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STATISTICAL ANALYSIS OF CLIMATE CHANGE EFFECTS ON ENVIRONMENTAL SUSTAINABILITY: EXAMINING RENEWABLE ENERGY, NATURAL RESOURCES, AND ECONOMIC GROWTH

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ABSTRACT
Climate change and environmental degradation have become major challenges for sustainable development, particularly in developing economies such as Pakistan. This study examines the impact of renewable energy consumption, natural resource rents, and economic growth on environmental sustainability in Pakistan using annual time-series data from 1990 to 2024. Environmental sustainability is measured by the ecological footprint, while trade openness and urbanization are included as control variables. The study employs the Augmented Dickey-Fuller (ADF) unit root test, Johansen cointegration test, Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS), and Canonical Cointegrating Regression (CCR) techniques to investigate the long-run relationship among the variables. The ADF results indicate that all variables are integrated of order one, I(1), while the Johansen cointegration test confirms the existence of a long-run equilibrium relationship among the variables. The FMOLS findings reveal that renewable energy consumption has a negative and statistically significant effect on ecological footprint, suggesting that increased renewable energy usage improves environmental sustainability. In contrast, natural resource rents, economic growth, and trade openness exert positive and significant effects on ecological footprint, indicating that resource exploitation, economic expansion, and trade activities contribute to environmental degradation. Urbanization shows a positive but statistically insignificant impact. The robustness of these findings is confirmed through DOLS and CCR estimations. The study concludes that expanding renewable energy adoption can play a vital role in reducing environmental pressure in Pakistan, whereas unsustainable resource extraction and conventional growth patterns continue to threaten environmental sustainability. The findings highlight the need for policies promoting renewable energy investment, sustainable resource management, and environmentally responsible economic development to achieve long-term climate and sustainability objectives.
Keywords: *Climate Change, Environmental Sustainability, Ecological Footprint, Renewable Energy Consumption, Natural Resource Rents, Economic Growth, Pakistan, FMOLS, DOLS, CCR.*

1. Introduction:

Climate change has emerged as one of the most significant environmental and socioeconomic challenges of the twenty-first century. Rising global temperatures, frequent floods, prolonged droughts, biodiversity loss, and increasing greenhouse gas emissions have intensified concerns regarding environmental sustainability and sustainable economic development. According to the Intergovernmental Panel on Climate Change (IPCC, 2023), climate change poses severe threats to developing economies that are highly dependent on natural resources and climate-sensitive sectors. Pakistan is considered one of the most vulnerable countries to climate change despite contributing only a small proportion of global greenhouse gas emissions. The devastating floods of 2022, recurring heatwaves, glacier melting in northern regions, and increasing environmental degradation have highlighted the urgency of addressing climate-related challenges in the country (Mustafa et al., 2024).

Environmental sustainability has become a central objective of national and international development agendas. The achievement of Sustainable Development Goals (SDGs), particularly SDG 7 (Affordable and Clean Energy), SDG 13 (Climate Action), and SDG 15 (Life on Land), requires balancing economic growth with environmental protection. Economic growth remains essential for poverty reduction, employment generation, and industrial development; however, growth driven by fossil fuel consumption often results in increased carbon emissions and environmental degradation (Nathaniel & Bekun, 2021). Consequently, policymakers increasingly emphasize renewable energy as a mechanism for achieving sustainable development while reducing environmental pressure (Mustafa et al., 2026).

Pakistan possesses substantial renewable energy potential through solar, wind, hydropower, and biomass resources. The promotion of renewable energy can contribute to reducing carbon emissions and improving environmental quality. Simultaneously, natural resources play a critical role in economic development by generating income and supporting industrial activities (Mustafa et al., 2024). However, excessive exploitation of natural resources may accelerate environmental degradation, deforestation, ecological imbalance, and resource depletion. Therefore, understanding the relationship among renewable energy consumption, natural resource utilization, economic growth, and environmental sustainability has become increasingly important for developing effective climate policies (Mustafa and Shah, 2024). Although numerous studies have investigated the nexus between economic growth and environmental degradation, while others have focused on renewable energy or natural resources separately, limited empirical evidence exists regarding the combined effects of renewable energy consumption, natural resource rents, and economic growth on environmental sustainability in Pakistan. Most existing studies employ carbon dioxide emissions as a proxy for environmental degradation and frequently rely on conventional econometric approaches. Moreover, recent climate-related developments and policy reforms necessitate updated empirical evidence using the most recent available data.

This study aims to examine the impacts of renewable energy consumption, natural resource rents, and economic growth on environmental sustainability in Pakistan. Specifically, the study seeks (i) to investigate the influence of renewable energy consumption on environmental sustainability, (ii) to examine the effect of natural resource rents on environmental sustainability, and (iii) to analyze the relationship between economic growth and environmental sustainability. The study further evaluates the long-run relationships among the

selected variables using advanced econometric techniques.

The significance of this study lies in its contribution to the growing literature on climate change and sustainable development in Pakistan. Unlike previous studies that focus primarily on carbon emissions, this study adopts a broader environmental sustainability perspective and integrates renewable energy, natural resource rents, and economic growth within a unified framework. The findings are expected to provide valuable policy insights for environmental planners, energy policymakers, and government authorities seeking to formulate sustainable climate and energy policies. Furthermore, the study contributes to achieving Pakistan's commitments under the Paris Climate Agreement and the Sustainable Development Goals.

2. Literature Review

The relationship among climate change, environmental sustainability, renewable energy, natural resources, and economic growth has received increasing attention in recent environmental economics literature. Recent studies show that environmental sustainability is not determined by a single factor; rather, it is shaped by the interaction of energy structure, natural resource exploitation, economic expansion, human capital, tourism, institutional risk, and urbanization.

Nathaniel, Yalçiner, and Bekun (2021) examined environmental sustainability in BRICS economies by linking natural resources, renewable energy, human capital, and ecological footprint. Their study highlighted that natural resource dependence can increase ecological pressure, while renewable energy and human capital can support environmental sustainability. The study is important because it moved beyond carbon emissions and used ecological footprint as a broader indicator of environmental degradation. Ullah, Ahmed, Raza, and Ali (2021) investigated the nonlinear relationship between renewable energy consumption, natural resource rents, and ecological footprint using a threshold approach. Their findings indicated that the environmental impact of renewable energy and natural resources may vary across different development levels. This study is significant because it showed that the relationship between energy use and environmental sustainability is not always linear, suggesting that policy effectiveness depends on economic and environmental thresholds. Arslan, Khan, Latif, Komal, and Chen (2022) analyzed the dynamic relationship among natural resource rents, environmental sustainability, and sustainable economic growth in China. Their findings suggested that natural resource rents may contribute to economic growth, but uncontrolled resource exploitation can create environmental costs. This study is relevant because it provides evidence from a major developing economy where rapid industrialization and resource use have created serious environmental challenges. Ahmad, Ahmed, Khan, and Alvarado (2023) examined environmental sustainability in E-7 countries by considering natural resources, economic growth, country risk, and energy transition. Their study emphasized that economic growth and natural resource use can worsen environmental degradation if not supported by clean energy transition and effective risk management. This study is useful for developing countries because it connects environmental sustainability with energy transition and macroeconomic risk.

Farooq, Faheem, and Nousheen (2023) specifically focused on Pakistan by examining renewable energy consumption, natural resources, urbanization, and environmental sustainability. Their study is highly relevant to the present research because it directly addresses Pakistan's environmental sustainability challenges. The findings suggest that renewable energy can improve environmental outcomes, while

urbanization and natural resource pressure may increase environmental degradation if not properly managed. Zaman, Abdullah, and Ali (2017) studied the linkages among energy consumption, air pollution, climate change, and natural resource depletion in Pakistan. Their research showed that energy consumption and resource depletion are closely connected with environmental degradation and climate change. Although this study is relatively older, it provides an important foundation for understanding Pakistan's long-standing energy-environment problems. Khan and Hassan (2019) explored the balance between economic growth and environmental sustainability through energy consumption in Pakistan. Their study suggested that economic growth based on conventional energy consumption can increase environmental pressure. This finding is important for Pakistan because the country's development process has historically depended on fossil fuel-based energy, creating a conflict between growth and sustainability. Alvi and Mudassar (2025) assessed the impact of green energy strategies on natural resource rents in Pakistan. Their study emphasized the role of green energy policies in improving resource management and promoting sustainable development. This work is important because it directly connects Pakistan's renewable energy strategies with natural resource sustainability. Fatima, Khan, Rehman, and Khalid (2026) examined the role of tourism, natural resources, and renewable energy in enhancing economic growth and combating climate change in OPEC economies. Their study indicated that renewable energy can support climate change mitigation, while tourism and natural resources can contribute to growth if managed sustainably. Although the study focuses on OPEC economies, its findings are useful for resource-dependent developing economies such as Pakistan.

Overall, the reviewed literature confirms that renewable energy plays a positive role in environmental sustainability, while natural resource rents and economic growth may increase environmental degradation if they are not supported by clean energy transition and sustainable resource governance. However, several gaps remain. First, many studies focus either on renewable energy or natural resources separately, while fewer studies examine their combined effects on environmental sustainability. Second, Pakistan-specific studies remain limited, particularly those using updated data and broader environmental sustainability indicators. Third, most existing research relies on conventional carbon emissions measures, whereas ecological footprint provides a more comprehensive picture of environmental pressure. Therefore, the present study contributes to the literature by examining the combined effects of renewable energy consumption, natural resource rents, and economic growth on environmental sustainability in Pakistan.

3. Data and Sources

This study examines the impact of renewable energy consumption, natural resource rents, and economic growth on environmental sustainability in Pakistan using annual time-series data from 1990–2024**.** Data are obtained from reliable sources, including the World Bank**,** Global Footprint Network**,** and the Pakistan Bureau of Statistics. Environmental sustainability is measured by the Ecological Footprint (EF)**,** which serves as the dependent variable. The main explanatory variables are renewable energy consumption**,** natural resource rents**,** and economic growth, while trade openness and urbanization are included as control variables due to their influence on environmental sustainability.

3.1 Variable Description and Measurement

Table 3.1 presents the variables used in the study, their measurement, and data sources.

Variable	Symbol	Measurement	Source
Ecological Footprint	EF	Global hectares per capita	Global Footprint Network
Renewable Energy Consumption	REC	% of total final energy consumption	World Bank (WDI)
Natural Resource Rents	NRR	% of GDP	World Bank (WDI)
Economic Growth	GDP	GDP per capita (constant 2015 US$)	World Bank (WDI)
Trade Openness	TO	Sum of exports and imports (% of GDP)	World Bank (WDI)
Urbanization	URB	Urban population (% of total population)	World Bank (WDI)

4. Model Specification

The relationship between environmental sustainability and its determinants is specified as:

EFt=f(RECt,NRRt,GDPt,TOt,URBt)

The econometric model is expressed as:

EFt=β0+β1RECt+β2NRRt+β3GDPt+β4TOt+β5URBt+εt

Where:

- EFEFEF = Ecological Footprint
- RECRECREC = Renewable Energy Consumption
- NRRNRRNRR = Natural Resource Rents
- GDPGDPGDP = Economic Growth
- TOTOTO = Trade Openness
- URBURBURB = Urbanization
- ε\varepsilonε = Error term

5. ESTIMATION TECHNIQUE

This study employs a series of econometric techniques to investigate the relationship between renewable energy consumption, natural resource rents, economic growth, trade openness, urbanization, and environmental sustainability in Pakistan. The Augmented Dickey-Fuller (ADF) test is first applied to examine the stationarity properties of the variables. After establishing the order of integration, the Johansen cointegration test is employed to determine the existence of a long-run equilibrium relationship among the variables. Following confirmation of cointegration, the Fully Modified Ordinary Least Squares (FMOLS) estimator is used to estimate the long-run coefficients. To verify the robustness of the findings, Dynamic Ordinary Least Squares (DOLS) and Canonical Cointegrating Regression (CCR) estimators are additionally applied. Finally, diagnostic tests including the Breusch-Godfrey LM test, Breusch-Pagan heteroskedasticity test, Ramsey RESET test, and Jarque-Bera normality test are conducted to assess the reliability and adequacy of the estimated model.

5.1 Unit Root Test Results

The Augmented Dickey-Fuller (ADF) test was employed to examine the stationarity properties of the variables. The results presented in Table 1 show that all variables are non-stationary at their level forms, as the null hypothesis of a unit root cannot be rejected. However, after first differencing, all variables become stationary at the 1% significance level. Therefore, ecological footprint (LNEF), renewable energy consumption (LNREC), natural resource rents (LNNRR), economic growth (LNGDP), trade openness (LNTO), and

urbanization (LNURB) are integrated of order one, I(1). Since all variables exhibit the same order of integration, the Johansen cointegration test can be applied to examine the existence of a long-run relationship among them.

Table 1: ***ADF Unit Root Test***

Variable	Level ADF	Prob.	1st Diff. ADF	Prob.	Order
LNEF	0.050	0.962	-6.176	0.000	I(1)
LNREC	-0.055	0.954	-7.313	0.000	I(1)
LNNRR	-1.182	0.681	-5.276	0.000	I(1)
LNGDP	1.194	0.996	-8.255	0.000	I(1)
LNTO	-1.315	0.622	-9.729	0.000	I(1)
LNURB	-0.826	0.811	-7.970	0.000	I(1)

All variables are stationary at first difference, so Johansen cointegration can be applied.

5.2 Johansen Cointegration Test Results

The Johansen cointegration test was conducted to determine whether a long-run equilibrium relationship exists among the variables. As reported in Table 2, the trace statistics for the first four hypotheses exceed their corresponding critical values, leading to the rejection of the null hypotheses of no cointegration. These results confirm the existence of a long-run relationship among ecological footprint, renewable energy consumption, natural resource rents, economic growth, trade openness, and urbanization in Pakistan. Therefore, FMOLS, DOLS, and CCR estimators are employed to estimate the long-run coefficients.

Table 2: ***Johansen Cointegration Test***

Hypothesis	Trace Statistic	5% Critical Value	Decision
None	158.033	95.754	Reject H0
At most 1	88.909	69.819	Reject H0
At most 2	57.732	47.855	Reject H0
At most 3	33.157	29.796	Reject H0
At most 4	15.194	15.494	Do not reject

There is evidence of long-run cointegration among the variables.

5.3 FMOLS Long-Run Estimation Results

The Fully Modified Ordinary Least Squares (FMOLS) results are presented in Table 3. The findings indicate that renewable energy consumption has a negative and statistically significant effect on ecological footprint (β = -0.209, $p < 0.01$), suggesting that increased renewable energy usage improves environmental sustainability in Pakistan. Specifically, a 1% increase in renewable energy consumption reduces the ecological footprint by approximately 0.21%.

Table 3: ***FMOLS Long-Run Results***

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNREC	-0.209	0.071	-2.960	0.003

LNNRR	0.099	0.010	9.923	0.000
LNGDP	0.340	0.087	3.928	0.000
LNTO	0.116	0.025	4.706	0.000
LNURB	0.343	0.251	1.366	0.172
C	-3.701	0.672	-5.508	0.000

Natural resource rents exert a positive and significant impact on ecological footprint (β = 0.099, p < 0.01), indicating that greater dependence on natural resource extraction contributes to environmental degradation. Similarly, economic growth positively affects ecological footprint (β = 0.340, p < 0.01), implying that economic expansion increases environmental pressure. Trade openness also shows a positive and significant relationship with ecological footprint (β = 0.116, p < 0.01), suggesting that increased trade activities may contribute to environmental degradation. Urbanization has a positive coefficient (β = 0.343) but remains statistically insignificant (p > 0.05), indicating that its impact on environmental sustainability is not strong enough to be statistically confirmed during the study period.

Overall, the FMOLS results suggest that renewable energy consumption enhances environmental sustainability, whereas natural resource exploitation, economic growth, and trade openness increase environmental pressure in Pakistan.

5.4 DOLS Robustness Results

To verify the robustness of the FMOLS estimates, Dynamic Ordinary Least Squares (DOLS) estimation was performed. The results reported in Table 4 generally support the FMOLS findings. Natural resource rents (β = 0.083, p < 0.01) and economic growth (β = 0.339, p < 0.05) continue to have positive and significant effects on ecological footprint.

Although renewable energy consumption maintains a negative coefficient (β = -0.144), its effect becomes statistically insignificant. Similarly, trade openness and urbanization remain statistically insignificant in the DOLS model. The consistency in the signs of the coefficients across FMOLS and DOLS indicates the robustness of the long-run relationship among the variables.

Table 4: ***DOLS Robustness Results***

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNREC	-0.144	0.182	-0.789	0.430
LNNRR	0.083	0.020	4.225	0.000
LNGDP	0.339	0.159	2.140	0.032
LNTO	0.037	0.042	0.878	0.380
LNURB	0.495	0.587	0.844	0.398

5.5 CCR Robustness Results

The Canonical Cointegrating Regression (CCR) results presented in Table 5 further confirm the robustness of the FMOLS estimates. Renewable energy consumption negatively and significantly affects ecological footprint (β = -0.209, p < 0.01), while natural resource rents (β = 0.099, p < 0.01), economic growth (β = 0.340, p < 0.01), and trade openness (β = 0.116, p < 0.01) positively and significantly influence ecological footprint.

Urbanization remains positive but statistically insignificant. The similarity of the CCR and

FMOLS results strengthens confidence in the estimated long-run relationships and confirms the reliability of the empirical findings.

Table 5: ***CCR Robustness Results***

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNREC	-0.209	0.068	-3.070	0.002
LNNRR	0.099	0.010	9.866	0.000
LNGDP	0.340	0.083	4.120	0.000
LNTO	0.116	0.023	5.000	0.000
LNURB	0.343	0.244	1.406	0.160

5.6 Diagnostic Test Results

To assess the reliability and adequacy of the estimated model, several diagnostic tests were conducted. The results are presented in Table 6.

Table 6: ***Diagnostic Tests***

Test	Statistic	Prob.	Decision
Breusch-Godfrey LM	1.085	0.581	No serial correlation
Breusch-Pagan	1.837	0.871	No heteroskedasticity
Ramsey RESET	0.795	0.380	Model correctly specified
Jarque-Bera	22.985	0.000	Residuals not normally distributed
Durbin-Watson	1.820	—	Acceptable

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The Breusch-Godfrey LM test indicates the absence of serial correlation, as the probability value (0.581) exceeds the 5% significance level. Similarly, the Breusch-Pagan test confirms the absence of heteroskedasticity, suggesting that the residuals have constant variance. The Ramsey RESET test is statistically insignificant, indicating that the model is correctly specified and does not suffer from functional form misspecification.

The Jarque-Bera test rejects the null hypothesis of normality, implying that the residuals are not normally distributed. However, this issue does not substantially affect the validity of the long-run estimators, as FMOLS, DOLS, and CCR are relatively robust to departures from normality in time-series analysis. Furthermore, the Durbin-Watson statistic of 1.820 is close to the benchmark value of 2, providing additional evidence of the absence of serious autocorrelation.

Overall, the diagnostic results confirm that the estimated model is statistically reliable and suitable for examining the long-run relationship between renewable energy consumption, natural resource rents, economic growth, and environmental sustainability in Pakistan.

6. Discussion of Findings

The empirical findings reveal that renewable energy consumption contributes to environmental sustainability by reducing the ecological footprint, highlighting the importance of clean energy adoption in Pakistan. In contrast, natural resource rents, economic growth, and trade openness increase ecological pressure, suggesting that current

patterns of resource utilization and economic expansion are associated with environmental degradation. These findings imply that while economic growth remains essential for development, greater emphasis should be placed on renewable energy investment, sustainable resource management, and environmentally friendly production practices.

The results are broadly consistent with the findings of Nathaniel S. P. and colleagues, who reported that renewable energy improves environmental quality while excessive dependence on natural resources increases ecological pressure. Similarly, the positive impact of economic growth on ecological footprint supports the conclusions of Ahmad M. and co-authors, who found that economic expansion in developing economies often occurs at the expense of environmental sustainability. The findings also align with the Pakistan-based evidence reported by Farooq F. and colleagues, emphasizing the role of renewable energy in mitigating environmental degradation.

Overall, the study suggests that achieving environmental sustainability in Pakistan requires a transition toward renewable energy, efficient utilization of natural resources, and the integration of environmental considerations into economic and trade policies.

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