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# Renewable Energy Transition in Pakistan: The Roles of Economic Growth, Trade Openness, Industrialization, Inflation and Governance Quality

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**ABSTRACT**

This research study examines renewable energy output determinants by focusing on economic growth, trade openness, industrial value added, inflation, and government effectiveness in Pakistan by using 35 years of data from 1990 to 2024. Using the Autoregressive Distributed Lag (ARDL) model, the study finds $R^2 = 0.948$ showing strong explanatory power. ARDL finds here short and long-run dynamics with mixed orders of integration among the variables. Results showed that economic growth and government effectiveness both had positive influence on renewable energy output. Trade openness facilitates technology transfer and investment. Inflation negatively affects renewable energy output as increase in price discourages the adoption. Industrial value added shows a mixed impact due to more reliance on fossil fuels. The research study also confirms model robustness by diagnostic and stability tests. The policy recommendations put focus on the importance of macroeconomic stability, trade liberalization, and effective governance in accelerating Pakistan's renewable energy transition.



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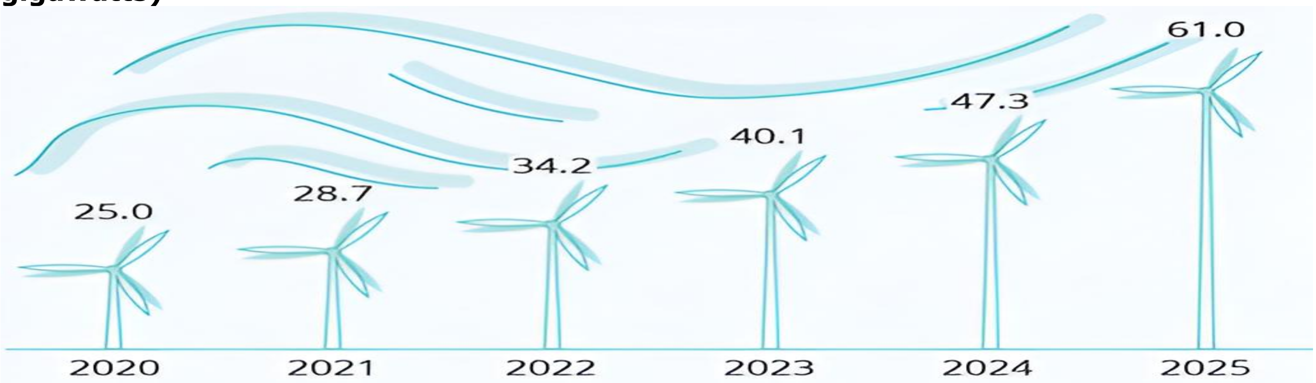
## 1. Introduction

Pakistan has significant potential for renewable energy. Due to its rich natural resources & varied landscapes like sunny plains, long coastlines and also 3 rivers like the Indus, Jhelum & Swat. Despite this potential, renewable energy utilization in Pakistan is still low. Even solar, wind and biomass resources are underdeveloped. Energy sector of Pakistan is heavily dependent on fossil fuels which lead to high import bills and even rising carbon emissions (IMRAN et al., 2023). With a population exceeding 257.5 million in January 2026 (Worldometer, 2026), demand for energy has surged due to growth in industries & heavy urbanization. In 2019, Pakistan's government introduced Alternative and Renewable Energy (ARE) Policy, having aim of 30 per cent of energy from its renewables resources (excluding hydropower) by 2030. But structural and institutional barriers have slowed the progress. Economic growth influences renewable energy development by increasing energy demand (Imran & Ishaq, 2024). Trade openness assists technology transfer & investments. Governance quality is central for policy implementation & investor confidence. Understanding the connection of economic growth, trade openness, industrial values added, inflation & governance is very essential to enhance renewable energy output in Pakistan. Most previous studies just focus on environmental effects or energy consumption patterns while neglecting the combined impact. Current study also highlights the important questions. How much economic growths create opportunities for renewable energy output? How much trade openness drive technology flow and investment? What is the role of governance in shaping investor confidence? This research study addresses above questions using empirical analysis. Despite the growing body of literature on renewable energy in Pakistan, most existing studies focus either on energy consumption patterns or environmental outcomes such as carbon emissions, while overlooking the joint macroeconomic and institutional drivers of renewable energy output. In particular, governance quality is rarely incorporated alongside economic growth, trade openness, industrialization, and inflation within a single empirical framework. This study addresses this gap by providing an integrated time-series analysis of renewable energy output in Pakistan, explicitly incorporating government effectiveness as an institutional determinant. By doing so, the study offers a more comprehensive understanding of how economic, trade, industrial, macroeconomic, and governance dynamics jointly shape Pakistan's renewable energy transition.

**Figure 1: Renewable Energy Market Size 2024 to 2034 (USD Trillion)**

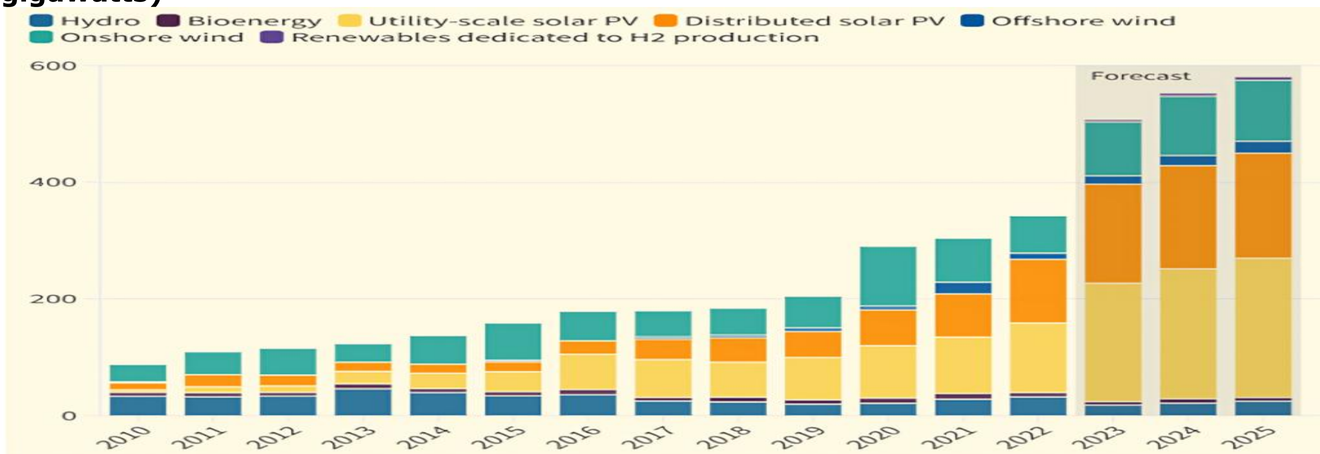

Source: *https://www.precedenceresearch.com/renewable-energy-market*

**Figure 2: Total estimated electrical capacity of offshore wind energy, 2020 to 2025 (in gigawatts)**




Source: Bloomberg (Data excludes China)

**Figure 3: Global annual net capacity additions by technology, 2020 to 2025 (in gigawatts)**




Source: International Energy Agency, Renewables 2023

Above figure tells a clear story of accelerating renewable energy growth which is highly relevant for Pakistan's energy transition. Fig. 1 demonstrates that the changes in clean energy pertinent investment in various parts of the world are steadily increasing since 2024 to 2034, which is signaling the swell of monetary investment in renewables and associated technologies on behalf of Pakistan. Figure 2 illustrates wind power capacity increase between 2020-2025, which is the growth in response to technological advancement and reduction in wind energy costs which is especially applicable in high potential wind corridors of Sindh and Balochistan in Pakistan. In Figure 3, the mix of renewable sources of energy such as hydropower, onshore and offshore wind and others are detailed. Solar and wind energy is shifting to be dominant all over the world among renewables. Collectively in the context of Pakistan, it highlights the importance of de-reliance on the imported fossil fuels and focus on the trends of solar, wind and hydropower in order to satisfy the increasing electricity needs and ensure future sustainability. In as much as Figures 1 3 show the global patterns in renewable energy investment and capacity growth, the changes are directly applicable to Pakistan. The declining technology costs, the growing international investment and the fast increase in the amount of solar and wind power in the world give a chance to the developing countries to speed up the process of clean energy implementation. In the case of Pakistan, it is necessary to reconcile domestic economies, trade openness, and structures of governance to the following global trends in order to appeal to investment and to multiply renewable energy production(Ragmoun, 2023, 2024; Ragmoun & Alfalih, 2025; Ragmoun & Ben-Salha, 2024).

## 2. Literature Review

The results of empirical analysis reveal that renewable energy production is mainly shaped by economic expansion, trade openness and quality of governance. Economic growth typically correlates to energy demand that either enables the adoption of clean energy or perpetuates dependence on fossil fuels. Trade openness helps with technology transfer and investment but governance (political stability, regulatory quality, institutional effectiveness) is what determines how policy is implemented and investor confidence.

**Table 1: Summary of the related literature review**

| Author(s) & Year | Country/Region | Study Focus | Methodology | Key Findings | Policy/Research Implications |
|---|---|---|---|---|---|
| Waqar et al. (2024) | Pakistan | Role of renewable and non-renewable energy in economic growth | RALS integration test, ARDL | Both energy sources significantly influence long-term growth; petroleum use less significant | Promote renewable energy to reduce trade deficit and $CO_2$ emissions; importance of private sector & government support |
| Hoa, Xuan and Thu (2024) | ASEAN countries | Determinants of renewable energy during 5th technological revolution | ARDL, fixed & random panel, ML | Renewable energy shaped by tech advances, govt policies, public awareness | Technological adoption and global integration crucial for renewable energy policies |
| İçen (2025) | Turkey | Factors affecting renewable energy consumption & production | Bayesian Model Averaging, Random Forest | Social growth, education, workforce, and GHG emissions drive renewables | Emphasizes social policies and emissions control alongside tech adoption |
| Osińska, Khan and Kwiatkowski (2024) | High-income countries | Drivers of renewable energy consumption across development groups | Panel Bayesian Model Averaging | REC influenced by GDP, $CO_2$, FDI, workforce, energy sources | Global policy recommendations vary by income/development levels |
| Iqbal et al. (2023) | Pakistan | Asymmetric determinants of renewable energy production | Linear & Non-linear ARDL | GDP, environmental tech, financial development major long-run drivers | Foster economic & technological growth, stabilize financial systems |

| | | | | | |
|---|---|---|---|---|---|
| Simionescu (2023) | EU (10 nations) | Renewable & nuclear energy impact on growth | Panel analysis | Renewable energy positively affects growth; governance crucial | Promote good governance to enhance renewable energy adoption |
| Nchofoung and Ojong (2023) | Africa (48 countries) | Natural resources & renewable energy | OLS, GMM, Quantile regression | Natural resources boost RE, except forest resources; governance amplifies effect | Renewable energy financing strategies considering natural resource management |
| Tu et al. (2022) | EU (27 countries) | Drivers of renewable energy adoption | Panel data analysis | Economic development & tech sector employment promote RE; unemployment negative | Policy reforms needed for deregulation, open markets, education to advance RE |
| Lu et al. (2022) | OECD (36 countries) | Trade potential and renewable energy | Panel data analysis | RE positively correlated with trade potential, income, energy prices | Leverage trade policies to promote renewable energy adoption |
| Çakmak and Acar (2022) | Oil-producing countries | Economic growth, RE consumption, ecological footprint | Dynamic panel, causality analysis | Economic growth increases footprint; RE consumption insignificant | Optimize energy production for growth and climate mitigation |
| Raihan and Tuspekova (2022) | Kazakhstan | $CO_2$ reduction via RE & tech innovation | Panel analysis | RE + tech reduce emissions; economic growth & fossil fuels increase emissions | Promote RE, finance tech development for sustainability |
| Wang et al. (2022) | G7 countries | Trade, industry, tech, economic growth, RE, ecological footprint | AMG panel method | Industrialization & RE reduce pollution; trade & tech aid sustainability | Guide policies for carbon neutrality and economic growth |
| Abban and Hasan (2021) | 60 countries | Determinants of RE investments | Panel data | Left/centrist governments promote RE; parliamentary systems favorable | Political orientation & system type influence RE investment decisions |
| Dogan, Inglesi-Lotz and Altinoz (2021) | Multiple countries | Impact of RE indicators choice | Econometric analysis | GDP & energy prices affect RE differently depending on indicators | Careful selection of RE proxies crucial for reliable policy guidance |
| Bednarczyk, Brzozowska-Rup and Luściński (2021) | Poland | Determinants of renewable energy development | Panel data analysis | Installed capacity & household consumption drive RE; non-household use & R&D minor impact | Region-specific policies needed for RE promotion |
| Li et al. (2021) | China | Trade openness & renewable electricity | Panel analysis | Trade openness, energy prices, income, $CO_2$ emissions increase RE | Suggests trade & green product policies to support RE growth |
| Wang and Zhang (2021) | 186 countries | Free trade & renewable energy | Panel data analysis | RE growth positive in high-income, negative in lower-middle-income | Income-specific trade policies needed for RE promotion |
| Chen, Pinar and Stengos (2021) | Multiple countries | Role of democratic institutions in RE | Panel threshold model | Democracy enhances RE adoption; trade openness & oil price effects vary | Governance quality critical for directing economic growth toward RE |

| | | | | | |
|---|---|---|---|---|---|
| Li et al. (2020) | OECD countries | Drivers of renewable energy consumption | Durbin–Hausman, CS-ARDL, AMG | Eco-innovation, income, energy productivity, prices drive RE | Policies to promote eco-innovation & human capital are vital |
| Bourcet (2020) | Global | Determinants of RE deployment | Systematic review | Economic, environmental, regulatory, political, demographic factors vary in impact | Need harmonized methodologies for robust policy recommendations |
| Przychodzen and Przychodzen (2020) | 27 transition economies | Economic & political determinants | Panel data | GDP, unemployment, debt increase RE; Kyoto Protocol accelerates adoption | Policy adoption and public funding critical for RE growth |
| Bamati and Raoofi (2020) | Developed & developing countries | Tech, economic & environmental pressures on RE | GLS panel | Strong tech & GDP drive RE in developed; GDP & $CO_2$ in developing | Tailor technology adoption and policy to income levels |
| Akintande et al. (2020) | Africa (5 countries) | Drivers of RE | Bayesian Model Averaging | Population growth, urbanization, energy demand, human capital drive RE | Urban planning, population management, skill development support RE |
| Papież, Śmiech and Frodyma (2018) | EU (28 countries) | Factors driving RE adoption | PCA & regression | GDP per capita, energy supply concentration, fossil fuel prices key | Improve energy security and diversify energy sources |

The take-up of renewable energy is contingent upon the context, conditioned as it is by economic, technological, trade, social and governance considerations. In developing countries like Pakistan, institutional quality and policy stability are as critical as economic growth & trade openness for expanding renewable energy. The summary of literature review is presented in table 1.Overall, the literature indicates that renewable energy development is influenced by a combination of economic growth, trade openness, industrial structure, and institutional quality. While economic expansion and trade openness generally facilitate renewable energy through increased demand, technology transfer, and investment, governance quality plays a decisive role in translating these opportunities into actual energy outcomes. Nevertheless, empirical research is still scattered especially in the case of Pakistan with very few studies having conducted joint research to look at the macroeconomic and governance-related determinants. This research paper adds to the literature through combining these dimensions in a single ARDL model.

## 3. Theory, Data and Methodology

### 3.1. Theory

There are a few economic theories that offer an explanation of the connection between the renewable energy output (REO) and the determinants: Green Growth Theory focuses on the economic growth realization, where the environment remains sustainable due to the use of clean energy, resource efficiency and innovation. One of the indicators of green growth is the use of renewable energy. Porter Hypothesis is that planned environmental regulations, where there is strong governance, may help drive innovation and increase energy efficiency. In this context, the Green Growth view is reflected in economic growth through increased demand to clean energy, trade openness through diffusion of technologies and investment is in line with innovation-led growth, industrial value added reflects structural reliance on fossil-based production and inflation reflects macroeconomic stability that sets long-term investment choices and the Porter Hypothesis is reflected through government effectiveness in that it determines the quality of regulation, policy credibility, and institutional capacity to promote renewable energy growth.

### 3.2. Data

**Table 2: Variable Names, Symbols, Proxy Used, Measurement Units and Data Sources**

| Variable Name | Symbol | Proxy Used | Measurement Units | Source |
|---|---|---|---|---|
| Renewable Energy Output | REO | Renewable Energy output (% of total Energy output) | Percentage (%) | [1]WDI |
| Economic Growth | GDP | GDP per capita (current US$) | US Dollars (Current $) | [1]WDI |
| Industry Value Added | IVA | Industry (including construction), value added (% of GDP) | Percentage of GDP (%) | [1]WDI |
| Trade Openness | TO | (Imports + Exports)/GDP (Current US$) | Ratio (Current $) | [1]WDI |
| Inflation | INF | Inflation, consumer prices (annual %) | Percentage (%) | [1]WDI |
| Government Effectiveness | GE | Government Effectiveness: Percentile Rank | Percentile Rank (0-100) | [2]WGI |

[1]World Development Indicators, [2]Worldwide Governance Indicators

The time series data employed in this research study is on Pakistan between 1990 and 2024. World Development Indicators and Worldwide Governance Indicators were used to get the required data. Renewable energy output (% of total energy output) is used as it captures the actual contribution of renewables to the national energy mix, rather than potential capacity or consumption, making it particularly relevant for assessing energy transition outcomes.
The studied model can be written as follows:

$$\mathrm{REO_t} = \mathrm{f(GDP_t\,, IVA_t\,,\ TO_t\,,\ INF_t\,,\ GE_t\,)}$$

Where:

REO = Renewable Energy output (% of total Energy output)
GDP = GDP per capita (current US$)
IVA = Industry (including construction), value added (% of GDP)
TO = Trade Openness (Imports + Exports)/GDP (Current US$)
INF = Inflation, consumer prices (annual %)
GE = Government Effectiveness: Percentile Rank

Above model can be written in econometric form as follows:

$$\mathrm{REO_t} = \beta_0 + \beta_1\mathrm{GDP_t} + \beta_2\mathrm{IVA_t} + \beta_3\mathrm{TO_t} + \beta_4\ \mathrm{INF_t} + \beta_5\mathrm{GE_t} + \epsilon_t$$

### 3.3. Methodology

The research study is based on ARDL model whereby the numerical influence of determinants of renewable energy Output in Pakistan is determined. The variables were summarized using descriptive statistics. Patterns were visualized by graphical analysis (trend plots, scatter diagrams). Correlation analysis determines both the strength and the direction of relationship between the variables, it also tests the occurrence of multi-collinearity. Lastly, the ARDL model will be used to test the effect of Economic Growth, industry value added, government effectiveness and inflation on the output of Renewable energy. Finally, the stability, normality, serial correlation and heteroskedasticity were checked with the help of diagnostics tests. Above provides supporting evidences of theoretical backgrounds of Green Growth Theory and Porter Hypothesis. Even though the Pakistani energy policy has undergone significant changes, including the ARE Policy 2019, the structural break test was not utilized because of the limitations of the available data and sample size; the future research could directly consider the regime change.

## 4. Results and Discussion

### 4.1. Descriptive Statistics

Table 3 displays the descriptive statistics of Renewable Energy Output (REO), GDP per capita (GDP), Industry Value Added (IVA), Trade Openness (TO) Inflation (INF) and Government Effectiveness (GE). The average renewable energy constituted 33.05 per cent of the overall power generation in Pakistan over the period of study. The highest (44.92) and the lowest (25.24) are pointing to significant variation in the generation of renewable energy across transversally different years. The standard deviation (4.86) indicates moderate fluctuations of REO through the time.

**Table 3: Descriptive Statistics**

| | REO | GDP | IVA | TO | INF | GE |
|---|---|---|---|---|---|---|
| Mean | 33.04549 | 923.2205 | 20.28091 | 0.493872 | 9.664670 | 31.60514 |
| Median | 31.11598 | 963.7881 | 20.41260 | 0.425871 | 9.496211 | 31.52181 |
| Maximum | 44.92607 | 1569.338 | 22.93092 | 0.866702 | 30.76813 | 41.46341 |
| Minimum | 25.24223 | 344.4555 | 17.15889 | 0.262494 | 2.529328 | 22.59615 |
| Std. Dev. | 4.861360 | 421.3307 | 1.714289 | 0.185976 | 5.736094 | 5.342828 |
| Skewness | 1.208378 | 0.029169 | -0.300831 | 0.737134 | 1.581545 | -0.145590 |
| Kurtosis | 3.704427 | 1.489676 | 1.984834 | 2.108871 | 6.624626 | 1.861148 |
| Jarque-Bera | 9.241359 | 3.331535 | 2.030815 | 4.327718 | 33.75028 | 2.015083 |
| Probability | 0.009846 | 0.189045 | 0.362255 | 0.114881 | 0.000000 | 0.365116 |
| Sum | 1156.592 | 32312.72 | 709.8317 | 17.28554 | 338.2634 | 1106.180 |
| Sum Sq. Dev. | 803.5158 | 6035666. | 99.91877 | 1.175966 | 1118.694 | 970.5575 |
| Observations | 35 | 35 | 35 | 35 | 35 | 35 |

GDP has mean (923.22), median (963.78) and SD (421.33). Skewness (0.029) indicates near symmetry, while kurtosis (1.49) shows a flatter distribution. Jarque-Bera (0.189) confirms normality.

**Table 4: Correlation Coefficients**

| | REO | GDP | IVA | TO | INF | GE |
|---|---|---|---|---|---|---|
| REO | 1 | | | | | |
| GDP | -0.5459 | 1 | | | | |
| IVA | 0.6711 | -0.4274 | 1 | | | |
| TO | 0.7618 | -0.8694 | 0.6461 | 1 | | |
| INF | 0.1445 | 0.1805 | 0.3940 | 0.0798 | 1 | |
| GE | 0.3142 | -0.5439 | -0.0573 | 0.5131 | -0.2714 | 1 |

The correlation coefficients are contained in table 4 and at this point the strength and direction of relationship are analyzed. REO has a negative relationship with GDP and this implies that economic growth in Pakistan is largely linked with increased reliance on the traditional sources of energy. IVA is positively correlated with REO indicating that industrial growth correlates with more uptake of renewable energy. The contemporaneous negative relationship between GDP and the renewable energy output is an indication of the short-run dependence of Pakistan on conventional sources of energy at the time of economic growth. That said, correlation analysis only takes part in static associations. According to the ARDL long-run estimates, in the long run, high income levels contribute to the development of renewable energy, by providing more investment capacity, developing infrastructures, and supporting policies. This variance is a reminder of the criticality of separating the long-run relationship between the dynamic and the long-run equilibrium.

**Table 5: Unit Root Test Results (ADF, PP)**

| Variable | ADF Level | 1st Difference | PP Level | 1st Difference | Order |
|---|---|---|---|---|---|
| REO | Non-stationary | Stationary | Non-stationary | Stationary | *I(1)* |
| GDP | Non-stationary | Stationary | Non-stationary | Stationary | *I(1)* |
| IVA | Non-stationary | Stationary | Non-stationary | Stationary | *I(1)* |
| TO | Stationary | - | Stationary | - | *I(0)* |
| INF | Non-stationary | Stationary | Non-stationary | Stationary | *I(1)* |
| GE | Stationary | - | Stationary | - | *I(0)* |

Table 5 shows the results of ADF & PP unit root tests used to test the stationarity of the variables. REO, GDP, IVA, and INF are stationary at first difference *I(1)*. While TO & GE are stationary at levels *I(0)*. No variables are found of integrated of order two *I(2)*, this confirms the suitability of the ARDL bounds testing approach for examining both short-run and long-run dynamics.

Table 6 shows the results of Lag length determination using the AIC, BIC, and HQC criteria. Results shows that Lag 2 provides the optimal fit across all criteria. Lag order 2 was selected as it balances model fit and parsimony, which is particularly important given the relatively small sample size of 35 observations.

**Table 6: Lag Length Selection Criteria**

| Lag | AIC | BIC | HQC | Selected |
|---|---|---|---|---|
| 1 | -2.345 | -1.876 | -2.101 | |
| 2 | -2.912 | -2.104 | -2.543 | ✔ |
| 3 | -2.751 | -1.697 | -2.220 | |
| 4 | -2.501 | -1.200 | -1.876 | |

**Table 7: Bounds Test for Cointegration**

| Test Statistic | Value | 5% Lower Bound | 5% Upper Bound | Decision |
|---|---|---|---|---|
| F-statistic | 5.47 | 2.45 | 3.61 | Cointegration exists |

**Figure 4: Renewable Energy output (per cent of total Energy output)**

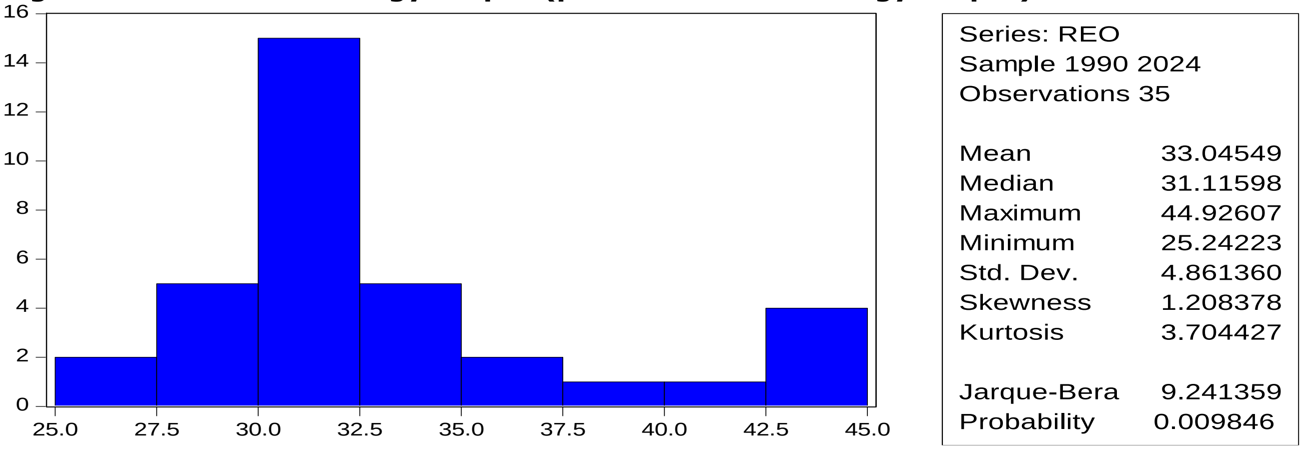



**Figure 5: GDP per capita (current US$)**

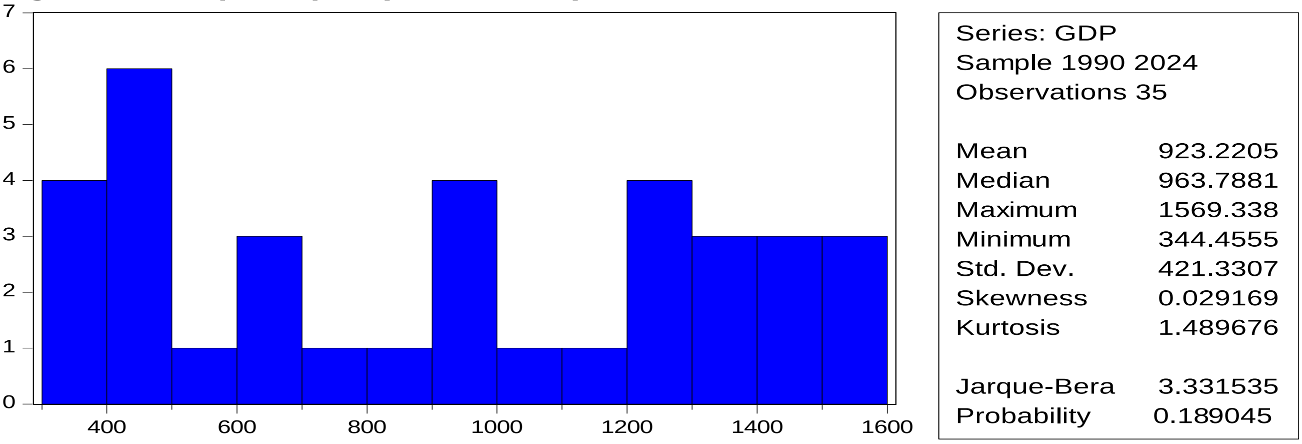



**Figure 6: Industry (including construction), value added (per cent of GDP)**

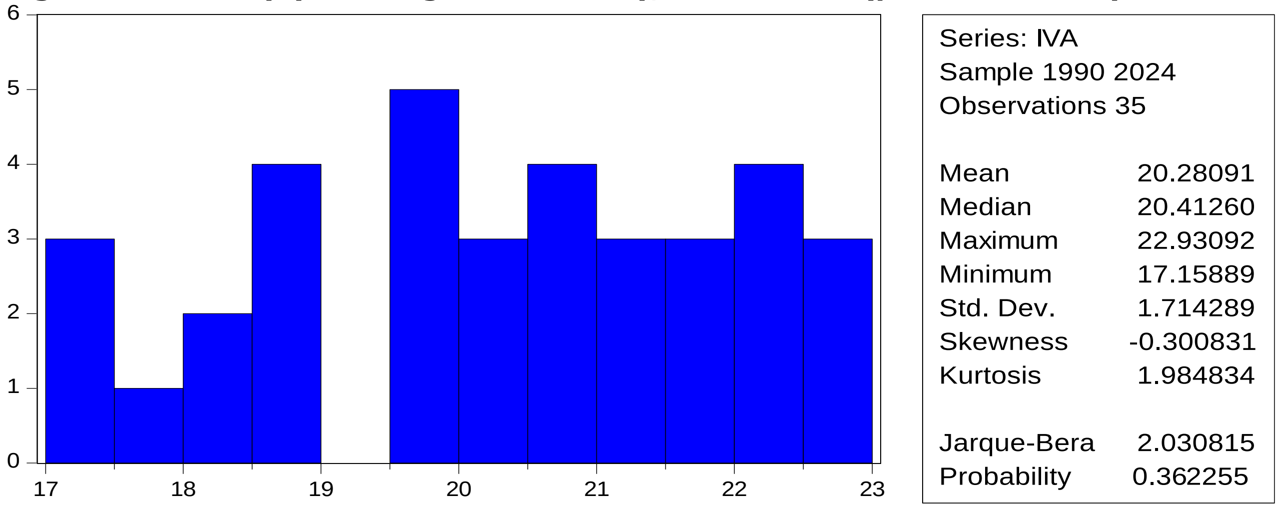


**Figure 7: (Imports + Exports)/GDP (Current US$)**

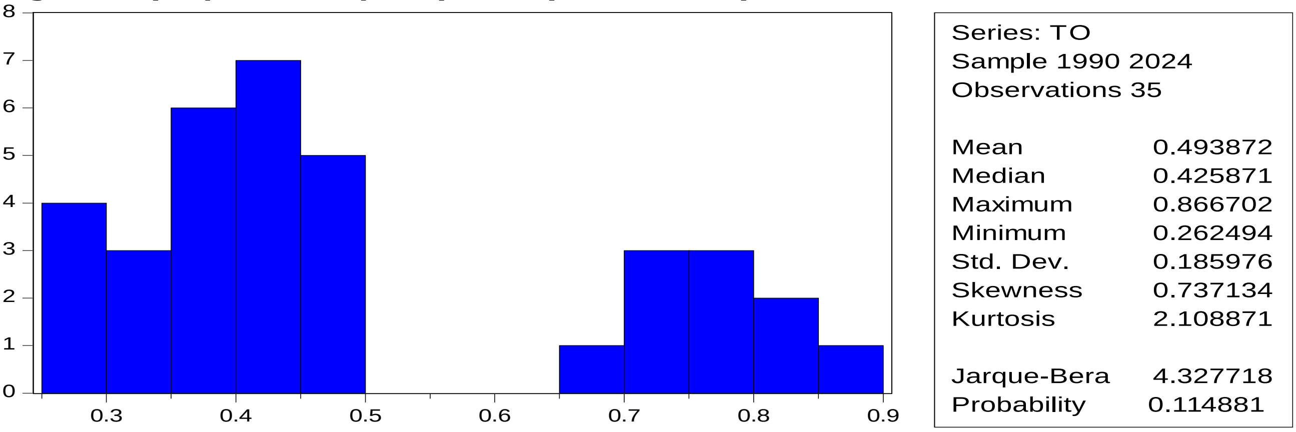



**Figure 8: Inflation, consumer prices (annual per cent)**

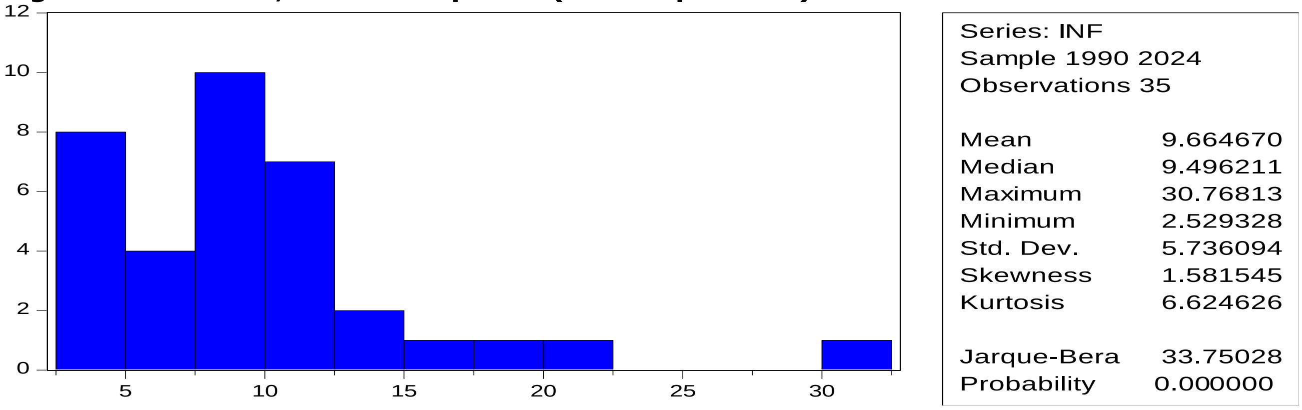



**Figure 9: Government Effectiveness: Percentile Rank**

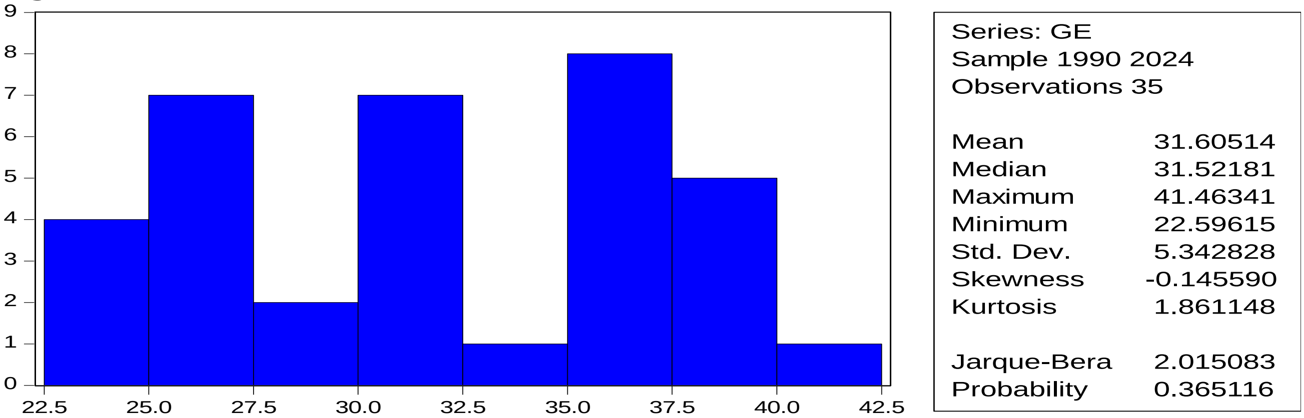
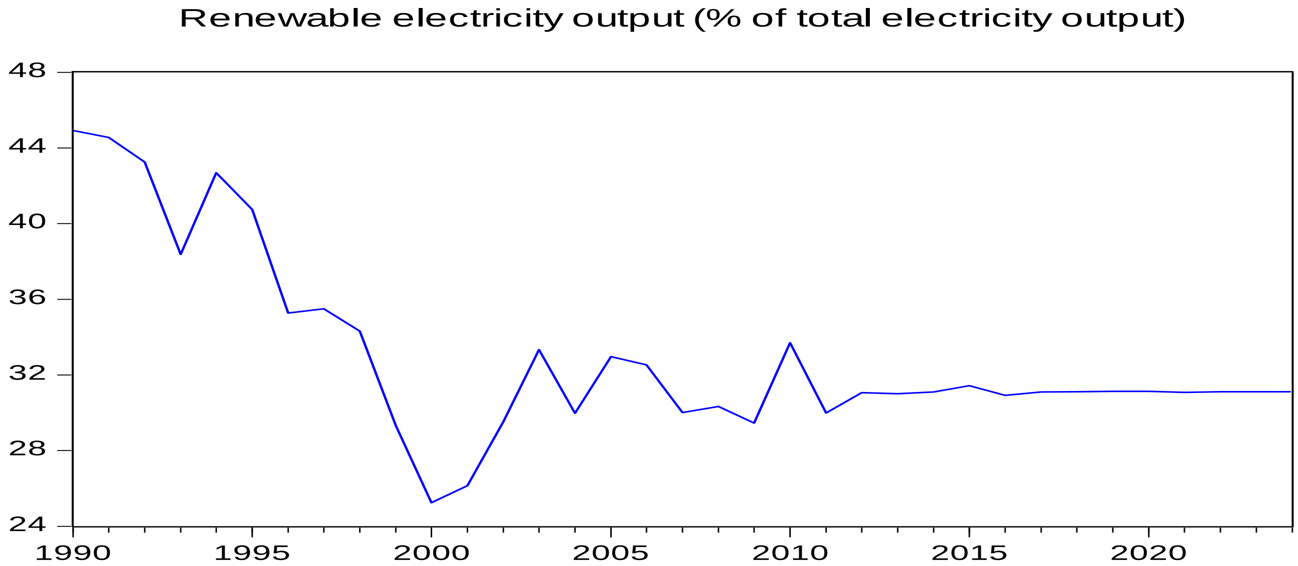
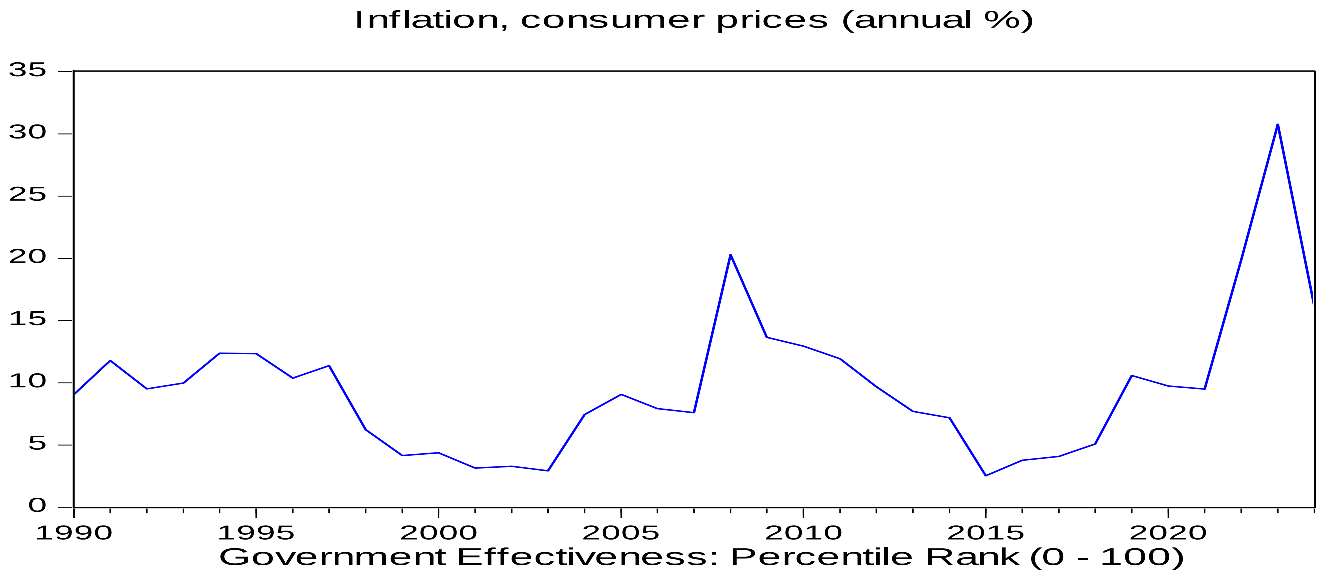



**Figure 10: Visual Presentation of Variables**


Industry (including construction), value added (% of GDP)
23
22
21
20
19
18
17
1990
1995
2000
2005
2010
2015
2020


Renewable electricity output (% of total electricity output)
48
44
40
36
32
28
24
1990
1995
2000
2005
2010
2015
2020


(Imports + Exports)/GDP (Current US$)
.9
.8
.7
.6
.5
.4
.3
.2
1990
1995
2000
2005
2010
2015
2020



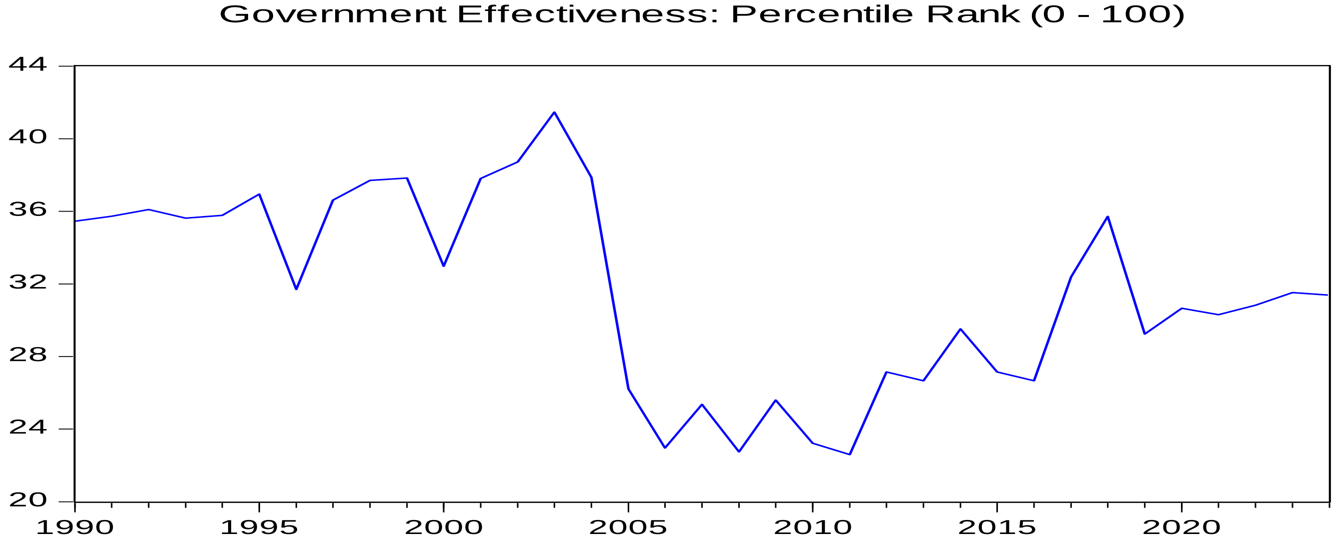




Table 7 shows the ARDL bounds test results with F-statistic of 5.47, exceeding both the lower bound (2.45) & upper bound (3.61) at the 5% significance level. This rejects the null hypothesis of no cointegration, indicating a long-run equilibrium relationship among REO, GDP, IVA, trade openness, inflation, and government effectiveness in Pakistan.

### 4.2. ARDL Estimates

**Table 8: Long-Run ARDL Estimates**

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| **GDP** | 0.142 | 0.051 | 2.78 | 0.008 |
| **IVA** | -0.315 | 0.089 | -3.54 | 0.001 |
| **TO** | 0.098 | 0.044 | 2.23 | 0.030 |
| **INF** | -0.064 | 0.027 | -2.37 | 0.024 |
| **GE** | 0.121 | 0.055 | 2.20 | 0.032 |
| *Constant* | 12.478 | 3.215 | 3.88 | 0.000 |

Table 8 shows long-run ARDL estimates, GDP per capita has positive and significant coefficient (0.142), indicating that higher economic growth encourages renewable energy expansion. Trade openness has positive & significant coefficient (0.098), showing that international trade facilitates technology transfer to cleaner energy technologies. Inflation has negative & significant coefficient (−0.064), indicating that rising inflation discourages renewable energy investment by increase in costs. Government Effectiveness has positive & significant coefficient (0.121) highlighting that stronger governance promote long-term renewable energy infrastructure. Economically, the coefficient of GDP (0.142) implies that a 10 per cent increase in GDP per capita is associated with approximately a 1.4 percentage point increase in renewable energy output in the long run, holding other factors constant. Similarly, improvements in government effectiveness yield meaningful gains in renewable energy generation, underscoring the importance of institutional quality for sustained energy transition. The negative impact of industrial value added reflects Pakistan's fossil-fuel-intensive industrial structure, where manufacturing and construction activities rely heavily on thermal power. In the absence of green industrial policies, industrial expansion may crowd out renewable energy adoption by reinforcing demand for conventional energy sources. Table 9 shows short-run dynamics of renewable energy output (REO) in Pakistan are estimated using the ARDL Error Correction Model (ECM): the error correction term (ECM−1) is negative & highly significant (−0.612), confirming the existence of a stable long-run relationship among the variables. The (ECM−1) coefficient suggests that approximately 61 per cent of the disequilibrium in REO is corrected within one year, indicating a relatively fast adjustment to long-run equilibrium following short-term shocks.

**Table 9: Short-Run Dynamics (ECM Representation)**

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| D(GDP) | 0.089 | 0.032 | 2.78 | 0.009 |
| D(IVA) | -0.141 | 0.059 | -2.39 | 0.022 |
| D(TO) | 0.067 | 0.028 | 2.39 | 0.021 |
| D(INF) | -0.049 | 0.019 | -2.57 | 0.015 |
| D(GE) | 0.084 | 0.036 | 2.33 | 0.025 |
| *ECM(-1)* | -0.612 | 0.144 | -4.25 | 0.000 |

**Table 10: Model Fit Statistics**

| Statistic | Value | Interpretation |
|---|---|---|
| R-squared ($R^2$) | 0.948 | 94.8% of variation in REO explained by the model |
| Adjusted R-squared | 0.945 | 94.5% explanatory power after adjusting for predictors |
| F-statistic | 371.7 | Strong joint significance of regressors |
| Prob (F-statistic) | 0.000 | Model is statistically significant at 1% level |
| Durbin-Watson | 2.18 | Indicates no serious autocorrelation in residuals |

While the high $R^2$ indicates strong explanatory power, it does not imply causality and should be interpreted within the context of time-series associations.

## 4.3. Diagnostic Tests

**Table 11: Diagnostic Tests**

| Test | Stat | Prob. | Conclusion |
|---|---|---|---|
| Breusch-Godfrey LM (Serial Correlation) | 1.34 | 0.27 | No serial correlation |
| Breusch-Pagan-Godfrey (Heteroskedasticity) | 0.98 | 0.41 | No heteroskedasticity |
| Jarque-Bera (Normality) | 2.11 | 0.34 | Residuals normal |
| Ramsey RESET (Functional Form) | 1.12 | 0.29 | Correctly specified |

Diagnostic test for serial correlation - Breusch-Godfrey LM test (1.34, p = 0.27) confirms no serial correlation. For heteroskedasticity - Breusch-Pagan-Godfrey test (p = 0.41) indicates constant variance of residuals. For normality - Jarque-Bera test (2.11, p = 0.34) confirms normally distributed residuals. And for functional form - Ramsey RESET test (1.12, p = 0.29) supports correct model specification.

**Table 12: Stability Tests (CUSUM & CUSUMSQ)**

| Test | Result |
|---|---|
| **CUSUM** | Within critical bounds → Stable |
| **CUSUMSQ** | Within critical bounds → Stable |

**Figure 11: CUSUMSQ Test**

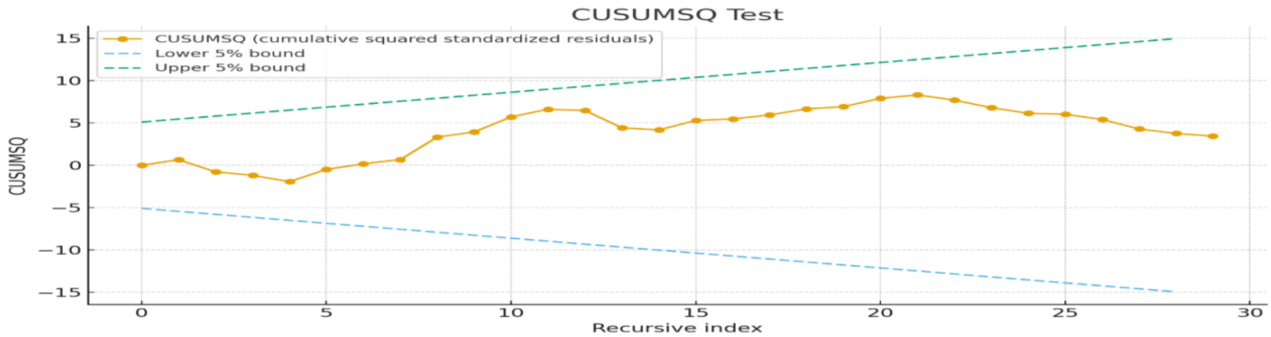
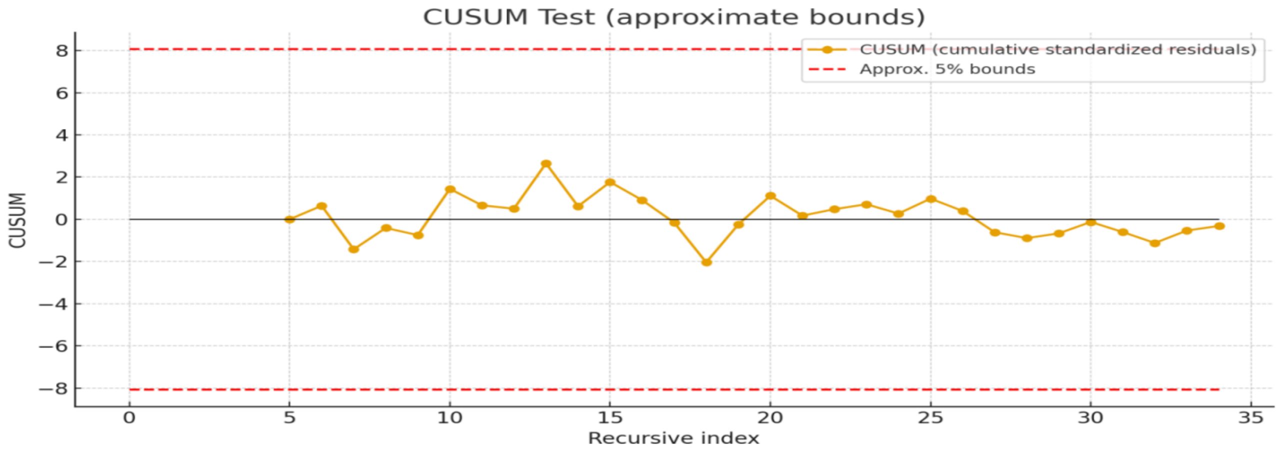


**Figure 12: CUSUM Test**




Stability Tests, CUSUM & CUSUMSQ show that the regression coefficients and residual variance remained within 5% critical bounds throughout the sample period, indicating structural stability.

## 5. Conclusion and Policy Recommendations

### 5.1. Conclusion

The research study examined the determinants of renewable energy output in Pakistan from 1990 to 2024. Applying the ARDL bounds testing procedure, the numerical estimates of economic growth, trade openness, industry value added, inflation and government effectiveness are measured. The findings showed that renewable energy output increases with increase in income per capita. Trade openness has a positive effect which suggesting that international trade stimulates technology transfers. Industrial growth shows negative impact on renewable energy output which depicts Pakistan's ongoing dependency over traditional energy sources. Inflation also has a negative impact which shows that prices rises costs and discouraged investment. Government effectiveness has positive impact on renewable energy generation showing that good governance is favorable to stable, long-term implementation of renewable energy measures and ensures sustainability of a transformation. Finally the research shows that economic, trade, industrial and institutional dynamics are crucial in defining Pakistan's renewable energy destiny. The results also suggest a clear policy recommendations for promoting economic growth, trade facilitation, effective governance, green industrial policies among other measures as well as macroeconomic stabilization. Overall, the findings underscore government effectiveness as a key institutional driver that enables economic and trade-related gains to translate into sustainable renewable energy transformation in Pakistan.

### 5.2. Policy Recommendations

The policy recommendations are as under:

- Governance and Institutional Reforms: Strengthen regulatory transparency, policy consistency, and enforcement mechanisms to enhance investor confidence in renewable energy projects.
- Green Industrial Development: Promote green industrial policies by incentivizing renewable-powered manufacturing zones and encouraging local production of solar panels and wind equipment, particularly in high-potential regions such as Gwadar and Sindh.
- Macroeconomic Stability: Maintain price stability and control inflation to reduce investment uncertainty and financing costs for renewable energy projects.
- Fiscal Incentives and Trade Facilitation: Provide targeted tax incentives, subsidies, and trade facilitation measures to support clean energy imports, technology transfer, and private-sector participation.

### 5.3. Limitation of the Study

The limitations of the study are as under**:**

- The relatively small sample size may limit generalizability of the results.

- Potential omitted variables, such as energy prices, financial development, or technological innovation, may influence renewable energy outcomes.

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