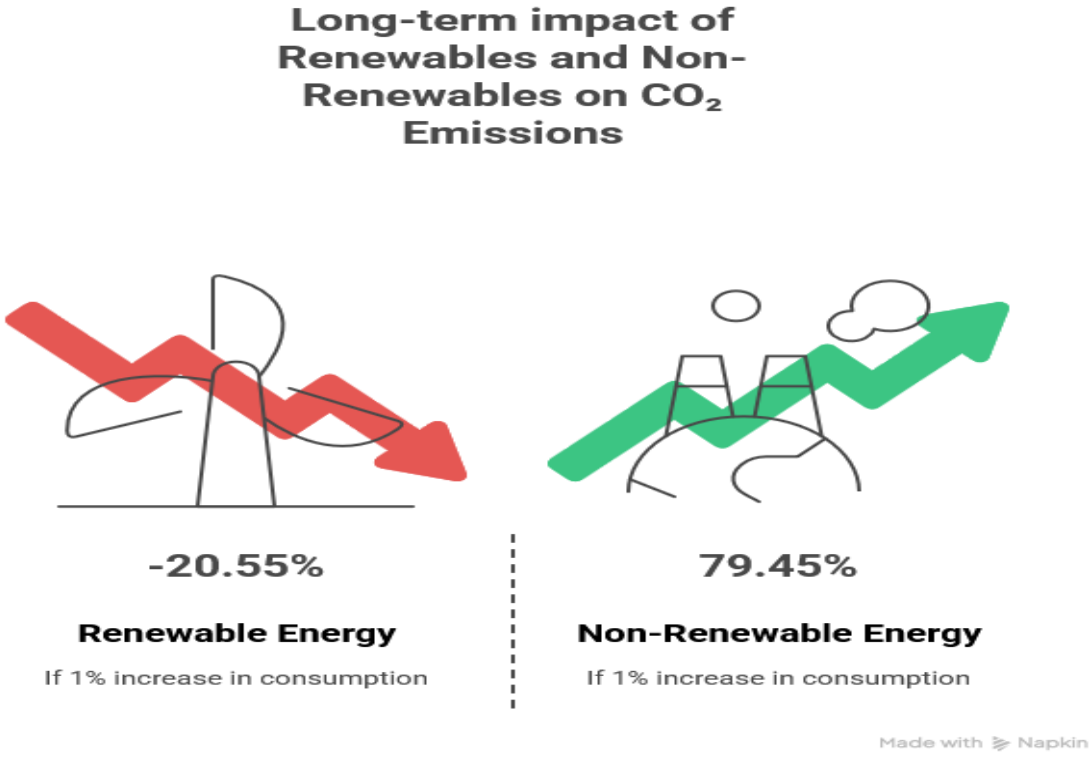


Fig 3: Impact of renewable and nonrenewable on CO_2 emissions.

Source: Author draws this diagram by Napkin.

The results provide clear picture for policymakers, and it is up to them if they want to reduce CO2 emissions to fullfill the commitment with UN's sustainable goals they will have to cut the use of non-renewable and replace them with renewable energy sources to achieve sustainability.

4.6 Error Correction Model

This model is an integral part of ARDL approach and is widely used to identify short-term relationships between variables and speed of adjustment to equilibrium levels from current to next period. Table 6 presents the results of ECM:

Table 6:

Short-Run ECM outcomes

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D (LRENEW (-2))	-0.583351	0.136238	4.281848	0.0016
D (LNONRENEW (-1))	1.199483	0.225974	-5.308058	0.0003
D (FDI (-1))	0.115065	0.031616	3.639444	0.0045
D (LINF (-1))	-0.070249	0.010989	-6.392544	0.0001
D (LNGDPC (-1))	2.559816	0.324805	7.881085	0.0000
D (LNGDPC (-2))	0.994322	0.260937	3.810580	0.0034
Coint Eq (-1)	-0.785030	0.089417	-8.779425	0.0000

*Dependent variable: CO2 emissions.

Source: Author owns calculation by E-view software.

Renewable energy's two-period lag (-0.5834, p=0.0016) reduces emissions in the short-term, reinforcing conventional theoretical wisdom. Non-renewable energy's first lag (1.1995, p=0.0003) sharply increase emissions, proving its role as a major pollutant. FDI (0.1151, p=0.0045) and GDP per capita (2.5598, p=0.0000) drive immediate emissions, reflecting trade-offs between growth and sustainability as mostly environmental theories and empirical analysis predicted. Inflation rate has a negative impact on CO_2 emission in the short-term.

The short-run ECM results highlight rapid adjustments. The error correction term (-0.7850, p=0.0000) indicates 78.5% of disequilibrium is corrected annually. A one-period lag in CO_2 emissions (-0.4445, p=0.0206) suggests short-term self-correction. The estimated results of ECM re shown in Figure 4 for observing visual impact of different variables on CO2 emissions in the short-term.

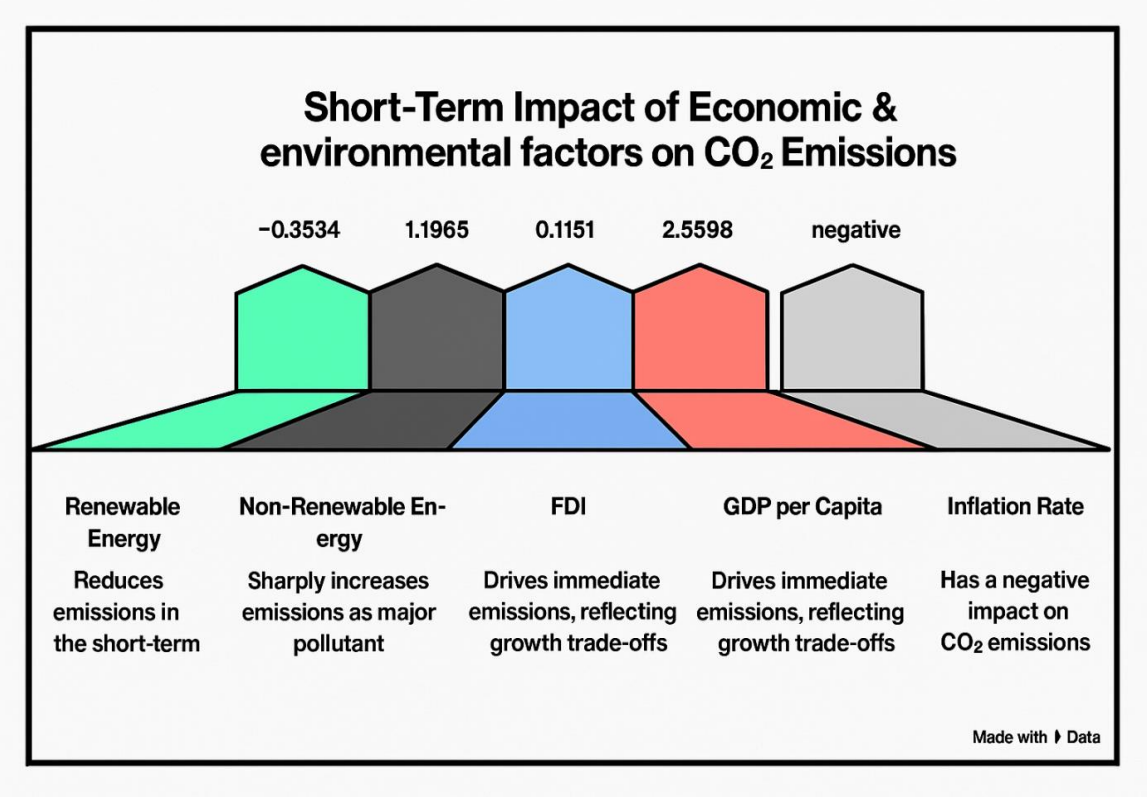


Fig 4: Short-term impact of various variables on CO2 emissions.

Source: Author draws this diagram by Napkin.

4.8 Diagnostic tests

The Breusch-Godfrey Serial correlation LM test, Harvey test, Glesjer test, and Breusch-pagan-Godfrey test were among several other tests which are commonly used to identify the heteroscedasticity and auto-correlation problems in the data and the model. Jarque Berra tests were used to determine whether the data is normally distributed. Tests of

heteroscedasticity are used to detect problems of heteroscedastic and auto-correlation among explanatory variables. The outcomes of this analysis are presented in Table 8.

Table 8:

Diagnostic tests results

Diagnostic tests statistics	Test	P-Value	Results
Heteroscedasticity	Harvey	0.6676	The analysis shows no problems related to heteroscedasticity
Heteroscedasticity	Glejser test	0.1398	No heteroscedastic issues exist in this situation.
Serial correlation/ Autocorrelation	Breusch-Godfrey Serial correlation LM test	0.7787	Proof shows that serial correlation does not exist.
Normality test	Normality test	0.3790	The statistical data exhibits normal distribution.

Source: Author owns calculation by E-view software.

The results in the above table show insignificant P-Values, which clearly indicate that there is no problem of Heteroscedasticity and auto-correlation. Similarly, JB value is also insignificant showing normal distribution of data. The data is plotted in the Figure 5 to observe its normal distribution.

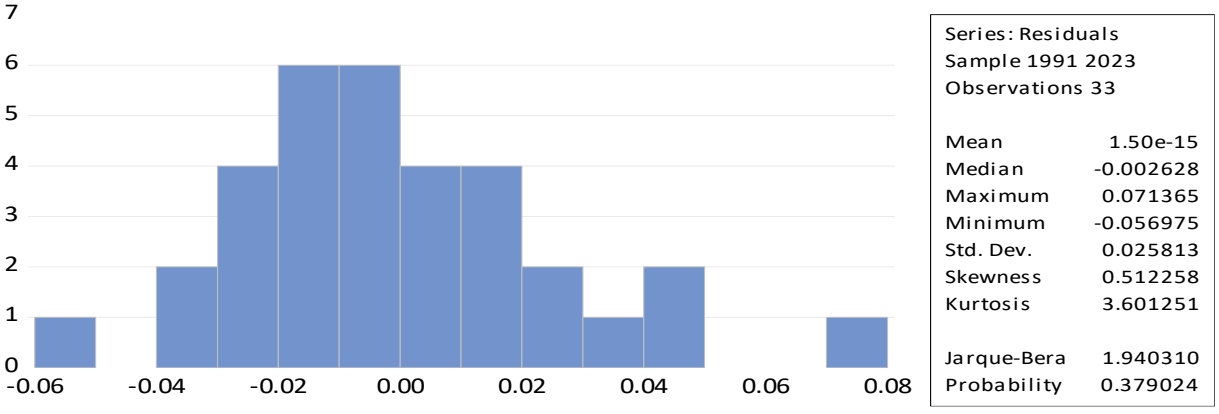


Fig 5: Normal distribution of data

If we look at the P-value it is 0.849 which is insignificant, it is also showing that the distribution of the data is normal. The model stability can be further checked through stability tests (CUSU & CUSUM Square tests) of which outcomes re displayed in Figure 6 and 7.

CUSUM Test

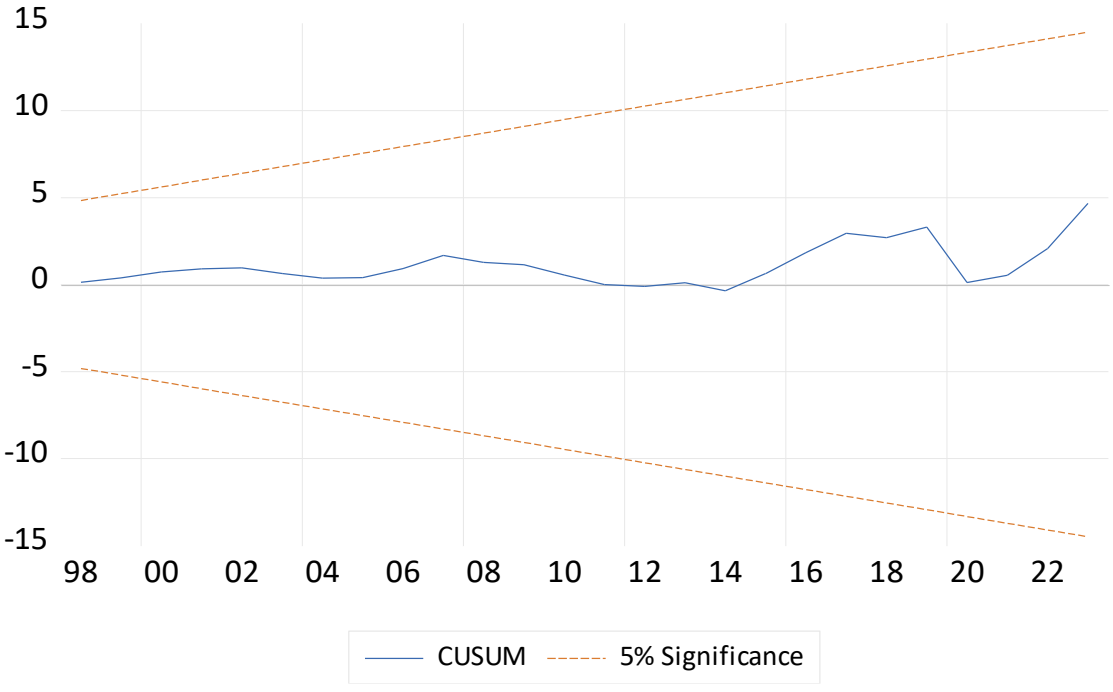


Fig.6: CUSUM test results

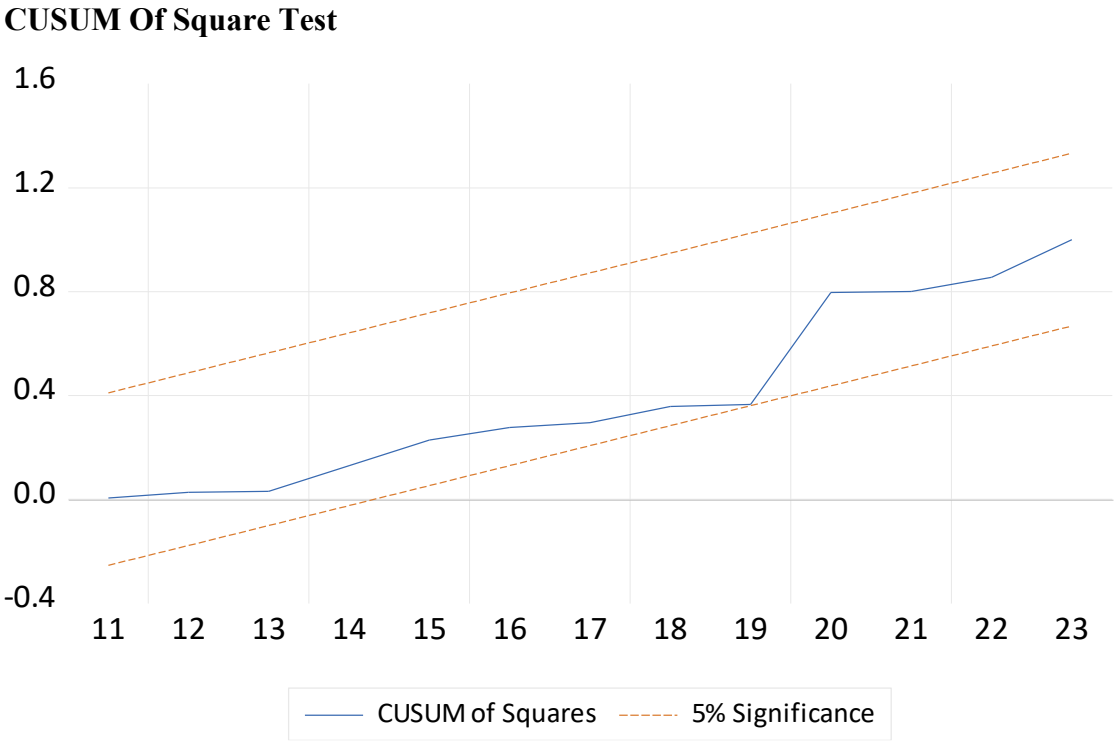


Fig.7: CUSUM Squares test.

Both Figures show that at the 5% level of significance, the blue lines are conspicuously below the significant lines, suggesting that the coefficients are stable, suggesting reliability and validity of the model.

5. Discussion

The objective this study was to investigate the dynamic relationships between renewable energy consumption and environmental quality in Pakistan, with a focus on sustainable development strategies. The study employed ARDL- ECM framework and annul time series data from 1991 to 2023 sourced from World Bunk's World Development Indicators to estimate statistical relationships between explanatory and explained variables. Carbon dioxide (CO_2) emissions serve as the primary indicator of environmental quality, while independent variables consisted of renewable and non-renewable energy consumption,

foreign direct investment (FDI), GDP per capita, and inflation rate. The auto-regressive distributed lag (ARDL) approach provides valuable insights into both long-term equilibrium relationships and short-term dynamic adjustments between CO_2 emissions and its key determinants. The findings reveal complex interactions between energy sources, economic factors, and environmental outcomes that carry important policy implications for sustainable development.

5.1 Key findings & Hypotheses results

The long-run estimates of ARDL model demonstrate several noteworthy relationships that largely align with established economic and environmental theories. Renewable energy consumption shows a statistically significant negative coefficient (-0.2055), indicating that a 1% increase in renewable energy use leads to a 0.21% reduction in CO2 emissions in the long run. This finding strongly supports ecological modernization theory, which posits that technological advancements and cleaner energy adoption can decouple economic growth from environmental degradation. Thus, Hypothesis **(H1)** is confirmed. The result corroborates empirical studies by Hussain et al., 2022) who found similar elasticizes in their panel analysis of OECD countries. Conversely, non-renewable energy consumption exhibits a substantial positive coefficient (0.7945), suggesting fossil fuel dependence remains the primary driver of carbon emissions (Rehman et al. (2023). This large elasticity estimate exceeds those found in many previous studies, potentially indicating increasing marginal damage from continued reliance on carbon-intensive energy ((Stern, 2017). The result aligns with the energy-environment theory that emphasizes the lock-in effects of existing energy infrastructure and the challenges of transitioning to low-carbon systems (Ang et al., (2022). Hence, second hypothesis (H2) is accepted because hard evidence supports it.

Foreign direct investment shows a moderate positive association (0.0693) with emissions, providing evidence for the *Pollution Haven Hypothesis proposed by* Cole & Elliott, (2005) in this context. This implies that foreign capital flows may be

disproportionately directed toward pollution-intensive industries, particularly in developing economies with less stringent environmental regulations (Rehman et al. (2023). The finding echoes the work of Cole and Elliott , 2005; Ali et al., 2020), who identified similar patterns in manufacturing sectors across developing countries. Hence, third hypothesis **(H3)** is confirmed by empirical evidence. The negative coefficient for GDP per capita (-0.1218) offers support for the environmental *Kuznets curve hypothesis,* suggesting that after reaching certain development thresholds, economies may begin to reduce their environmental impact through structural changes and cleaner technology adoption. However, the relatively modest elasticity indicates this automatic improvement effect should not be overestimated due to low per capita income and slow pace of clean energy adoption., requiring complementary policy interventions as reported by Khan & Ozturk, (2021). Thus, fourth Hypothesis **(H4)** is validated. Conversely, inflation marginally increases emissions (0.0153, p=0.0007) in the long run. This finding support to the study of Ahmad et al. 2021; Sua, Wang, & Huang, (2025), who identified that rise in inflation trigger pollutant emissions and spoil clean environment. Economic theory also predicts that inflation has negative impact on environment in the long run. Hence, our fifth hypothesis **(H5**) is confirmed by empirical analysis.

The Error Correction Model reveals important insights into short-term adjustments and transitional dynamics. The highly significant error correction term (-0.7850) indicates rapid convergence to long-run equilibrium, with about 78.5% of any disequilibrium corrected within one year. This quick adjustment speed suggests that policy changes can produce relatively fast environmental improvements but also implies that negative shocks may have immediate detrimental effects.

Renewable energy's impact shows interesting temporal dynamics, with the two-period lagged effect (-0.5834) being nearly three times larger than the long-run elasticity. This may reflect initial deployment phases where renewable capacity replaces the most carbon-intensive generation sources first, yielding disproportionate early benefits. The pattern

aligns with the *Energy Transition Theory* (Geels,.Sovacool & Schwanen, 2017; Benjamin, David, Cantoni, (2021) that emphasizes non-linear adoption curves for clean technologies. Non-renewable energy demonstrates even more pronounced short-term effects, with a first-lag coefficient (1.1995) substantially exceeding its long-run impact. This accentuated short-run elasticity suggests that fossil fuel use creates immediate environmental costs that may moderate over time as adaptation occurs. The finding supports the *Concept of carbon inertia* in energy systems, where current emissions are largely locked-in by existing infrastructure and consumption patterns (Gregory et al. 2009; Mirza et al., 2021; Palazzo Corner et al. 2023). The short-run positive coefficients for FDI (0.1151) and GDP growth (2.5598) highlight the trade-offs between economic expansion and environmental quality during development transitions. These results support the "Grow first, Clean later" Hypothesis" observed in many emerging economies, though the rapid adjustment mechanism offers hope that such trade-offs may be temporary with appropriate policy interventions (Azadi, et al. (2023).

5.2 Policy Implications

The empirical findings suggest several policy implications for sustainable development. First, accelerating renewable energy deployment through targeted subsidies, feed-in tariffs, and R&D investments could yield both immediate and lasting emission reductions. The large short-term elasticity suggests that even modest increases in clean energy adoption can produce significant near-term benefits while establishing the foundation for long-run de-carbonization (Saud et al., 2022). Second, the strong effects of non-renewable energy in both time horizons underscore the need for comprehensive fossil fuel phase-out strategies. Carbon pricing mechanisms, combined with gradually tightening performance standards, could help overcome the lock-in effects revealed by the analysis. The differential short- and long-run elasticizes suggest that early, aggressive action on the most polluting sources may yield disproportionate benefits (Nasir et al., 2021); Sua, Wang , & HHuang, (2025). Third, the FDI findings indicate a need to reform investment frameworks to prevent

pollution haven effects. Environmental impact assessments, green investment guidelines, and sustainable finance initiatives could help align foreign capital flows with climate objectives (Javid & Sharif, 2016; (Nasir et al., 2021). The results suggest that without such safeguards, economic globalization may inadvertently exacerbate emission challenges. Fourth, the GDP per capita results imply that development strategies should incorporate environmental quality as an explicit component of progress. While the long-run negative association offers some optimism, the substantial short-term trade-offs emphasize the need for proactive policies to "flatten" the environmental Kuznets curve through cleaner growth pathways (Grossman & Krueger, 1995; Stern, 2017). Finally, the rapid adjustment coefficient suggests that policy consistency is crucial, as the system responds quickly to both positive and negative changes. This underscores the value of stable, long-term policy frameworks over stop-and-go approaches to environmental regulation.

5.3 Ideas for future Research

While the ARDL approach provides robust estimates for the examined relationships, several extensions could enrich future analysis. Disaggregating the energy and FDI variables by sector could reveal important differences in their environmental impacts. Incorporating additional control variables like technological innovation indicators or institutional quality measures might provide more nuanced understanding. Panel data approaches across similar economies could help verify the generalizability of these findings. The distinct time horizons captured by the model also suggest the value of examining non-linear effects and threshold relationships. For instance, the renewable energy impacts might follow an S-curve pattern where initial investments yield increasing returns before eventually plateauing. Similarly, the GDP-emissions relationship might involve multiple turning points rather than a simple inverted-U pattern.

5.4 Conclusion

This analysis of ARDL-ECM estimation framework provides compelling evidence that energy choices, investment patterns, and development strategies all significantly influence

CO_2 emissions trajectories. The findings highlight both challenges and opportunities in decoupling economic growth from environmental degradation. While the results confirm some conventional theoretical expectations, they also reveal important nuances in how these relationships evolve over different time horizons. The policy implications point toward an integrated approach combining energy transition policies, sustainable investment frameworks, and green growth strategies. The rapid adjustment dynamics suggest that well-designed interventions can produce meaningful results relatively quickly, though lasting solutions will require persistent, long-term commitments. Future research could build on these findings by exploring sect-oral dis-aggregation, non-linear effects, and cross-country comparisons to further refine our understanding of these critical relationships.

Data availability statement

The data that is used in this study will be made available for the corresponding author on strong requests.

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