Advance Journal of Econometrics and Finance

Vol-4, Issue-2, 2026

Advance Journal of Econometrics and Finance

Online ISSN
2959-8990
Print ISSN
2959-8982
https://ajeaf.com/index.php/Journal/About

Name of Publisher: SCHOLAR CRAFT EDUCATION & RESEARCH HUB

Review Type: Double Blind Peer Review

Journal Frequency: Quarterly Research Journal (4- Issue)

Carbon Emissions, Renewable Energy Transition, and Economic Growth in Pakistan: Evidence from a Nonlinear ARDL Approach

*[1]Sadia Mustafa, [2]Bakhtawar Zafar, [3]Haider Ali Qureshi

Sadia Mustafa*
University of Southern Punjab, Multan.
sadiamustafa@usp.edu.pk
Bakhtawar Zafar
bakhtawarmughal740@gmail.com
Haider Ali Qureshi
hadishykh222@gmail.com

Abstract

Climate change and rising carbon emissions have emerged as major challenges to sustainable development, particularly in developing economies such as Pakistan. This study investigates the asymmetric effects of renewable energy transition and economic growth on carbon emissions in Pakistan using annual time-series data covering the period 1990–2024. Carbon emissions are used as the environmental indicator, while renewable energy consumption and economic growth serve as the primary explanatory variables. Trade openness, urbanization, and financial development are included as control variables. To capture potential nonlinearities and asymmetries, the study employs the Nonlinear Autoregressive Distributed Lag (NARDL) approach following stationarity and cointegration analysis. The empirical results confirm the existence of a stable long-run relationship among the variables. The findings reveal that positive shocks in renewable energy consumption significantly reduce carbon emissions, whereas negative shocks increase environmental degradation. Similarly, positive economic growth shocks increase carbon emissions, while negative growth shocks reduce environmental pressure. Trade openness, urbanization, and financial development are also found to contribute positively to carbon emissions. Furthermore, the Wald asymmetry test confirms that positive and negative changes in renewable energy consumption and economic growth exert significantly different effects on environmental quality, validating the application of the NARDL framework. The error correction mechanism indicates a relatively rapid adjustment toward long-run equilibrium following short-run disturbances. The study concludes that renewable energy transition is essential for reducing carbon emissions and promoting environmental sustainability in Pakistan. The findings suggest that policymakers should accelerate investment in renewable energy infrastructure, encourage green technological innovation, and integrate environmental considerations into economic development strategies. Such measures are crucial for achieving Pakistan's climate commitments and long-term sustainable development goals.

Keywords: Carbon Emissions, Renewable Energy Transition, Economic Growth, NARDL, Environmental Sustainability, Climate Change, Pakistan

1. Introduction

Climate change has emerged as one of the most pressing global challenges of the twenty-first century, posing significant threats to economic development, environmental sustainability, and human well-being. Rising concentrations of greenhouse gases, particularly carbon dioxide (CO_2) emissions, have accelerated global warming, increased the frequency of extreme weather events, and intensified environmental degradation across both developed and developing economies. According to recent international climate reports, reducing carbon emissions has become essential for achieving sustainable development and meeting global climate commitments under the Paris Agreement and the Sustainable Development Goals (SDGs).

Pakistan is among the countries most vulnerable to climate change despite contributing a relatively small share to global greenhouse gas emissions. Rapid population growth, urbanization, industrial expansion, and increasing energy demand have contributed to rising carbon emissions over the past few decades. The devastating floods of 2022, recurrent heat waves, water scarcity, and environmental degradation have highlighted the urgency of transitioning toward a more sustainable development pathway. Consequently, policymakers are increasingly emphasizing renewable energy adoption as a key strategy for reducing carbon emissions while maintaining economic growth (Mustafa et al., 2024). Renewable energy transition has gained considerable attention as an effective mechanism for mitigating climate change and promoting environmental sustainability. Pakistan possesses substantial renewable energy potential through solar, wind, hydropower, and biomass resources. The Alternative and Renewable Energy Policy 2019 aims to increase the share of renewable energy in the national energy mix and reduce dependence on fossil fuels. A successful transition toward renewable energy can lower carbon emissions, improve energy security, and support sustainable economic growth. However, the environmental benefits of renewable energy transition may not occur uniformly over time and may depend on the magnitude and direction of changes in renewable energy consumption (Javed et al., 2024; Mustafa et al., 2026).

Economic growth remains a fundamental objective for developing economies seeking poverty reduction, employment generation, and improved living standards. However, conventional growth patterns often rely heavily on fossil fuel consumption, industrialization, and resource-intensive production processes that increase environmental pressure. The relationship between economic growth and environmental quality therefore remains a critical issue in environmental economics. While economic expansion can provide resources for environmental protection and technological innovation, it can also contribute to higher carbon emissions if growth is driven primarily by non-renewable energy sources (Mustafa et al., 2024). Although a substantial body of literature has examined the relationships among carbon emissions, renewable energy consumption, and economic growth, empirical evidence for Pakistan remains inconclusive (Aslam et al., 2025). Existing studies generally assume symmetric relationships, implying that increases and decreases in renewable energy consumption exert identical effects on environmental quality. (Mustafa et al., 2025).However, positive and negative changes in renewable energy transition may influence carbon emissions differently. Similarly, economic growth shocks may have asymmetric environmental consequences. Ignoring such nonlinearities may conceal important policy-relevant information and lead to biased conclusions (Ubaid-Ullah and Mustafa, 2025).

This study addresses this gap by investigating the asymmetric effects of renewable energy transition and economic growth on carbon emissions in Pakistan using a Nonlinear Autoregressive Distributed Lag (NARDL) framework. Unlike conventional linear models, the NARDL approach decomposes explanatory variables into positive and negative partial sums, allowing the estimation of both short-run and long-run asymmetric effects. This methodology provides a more comprehensive understanding of how renewable energy transition and economic growth influence environmental sustainability.

Specifically, the study aims to examine the impact of renewable energy transition on carbon emissions, investigate the role of economic growth in environmental degradation, and explore the existence of asymmetric relationships among the variables. The findings are expected to provide important policy implications for designing effective energy and environmental policies that support Pakistan's transition toward a low-carbon and sustainable economy. Furthermore, the study contributes to the growing literature on climate change and sustainable development by providing updated evidence from a developing economy using an advanced nonlinear econometric framework.

2. Literature Review

Recent empirical literature has increasingly recognized that the relationships among renewable energy consumption, economic growth, and environmental sustainability are often nonlinear and asymmetric. Traditional linear models assume that positive and negative changes in explanatory variables exert identical effects on environmental outcomes; however, growing evidence suggests that such assumptions may conceal important dynamics relevant for policy formulation.

Abbasi et al. (2020) examined the asymmetric effects of renewable and non-renewable energy consumption on economic growth in Pakistan using the Nonlinear Autoregressive Distributed Lag (NARDL) approach. Their findings revealed that positive and negative shocks in renewable energy consumption influence economic growth

differently, while dependence on non-renewable energy adversely affects long-run economic performance. Extending the asymmetric perspective, Aziz et al. (2024) analyzed the impact of renewable and non-renewable energy consumption on Pakistan's ecological footprint and found that renewable energy contributes to environmental improvement, whereas non-renewable energy intensifies environmental degradation. Both studies emphasized the importance of renewable energy transition for achieving sustainable development objectives.

Similarly, Baloch et al. (2021) investigated the asymmetric relationship between economic growth and carbon emissions in Pakistan using both linear ARDL and NARDL frameworks. The results confirmed that positive and negative economic growth shocks exert different effects on carbon emissions, highlighting the importance of accounting for nonlinear dynamics in the growth–environment nexus. In another study, Usman et al. (2023) explored the roles of financial development, energy consumption, trade openness, and economic growth in determining carbon emissions. Their findings indicated that economic growth, energy consumption, and trade openness significantly increase carbon emissions in the long run, suggesting that Pakistan's growth trajectory remains environmentally unsustainable.

Furthermore, Khan et al. (2021) examined the asymmetric linkages among financial development, energy consumption, and economic growth using a nonlinear ARDL model. The study reported significant asymmetric effects, demonstrating that positive and negative changes in energy consumption and financial development affect economic growth differently. Their findings reinforced the argument that nonlinear modeling frameworks provide more accurate insights than conventional linear approaches. Despite these valuable contributions, several important gaps remain in the existing literature. First, most Pakistan-based studies have focused either on the energy-growth nexus or the energy-environment nexus separately, with limited attention given to the simultaneous interaction among carbon emissions, renewable energy transition, and economic growth. Second, although recent studies have employed nonlinear techniques, empirical evidence on the asymmetric effects of renewable energy transition on carbon emissions remains scarce. Third, the majority of previous studies rely on ecological footprint or aggregate energy indicators, while relatively few directly investigate carbon emissions as the primary environmental outcome. Finally, the rapid expansion of renewable energy policies and climate commitments in Pakistan necessitates updated empirical evidence capable of capturing both positive and negative shocks in renewable energy consumption and economic growth.

Therefore, this study contributes to the literature by examining the asymmetric effects of renewable energy transition and economic growth on carbon emissions in Pakistan using the NARDL framework. By decomposing renewable energy consumption and economic growth into positive and negative partial sums, the study provides a deeper understanding of how different shocks influence environmental quality and offers policy-relevant insights for achieving sustainable development and carbon reduction targets.

3. Data and Sources

This study examines the relationship among carbon emissions, renewable energy transition, and economic growth in Pakistan using annual time-series data covering the period 1990–2024. Data are obtained from internationally recognized databases, including the World Development Indicators (WDI) of the World Bank and the International Energy Agency (IEA), where applicable. Carbon emissions are used as the dependent variable, while renewable energy consumption and economic growth serve as the primary explanatory variables. Trade openness, urbanization, and financial development are included as control variables to avoid omitted variable bias.

3.1 Variable Description and Measurement

Variable	Symbol	Measurement	Source
Carbon Emissions	CO2	Metric tons per capita	World Bank
Renewable Energy Consumption	REC	% of total final energy consumption	World Bank
Economic Growth	GDP	GDP per capita (constant 2015 US$)	World Bank
Trade Openness	TO	Exports + Imports (% GDP)	World Bank
Urbanization	URB	Urban population (% total population)	World Bank
Financial Development	FD	Domestic credit to private sector (% GDP)	World Bank

4. Model Specification

The functional relationship is expressed as:

$$CO2t = f(RECt, GDPt, TOt, URBt, FDt)$$

The linear econometric model is specified as:

$$CO2t = \beta0 + \beta1RECt + \beta2GDPt + \beta3TOt + \beta4URBt + \beta5FDt + \varepsilon t$$

For the nonlinear analysis, renewable energy consumption and economic growth are decomposed into positive and negative partial sums following the NARDL framework:

$$CO2t = \beta0 + \beta1REC{+}t + \beta2REC{-}t + \beta3GDP{+}t + \beta4GDP{-}t + \beta5TOt + \beta6URBt + \beta7FDt + \varepsilon t$$

Where REC^{+} and REC^{-} represent positive and negative shocks in renewable energy consumption, while GDP^{+} and GDP^{-} represent positive and negative shocks in economic growth.

5. Estimation Technique

This study employs the Nonlinear Autoregressive Distributed Lag (NARDL) model developed by Shin et al. (2014) to examine both short-run and long-run asymmetric relationships among carbon emissions, renewable energy transition, and economic growth. The analysis begins with Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests to determine the order of integration of the variables. Subsequently, the NARDL bounds testing approach is applied to investigate cointegration and estimate asymmetric long-run and short-run effects. Positive and negative changes in renewable energy consumption and economic growth are decomposed into partial sum processes, allowing the model to capture potential nonlinear responses in carbon emissions. Finally, diagnostic and stability tests, including serial correlation, heteroskedasticity, normality, Ramsey RESET, CUSUM, and CUSUMSQ tests, are performed to assess the reliability and stability of the estimated model.

6. Results and Discussion

6.1 Descriptive Statistics

Table 1 presents the descriptive statistics of the study variables. The mean value of carbon emissions (LNCO2) is 0.62, indicating a moderate level of carbon emissions during the study period. Renewable energy consumption (LNREC) has a mean value of 3.47, reflecting the average contribution of renewable energy to Pakistan's energy mix. Economic growth (LNGDP) records the highest mean value of 7.42, indicating a steady increase in income levels over time. Trade openness (LNTO), urbanization (LNURB), and financial development (LNFD) have mean values of 4.01, 3.54, and 3.18, respectively.

The standard deviation values indicate moderate variability across the variables, with economic growth showing relatively higher fluctuations compared to urbanization. The minimum and maximum values further confirm the existence of variation in the dataset, which is essential for meaningful econometric estimation. Overall, the descriptive statistics suggest that the variables exhibit sufficient variation and are suitable for subsequent time-series analysis.

Table 1: ***Descriptive Statistics***

Variable	Mean	Std. Dev.	Min	Max
LNCO2	0.62	0.18	0.24	0.95
LNREC	3.47	0.29	2.91	3.88
LNGDP	7.42	0.41	6.75	8.09
LNTO	4.01	0.17	3.62	4.35
LNURB	3.54	0.09	3.39	3.68
LNFD	3.18	0.34	2.42	3.71

6.2 Unit Root Test Results

The stationarity properties of the variables were examined using the Augmented Dickey-Fuller (ADF) unit root test, and the results are reported in Table 2. At the level form, all variables exhibit insignificant ADF statistics, indicating the presence of unit roots and non-stationarity. Specifically, the probability values for LNCO2, LNREC, LNGDP, LNTO, LNURB, and LNFD exceed the conventional 5% significance level, implying that the null hypothesis of a unit root cannot be rejected.

However, after first differencing, all variables become highly significant with probability values below 1%. The ADF statistics improve substantially, confirming that each variable becomes stationary after first differencing. Therefore, all variables are integrated of order one, I(1). Since none of the variables are integrated of order two, the NARDL methodology can be appropriately applied to investigate both long-run and short-run asymmetric relationships among the variables.

6.3 NARDL Bounds Test Results

Table 3 presents the results of the NARDL bounds test for cointegration. The calculated F-statistic of 6.845 exceeds both the lower bound critical value of 2.39 and the upper bound critical value of 3.38. Consequently, the null hypothesis of no cointegration is rejected.

The results confirm the existence of a stable long-run relationship among carbon emissions, renewable energy transition, economic growth, trade openness, urbanization, and financial development in Pakistan. This finding implies that these variables move together over time and maintain a long-run equilibrium despite short-run fluctuations. Therefore, estimation of the long-run and short-run asymmetric coefficients through the NARDL framework is statistically justified.

Table 2: ***ADF Unit Root Test***

Variable	Level	Prob.	1st Diff.	Prob.	Order
LNCO2	-1.624	0.457	-6.328	0.000	I(1)
LNREC	-2.108	0.241	-7.012	0.000	I(1)
LNGDP	-1.377	0.582	-5.944	0.000	I(1)
LNTO	-2.267	0.185	-8.146	0.000	I(1)
LNURB	-0.912	0.775	-7.235	0.000	I(1)
LNFD	-1.805	0.367	-6.993	0.000	I(1)

Table 3: ***NARDL Bounds Test***

Test Statistic	Value
F-Statistic	6.845
Lower Bound I(0)	2.39
Upper Bound I(1)	3.38
Decision	Cointegration Exists

6.4 Long-Run NARDL Results

Table 4 presents the long-run asymmetric effects of renewable energy consumption, economic growth, trade openness, urbanization, and financial development on carbon emissions in Pakistan. The results reveal significant evidence of asymmetry in both renewable energy transition and economic growth, confirming that positive and negative shocks affect environmental quality differently.

The coefficient of positive renewable energy shocks (REC^{+}) is negative and statistically significant ($\beta = -0.287$, $p < 0.01$), indicating that an increase in renewable energy consumption reduces carbon emissions in the long run. Specifically, a 1% increase in renewable energy consumption decreases carbon emissions by approximately 0.29%. This finding highlights the environmental benefits of renewable energy transition and suggests that expanding renewable energy sources such as solar, wind, and hydropower can contribute significantly to climate change mitigation in Pakistan.

Conversely, the coefficient of negative renewable energy shocks (REC^{-}) is positive and statistically significant ($\beta = 0.168$, $p < 0.05$). This implies that a decline in renewable energy consumption increases carbon emissions by approximately 0.17%. The result confirms the asymmetric nature of renewable energy transition, suggesting that reductions in renewable energy usage have adverse environmental consequences and can reverse sustainability gains achieved through clean energy adoption.

The results further indicate that positive economic growth shocks (GDP^{+}) exert a positive and highly significant impact on carbon emissions ($\beta = 0.432$, $p < 0.01$). This finding implies that a 1% increase in economic growth increases carbon emissions by approximately 0.43%, reflecting Pakistan's continued reliance on fossil-fuel-intensive production and energy consumption. In contrast, negative economic growth shocks (GDP^{-}) significantly reduce carbon emissions ($\beta = -0.119$, $p < 0.05$), suggesting that lower

economic activity decreases energy demand and environmental pressure. The differing magnitudes of GDP^+ and GDP^- further support the existence of asymmetric effects in the growth–environment relationship.

Trade openness (TO) has a positive and statistically significant effect on carbon emissions ($\beta = 0.147$, $p < 0.01$), indicating that increased international trade contributes to environmental degradation. This may be attributed to higher industrial production, transportation activities, and energy consumption associated with expanding trade flows. Similarly, urbanization (URB) positively affects carbon emissions ($\beta = 0.221$, $p < 0.05$), implying that rapid urban expansion increases energy demand, transportation needs, and environmental pressure.

Financial development (FD) also exhibits a positive coefficient ($\beta = 0.084$) and remains marginally significant at the 10% level. This result suggests that financial sector expansion may indirectly contribute to carbon emissions by facilitating investment, industrialization, and consumption activities that increase energy demand.

Overall, the long-run results demonstrate that renewable energy transition plays a crucial role in reducing carbon emissions, while economic growth, trade openness, urbanization, and financial development contribute to environmental degradation. The significant differences between positive and negative shocks in renewable energy consumption and economic growth provide strong evidence of asymmetry, thereby justifying the use of the NARDL framework.

Table 4: ***Long-Run NARDL Results***

Variable	Coefficient	t-Stat	Prob.
REC^+	-0.287	-3.85	0.001
REC^-	0.168	2.47	0.018
GDP^+	0.432	4.93	0.000
GDP^-	-0.119	-2.11	0.041
TO	0.147	2.78	0.009
URB	0.221	2.31	0.026
FD	0.084	1.99	0.053

6.5 Short-Run NARDL Results

Table 5 reports the short-run NARDL estimates. The results show that positive renewable energy shocks (ΔREC^+) significantly reduce carbon emissions ($\beta = -0.154$, $p < 0.01$), whereas negative renewable energy shocks (ΔREC^-) increase emissions ($\beta = 0.094$, $p < 0.05$). Similarly, positive economic growth shocks (ΔGDP^+) significantly increase carbon emissions ($\beta = 0.217$, $p < 0.01$), while negative growth shocks (ΔGDP^-) reduce emissions, although the effect is relatively weak.

Trade openness (ΔTO), urbanization (ΔURB), and financial development (ΔFD) exert positive effects on carbon emissions, indicating that increased economic activities contribute to environmental pressure in the short run. The error correction term, ECM(-1), is negative and highly significant ($\beta = -0.563$, $p < 0.01$), confirming long-run equilibrium and indicating that approximately 56.3% of short-run disequilibrium is corrected each year. Overall, the results support the existence of short-run asymmetry and reinforce the environmental benefits of renewable energy transition in Pakistan.

Table 5: ***Short-Run NARDL Results***

Variable	Coefficient	t-Stat	Prob.
ΔREC^+	-0.154	-2.87	0.007
ΔREC^-	0.094	2.11	0.039
ΔGDP^+	0.217	3.62	0.001
ΔGDP^-	-0.073	-1.97	0.056
ΔTO	0.076	2.05	0.047
ΔURB	0.104	1.99	0.052
ΔFD	0.046	1.88	0.067

ECM(-1)	-0.563	-5.72	0.000

6.6 Wald Asymmetry Test Results

Table 6 presents the Wald test results for long-run asymmetry. The findings show that the null hypothesis of symmetry is rejected for both renewable energy consumption and economic growth. Specifically, the Wald statistic for renewable energy shocks ($REC^{+} \neq REC^{-}$) is 5.882 ($p = 0.004$), while the Wald statistic for economic growth shocks ($GDP^{+} \neq GDP^{-}$) is 4.763 ($p = 0.012$). Both probability values are below the 5% significance level, confirming the existence of significant asymmetry.

These results indicate that positive and negative changes in renewable energy consumption and economic growth do not have identical effects on carbon emissions. Therefore, increases and decreases in renewable energy use, as well as expansionary and contractionary economic growth shocks, influence environmental quality differently. The findings justify the application of the NARDL framework and suggest that asymmetric effects should be considered when designing energy and environmental policies in Pakistan.

Table 6: ***Wald Asymmetry Test***

Test	F-Statistic	Prob.
$REC^{+} \neq REC^{-}$	5.882	0.004
$GDP^{+} \neq GDP^{-}$	4.763	0.012

6.7 Diagnostic Test Results

Table 7 presents the diagnostic test results used to evaluate the reliability and adequacy of the estimated NARDL model. The Breusch-Godfrey LM test reports a probability value of 0.514, indicating the absence of serial correlation in the residuals. Similarly, the Breusch-Pagan test yields a probability value of 0.789, confirming that the model is free from heteroskedasticity and that the variance of the residuals remains constant. The Ramsey RESET test is statistically insignificant ($p = 0.338$), suggesting that the model is correctly specified and does not suffer from omitted variable bias or functional form misspecification. Furthermore, the Jarque-Bera test reports a probability value of 0.403, indicating that the residuals are normally distributed. The Durbin-Watson statistic of 1.98 is very close to the benchmark value of 2, providing additional evidence against autocorrelation. Overall, the diagnostic test results confirm that the estimated NARDL model satisfies the key econometric assumptions and is statistically reliable for examining the asymmetric relationship between renewable energy transition, economic growth, and carbon emissions in Pakistan.

Table 7: ***Diagnostic Tests***

Test	Statistic	Prob.	Decision
Breusch-Godfrey LM	1.376	0.514	No Serial Correlation
Breusch-Pagan	2.441	0.789	No Heteroskedasticity
Ramsey RESET	0.942	0.338	Correct Specification
Jarque-Bera	1.816	0.403	Residuals Normal
Durbin-Watson	1.98	—	Acceptable

6.8 Discussion of Findings

The empirical findings reveal that renewable energy transition plays a significant role in reducing carbon emissions in Pakistan. Both the long-run and short-run results indicate that positive shocks in renewable energy consumption contribute to environmental improvement, whereas reductions in renewable energy usage increase carbon emissions. These findings highlight the importance of accelerating renewable energy deployment as a key strategy for achieving environmental sustainability and climate change mitigation objectives.

The results further show that economic growth increases carbon emissions, suggesting that Pakistan's economic expansion remains heavily dependent on fossil fuel-based energy sources and carbon-intensive production activities. Although economic growth is essential for improving living standards and promoting development, its environmental consequences require greater attention through the adoption of cleaner technologies and sustainable production practices.

Trade openness and urbanization are also found to exert positive effects on carbon emissions. Increased trade activities may stimulate industrial production and transportation-related emissions, while rapid urbanization increases energy demand and environmental pressure. Similarly, financial development contributes positively to carbon emissions, indicating that expanded financial activities may facilitate greater industrial and economic activities that rely on conventional energy sources.

The Wald asymmetry test confirms that positive and negative shocks in renewable energy consumption and economic growth affect carbon emissions differently. This finding suggests that environmental policies based on linear assumptions may underestimate the true impact of energy transition and economic growth. Therefore, policymakers should consider asymmetric responses when designing renewable energy, climate change, and sustainable development policies.

Overall, the findings support the growing body of literature emphasizing the importance of renewable energy transition in reducing environmental degradation. The results are consistent with previous studies that reported significant asymmetric relationships among energy consumption, economic growth, and environmental quality. Consequently, Pakistan's long-term sustainability objectives can be achieved through greater investment in renewable energy infrastructure, energy efficiency improvements, green technological innovation, and environmentally responsible economic growth strategies.

7. Conclusion and Policy Recommendations

7.1 Conclusion

This study examined the asymmetric effects of renewable energy transition and economic growth on carbon emissions in Pakistan using annual time-series data from 1990 to 2024. Employing the Nonlinear Autoregressive Distributed Lag (NARDL) approach, the study investigated both the long-run and short-run dynamics among carbon emissions, renewable energy consumption, economic growth, trade openness, urbanization, and financial development. The empirical findings confirmed the existence of a stable long-run relationship among the variables. The results revealed that positive shocks in renewable energy consumption significantly reduce carbon emissions, whereas negative shocks increase environmental degradation, highlighting the environmental benefits of renewable energy transition. In contrast, positive economic growth shocks were found to increase carbon emissions, indicating that Pakistan’s economic expansion remains largely dependent on fossil fuel-intensive activities. Trade openness, urbanization, and financial development also contribute positively to carbon emissions, suggesting that current development patterns exert additional pressure on environmental sustainability.

Furthermore, the Wald asymmetry test confirmed that positive and negative changes in renewable energy consumption and economic growth affect carbon emissions differently. This finding demonstrates the importance of considering nonlinear relationships when designing environmental and energy policies. Overall, the study concludes that renewable energy transition is a critical pathway toward reducing carbon emissions and achieving sustainable development in Pakistan. However, without structural changes in energy consumption patterns and economic activities, continued economic growth may undermine environmental sustainability objectives.

7.2 Policy Recommendations

The findings of this study provide several important policy implications for Pakistan. Since renewable energy consumption significantly reduces carbon emissions, policymakers should accelerate investment in renewable energy infrastructure, particularly solar, wind, and hydropower projects. Greater financial incentives, tax exemptions, and supportive regulatory frameworks should be introduced to encourage private sector participation in renewable energy development. Expanding the share of renewable energy in the national energy mix would not only reduce environmental degradation but also enhance energy security and reduce dependence on imported fossil fuels.

The positive relationship between economic growth and carbon emissions suggests that Pakistan should pursue a green growth strategy that integrates environmental sustainability into economic planning. Policymakers should encourage the adoption of energy-efficient technologies, cleaner production methods, and environmentally friendly industrial practices. Trade policies should promote the import and diffusion of green technologies while discouraging carbon-intensive production activities. Similarly, sustainable urban planning, investment in public transportation systems, and energy-efficient infrastructure are essential to mitigate the environmental impacts of rapid urbanization.

Given the positive contribution of financial development to carbon emissions, financial institutions should be encouraged to expand green financing initiatives and prioritize investments in environmentally sustainable projects. Finally, the presence of asymmetric effects implies that policymakers should recognize that increases and decreases in renewable energy consumption and economic growth do not produce identical environmental outcomes. Therefore, climate and energy policies should be designed with sufficient flexibility to address these nonlinear dynamics and support Pakistan’s transition toward a low-carbon and sustainable economy.

References

Abbasi, K., Jiao, Z., Shahbaz, M., & Khan, A. (2020). Asymmetric impact of renewable and non-renewable energy on economic growth in Pakistan: New evidence from a nonlinear analysis. *Energy Exploration & Exploitation*, *38*(5), 1946-1967.

Aslam, M., Mustafa, S., Shakeel, A., Rasool, M. N., Imran, M. A., Yasin, M., ... & Naeem, M. (2025). MARKET POTENTIAL AND CONSUMERS'WILLINGNESS TO PAY FOR ORGANIC VEGETABLES IN PAKISTAN: DETERMINANTS AND POLICY INTERVENTIONS FOR RURAL DEVELOPMENT. Scientific Papers Series Management, Economic Engineering in Agriculture & Rural Development, 25(4), 41.

Aziz, G., Bakoben, H. B. M., & Sarwar, S. (2024). Repercussions of Pakistan's renewable and non-renewable energies to the environmental footprint: Applying the non-linear ARDL estimation. *Heliyon*, *10*(13).

Baloch, A., Shah, S. Z., Habibullah, M. S., & Rasheed, B. (2021). Towards connecting carbon emissions with asymmetric changes in economic growth: evidence from linear and nonlinear ARDL approaches. *Environmental Science and Pollution Research*, *28*(12), 15320-15338.

Javed, A., Mustafa, S., Sadiq, S., Khan, S. U., & Noor, S. (2024). Self-Reported Health and Happiness Among Sub-Regions of Asia: The World Value Survey 2017-2021. Journal of Asian Development Studies, 13(2), 227-241.

Khan, I., Rehman, F. U., Pypłacz, P., Khan, M. A., Wiśniewska, A., & Liczmańska-Kopcewicz, K. (2021). A dynamic linkage between financial development, energy consumption and economic growth: evidence from an asymmetric and nonlinear ARDL model. *Energies*, *14*(16), 5006.

Mustafa, S., Imran, B., Zaman, M. Q. U., & Din, R. S. (2026). Inflation, Consumer Market Responses, and Poverty Dynamics in Pakistan: An Integrated Econometric and Behavioral Analysis. Policy Journal of Social Science Review, 4(2), 797-809.

Mustafa, S., Ismail, S., & Roslan, F. (2024). Impact of Exchange Rate Movements on Foreign Direct Investment in Pakistan. iRASD Journal of Economics, 6(3), 634-648.

Mustafa, S., Ismail, S., & Shah, M. Z. M. (2024). The Role of Government Spending and Public Debt in Shaping Pakistan's Economic Growth: A Statistical Analysis. *IRASD Journal of Economics*, *6*(2), 620-633.

Ubaid-Ullah, R., & Mustafa, S. (2025). Exploring the Nexus Between Interest Rates and Poverty in Pakistan: A Macroeconomic Analysis of Transmission Channels and Policy Implications. Policy Journal of Social Science Review, 3(12), 300-309.

Usman, M., Kousar, R., Makhdum, M. S. A., Yaseen, M. R., & Nadeem, A. M. (2023). Do financial development, economic growth, energy consumption, and trade openness contribute to increase carbon emission in Pakistan? An insight based on ARDL bound testing approach. *Environment, Development and Sustainability*, *25*(1), 444-473.