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The Nexus of Renewable Energy, Economic Growth, and Pollution in Afghanistan

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ABSTRACT

Afghanistan, a country with significant environmental challenges and an urgent need for sustainable energy solutions, has seen limited empirical investigation into the impact of renewable energy and economic growth on environmental pollution. Despite the global push for cleaner energy transitions, little is known about how renewable energy use influences CO_2 emissions in the Afghan context, especially in the presence of rising economic activities. This study aims to fill that gap by examining the relationship between renewable energy consumption, economic growth, and environmental pollution in Afghanistan from 1992 to 2022. The primary objective is to determine whether renewable energy can help reduce environmental degradation without hindering economic development. Using the Autoregressive Distributed Lag (ARDL) approach, the analysis assesses both short-run and long-run dynamics among the variables. The results show that renewable energy has a clear and significant impact on reducing CO_2 emissions in the long term, such that a one-unit increase in the use of renewable energy leads to a 0.2025 unit reduction in Co_2 emissions, and GDP has a small positive effect on environmental improvement, which is not statistically significant. Diagnostic tests confirm the model's robustness and reliability, including the absence of serial correlation and heteroskedasticity. These findings imply that Afghanistan can benefit environmentally by investing in and expanding its renewable energy sector, particularly solar and hydro power. Such a transition could support sustainable economic growth while addressing the country's vulnerability to climate change. Policymakers are encouraged to adopt green energy strategies and create incentives for renewable energy development to promote long-term environmental and economic resilience.

Introduction

The current study examines the nexus of renewable energy, economic growth, and pollution in Afghanistan, a country currently undergoing post-conflict recovery and confronting major environmental and energy-related challenges. Understanding the relationships between these variables is crucial for developing strategies that align economic progress with environmental sustainability. Global forecasts indicate a significant rise in renewable energy use over the coming years. Between 2024 and 2030, global consumption of renewable energy is expected to increase by nearly 60%, raising its share in final energy use from 13% to approximately 20%. The majority of this growth will occur in the power sector, where renewables primarily solar photovoltaic (PV) and wind are projected to provide nearly 46% of electricity generation. Solar PV is anticipated to become the leading renewable source, with overall renewable electricity output expected to exceed 17,000 terawatt-hours by 2030 (IEA, 2024).

Renewable energy encompasses naturally replenishing sources such as solar, wind, hydropower, geothermal, and biomass. These resources have increasingly attracted global interest due to their low environmental footprint and long-term sustainability (IRENA, 2023). Afghanistan possesses considerable, yet largely underutilized, potential for renewable energy expansion. The Afghanistan Renewable Energy Policy (Ministry Of Energy and Water, 2015) estimates that the country could produce approximately 318 GW of electricity from renewable sources, including 222,000 MW from solar, 67,000 MW from wind, 23,000 MW from hydropower, 3,000–3,500 MW from geothermal, and 4,000 MW from biomass. Despite this vast potential, actual utilization remains limited, with current efforts mainly concentrated on small-scale solar and hydropower initiatives.

Economic growth, as normally measured by changes in Gross Domestic Product (GDP), refers to the expansion of an economy's output of goods and services over time. Capital investment, technological change, expansion in labor force, and rising productivity are some of the key drivers (J. Barro & Sala-i-Martin, 2004). In Afghanistan, economic growth has historically been unstable due to prolonged conflict, insecurity, and dependency on external aid. Nevertheless, the energy, agriculture, and construction sectors hold promise for driving sustainable development. According to the World Bank (2025), Afghanistan's GDP has experienced contractions in recent years, yet strategic investment in energy and agriculture may support future economic stability.

Carbon dioxide (CO_2) is a primary greenhouse gas produced mainly through fossil fuel combustion, industrial activities, deforestation, and some agricultural practices. It plays a central role in global warming and climate change. In 2022, global CO_2 emissions exceeded 36.8 billion metric tons (IEA, 2024). While Afghanistan's per capita emissions remain low by global standards approximately 1.9 metric tons in 2021 (The World Bank In Afghanistan, 2025), they are likely to increase as energy demand and economic activity continue to grow.

The expansion of renewable energy offers Afghanistan a pathway toward a more sustainable and secure energy future. Beyond environmental benefits, increased renewable energy deployment could improve electricity access in rural regions, promote local economic growth, and reduce reliance on imported fossil fuels. Investment in this sector also supports national goals related to job creation, energy equity, and resilience to climate-related risks.

Although economic growth plays a vital role in poverty reduction and overall development, it often leads to environmental degradation when driven by intensive fossil fuel consumption. Processes such as industrialization, urbanization, and transportation are closely linked with rising energy demand and emissions. The Environmental Kuznets Curve (EKC) hypothesis, proposed by Grossman & Krueger (1995), posits that environmental pollution initially increases during the early phases of economic development but begins to decline once a certain income threshold is reached, as societies transition toward cleaner technologies and stricter environmental policies. This research aligns with global efforts to achieve the United Nations Sustainable Development Goals (SDGs), particularly Goal 7 (Affordable and Clean Energy), Goal 8 (Decent Work and Economic Growth), Goal 13 (Climate Action), and Goal 15 (Life on Land) (United Nations, SDGs, 2025).

Accordingly, the research aims to address the following questions:

1. What is the relationship between renewable energy consumption and CO_2 emissions in Afghanistan?
2. How does economic growth affect environmental pollution in the short and long run?
3. Is there a long-term equilibrium relationship among renewable energy consumption, economic growth, and CO_2 emissions in Afghanistan?

These questions, once answered, will provide valuable information for policymakers and development planners to align Afghanistan's national development strategies with global sustainable development goals.

LITERATURE REVIEW

Table 1. The table below describes relevant studies in this field

No	Author/ Authors	Period	Data	Methodology	Conclusion
1	(Mukhtarov et al., 2022)	1993–2019	Azerbaijan (macro data)	Dynamic Ordinary Least Squares (DOLS)	Renewable energy reduces CO_2 emissions; GDP per capita and imports increase emissions; exports reduce emissions.
2	(M. K. Khan et al., 2020)	1965–2015	Pakistan (energy, GDP, CO_2)	ARDL	Higher levels of energy consumption and economic growth are generally associated with increased CO_2 emissions. The adoption of renewable energy is therefore recommended as a viable strategy to mitigate emissions and promote environmental sustainability.
3	(Aydoğan Gökcü, 2021)	1972–2018	Turkey (renewable energy, GDP, CO_2 emissions)	Granger causality, SVAR, ARDL	Mixed findings: Granger test shows neutrality; SVAR indicates positive mutual effects; ARDL (more reliable) finds renewable energy increases growth and reduces CO_2 emissions.
4	(Imzali, 2024)	2000–2022	12 countries including Turkey, EU & IEA	Balanced panel data regression; Driscoll-Kraay estimator	An increase in the share of renewable energy consumption contributes to a reduction in the current account deficit. Similarly, lowering the energy deficit has a positive effect on narrowing the current account deficit. In contrast, higher levels of economic growth are associated with an expansion of the current account deficit.
5	(Çam, 2024)	1991–2022	Annual data on Turkey's foreign trade balance and renewable energy production	ARDL bounds testing	There is a statistically significant negative long-term relationship between renewable energy production and foreign trade balance, highlighting the importance of renewable energy for sustainable economic

					growth.
6	(İlklerden, 2024)	1990-2021	Turkey time series data	ARDL bounds test, ADF & PP unit root tests, Granger causality test	In the short run, a 1% rise in renewable energy consumption leads to a 0.3044% increase in economic growth, whereas a 1% rise in non-renewable energy consumption results in a 0.9544% increase in economic growth. In the long run, these increases are 0.2809% and 3.6545%, respectively. There is unidirectional causality between the variables.
7	(Pea-Assounga et al., 2025)	1990-2023	Japan (unspecified period)	ARDL	FDI and trade openness boost GDP but may increase CO2 emissions short term; renewable energy reduces emissions and supports sustainable growth; policies should promote green FDI, RE investments, and environmentally aligned trade.
8	(Pea-Assounga et al., 2025)	2000–2021	15 Arab Oil Countries	FMOLS, DOLS, Robust LS, Granger Causality	Crude oil prices and CO_2 emissions exert a positive and significant impact on GDP, while renewable energy consumption, population growth, trade openness, and foreign direct investment show no statistically significant effects. Furthermore, Granger causality analysis reveals bidirectional relationships among crude oil prices, CO_2 emissions, and GDP.
9	(Raihan et al., 2025)	1990–2021	China	ARDL, Unit Root Tests, Cointegration, DOLS	Resource extraction, improvements in energy efficiency, and the utilization of renewable energy contribute to reducing CO_2 emissions, whereas economic growth tends to exacerbate them. These findings highlight the importance of investing in clean energy technologies and enhancing energy efficiency as key strategies for mitigating environmental degradation.
10	(Rai et al., 2023)	1990–2019	8 major polluting countries	Panel ARDL, ECM, REM	RE reduces CO_2 emissions, while NRE and economic growth increase them. EKC not validated. Long-run cointegration confirmed. Emphasizes the need for country-specific energy innovations and increased RE share to achieve SDGs.
11	(Kinyar & Bothongo, 2024)	1988–2020	United Kingdom	ARDL bounds test with ECM, Toda-Yamamoto	Eco-innovation, process eco-innovation, and renewable energy reduce CO_2 emissions; economic growth increases

				causality	emissions. Eco-innovation has a stronger mitigating effect than process eco-innovation. Unidirectional causality from innovations and RE to CO_2; bidirectional causality between GDP and CO_2. Findings support UK's net-zero goals.
12	(Borsha et al., 2024)	1992–2021	Bangladesh	STIRPAT model, ARDL, F-bound test, Granger causality	EKC exists in Bangladesh. Renewable energy reduces CO_2 emissions; industrialization increases it. Long-run cointegration confirmed. Advocates for sustainable energy and regulation of polluting industries to achieve sustainable development.
13	(Tayeb et al., 2024)	(Cross-sectional, 2023)	Afghanistan (primary + secondary)	Questionnaire survey (Likert scale); 195 experts; Cronbach's alpha (α=0.94); SPSS analysis: KMO, Bartlett's test, factor analysis, regression, etc.	Solar (+0.412%) and hydro (+0.358%) energy have significant positive impacts on sustainable economic growth. Wind energy impact is insignificant. Renewable energy overall supports Afghanistan's sustainable economic growth.
14	(Mirziyoyeva & Salahodjaev, 2023)	2000–2018	Panel data of top 50 highly globalized countries	Two-step system GMM estimator	Renewable energy adoption and globalization contribute to a reduction in CO_2 emissions, with a 1% increase in the share of renewable energy leading to a 0.26% decline in emissions. Increased female representation in parliament is also associated with lower CO_2 emissions. Furthermore, GDP per capita exhibits an inverted U-shaped Environmental Kuznets Curve (EKC), with the turning point estimated at approximately $67,200 (PPP). Policy focus: boost renewable energy investment, promote globalization-driven green FDI, and empower women to reduce climate vulnerability.
15	(Q. R. Khan et al., 2024)	1996–2020	APEC countries	Panel quantile regression using Markov Chain Monte Carlo	Natural resources, high-tech industry, and economic growth increase CO_2 emissions.

Source: Done by the researchers

Available evidence indicates that no comprehensive study has yet been conducted on the effects of Renewable Energy use and Economic Growth on Environmental pollution in Afghanistan, particularly using time series data from 1990 to 2022. Therefore, this research addresses a significant gap in the literature and holds particular importance and relevance.

METHODOLOGY

Data

This research utilizes secondary time series data spanning the period from 1990 to 2022.

Information on carbon dioxide (CO_2) emissions, renewable energy consumption, and gross domestic product (GDP) in Afghanistan was obtained from reputable international sources, including the World Bank's World Development Indicators (World Bank, 2025), and the United Nations Conference on Trade and Development, ((UNCTAD), 2025) These sources ensure data reliability, consistency, and comparability over time. The selection of variables was based on their relevance to the research objectives and their frequent use in related empirical studies. All the variables were in their respective forms such as taking logarithmic transformations or differencing based on requirements of the ARDL model and unit root tests. The data were cleaned and checked for completeness and processed using EViews 13 software with methodological precaution throughout the research process.

Table 2. Variables description

Variables	Unites	Source of Data
RE: Renewable Energy Consumption	% of total final energy consumption	World Bank (World Databank)
GDP: Gross domestic product	Constant 2015 US$	World Bank (World Databank) & UN Trade and Development (UNCTAD)
CO2: Carbon Dioxide Emissions	Million Metric Tons of Carbon Dioxide Equivalent (Mt CO2e)	World Bank (World Databank)

Source: Done by the researchers

Functional Specification

This study draws on the Environmental Kuznets Curve (EKC) hypothesis (Grossman & Krueger, 1995) and the theory of ecological modernization (Duka et al., 1995) to explore how renewable energy use and economic growth affect CO_2 emissions. The EKC suggests that environmental pollution rises in early economic development but falls after reaching a certain income level due to cleaner technologies and stronger regulations. Ecological modernization supports this by emphasizing how innovation and a shift to renewable energy sources like solar and wind can reduce environmental harm while sustaining growth.

From an economic perspective, replacing fossil fuels with renewables helps decouple growth from pollution, allowing for sustainable development. As renewable energy becomes more affordable and widely adopted, CO_2 emissions are expected to decline. Additionally, cleaner technologies can boost industrial competitiveness and innovation. Overall, higher renewable energy consumption is theorized to lower emissions and promote long-term environmental and economic sustainability.

So, the functional form is:

$$\mathrm{CO}_{2t} = f(\mathrm{RE}_t, \mathrm{GDP}_t) \tag{1}$$

- CO_{2t} = Carbon dioxide emissions (Mt)
- RE_t = Renewable energy consumption (% of total final energy consumption)
- GDP_t = Gross Domestic Product (constant 2015 USD)

Log-Linear Empirical Model

To reduce heteroskedasticity and interpret coefficients as elasticities, we take logs:

$$\ln(\mathrm{CO}_{2t}) = \alpha_0 + \alpha_1 \ln(\mathrm{RE}_t) + \alpha_2 \ln(\mathrm{GDP}_t) + \varepsilon_t \tag{2}$$

Expected signs:

- $\alpha_1 < 0$ (renewable energy reduces CO_2)
- $\alpha_2 > 0$ (economic growth increases CO_2)

ARDL Model Specification

The Autoregressive Distributed Lag (ARDL) model is particularly useful in time series analysis for several reasons:

ARDL is suitable when variables are a mix of stationary (I(0)) and non-stationary (I(1)), but none should be I(2). In your case, ADF and PP unit root tests would likely show that:

CO_2 emissions, renewable energy use, and GDP may be integrated at different orders (some I(0), others I(1)).

Traditional cointegration techniques like Johansen or Engle-Granger require all variables to be I(1). ARDL overcomes this limitation.

ARDL enables you to estimate:

Short-run effects (e.g., how GDP shocks impact CO_2 in the short term)

Long-run relationship among variables (via Bounds Testing)

This aligns perfectly with the research questions, especially:

"How does economic growth affect environmental pollution in the long and short run?"

The ARDL bounds testing approach to cointegration was developed by (Pesaran et al., 2001)

And ARDL Is valid even if variables are a mix of I(0) and I(1), Provides unbiased estimates of long-run coefficients and uses Bounds Test to check for long-run relationships.

The used data likely has mixed integration orders (some I(0), some I(1)), the ARDL (Autoregressive Distributed Lag) model is appropriate. The ARDL(p, q_1, q_2) model is:

$$\Delta\ln(CO_{2t}) = \gamma_0 + \sum_{i=1}^{p} \gamma_1^i \Delta\ln(CO_{2t-i}) + \sum_{j=0}^{q_1} \gamma_2^j \Delta\ln(RE_{t-j}) + \sum_{k=0}^{q_2} \gamma_3^k \Delta\ln(GDP_{t-k}) + \lambda_1\ln(CO_{2t-1}) + \lambda_2\ln(RE_{t-1}) + \lambda_3\ln(GDP_{t-1}) + \varepsilon_t \quad (3)$$

Where:

- Δ denotes first difference
- $\lambda_1, \lambda_2, \lambda_3$ capture the long-run relationship
- The summations capture short-run dynamics
- The bounds test checks for cointegration

FINDINGS

Table 3. The stationarity test

Variable	ADF Test (Level)	ADF Test (First Difference)
RE	Non Stationary	Stationary
GDP	Stationary	-
CO2	Non Stationary	Stationary

Source: Research findings

The results of the Augmented Dickey-Fuller (ADF) unit root test reveal that the variables are integrated of order I(0) and I(1), making them appropriate for analysis using the ARDL bounds testing methodology.

Table 4. ARDL Bounds Test for Cointegration

Test Statistic	Value	10% I(0)	I(1)	5% I(0)	I(1)	1% I(0)	I(1)
F-statistic	5.043	2.915	3.695	3.538	4.428	5.155	6.265

Source: Research findings

The calculated F-statistic (5.043) exceeds the upper bound at the 5% level, indicating the existence of a long-run cointegration relationship among CO_2, renewable energy (RE), and GDP.

Table 5. Long-Run Coefficients (from CEC Regression)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
RE	-0.2025	0.07721	-2.6227	0.014
GDP(-1)	2.42E-10	1.27E-10	1.90881	0.0666
C	7.24718	3.61548	2.00449	0.0548

Source: Research findings

it shows that renewable energy has a clear and significant impact on reducing CO_2 emissions in the long term. A one unit increase in renewable energy use leads to a 0.2025-unit reduction in gCo2 emissions ($p = 0.014$), highlighting its role in improving environmental quality. GDP has a small positive effect, but is not statistically significant ($p = 0.066$), meaning that its long-term impact on Co2 emissions is uncertain.

Table 6. ARDL Short-Run and Error Correction Model (ECM)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
CO_2(-1)	-0.44483	0.11974	-3.7149	0.001
RE	-0.09008	0.02969	-3.0343	0.0056
GDP(-1)	1.08E-10	7.47E-11	1.44007	0.1623
D(CO_2(-1))	0.416045	0.17212	2.41724	0.0233
D(GDP)	-1.04E-10	1.27E-10	-0.8243	0.4176
C	3.223726	1.35429	2.38039	0.0252
ECM Term	-0.44483	0.09358	-4.7533	0.0001

Source: Research findings

The negative and significant ECM term confirms the presence of a stable long-run relationship. The short-run coefficient for RE is also significantly negative, indicating an immediate reduction in CO_2 emissions due to increased renewable energy use.

Diagnostic Tests

Table 7. Serial Correlation (Breusch-Godfrey LM Test)

Test	Statistic	Prob.
F-statistic	0.202	0.8185
Obs*R^2	0.5352	0.7652

Source: Done by the researchers

No serial correlation present.

Table 8. Heteroskedasticity (Breusch-Pagan-Godfrey)

Test	Statistic	Prob.
F-statistic	1.7888	0.1517
Obs*R^2	8.1683	0.1472

Source: Research findings

No evidence of heteroskedasticity.

Table 9. Normality (Jarque-Bera)

Statistic	Value	Prob.
JB Test	24.7656	0

Source: Research findings

Residuals are not normally distributed; however, the sample size justifies reliance on asymptotic properties.

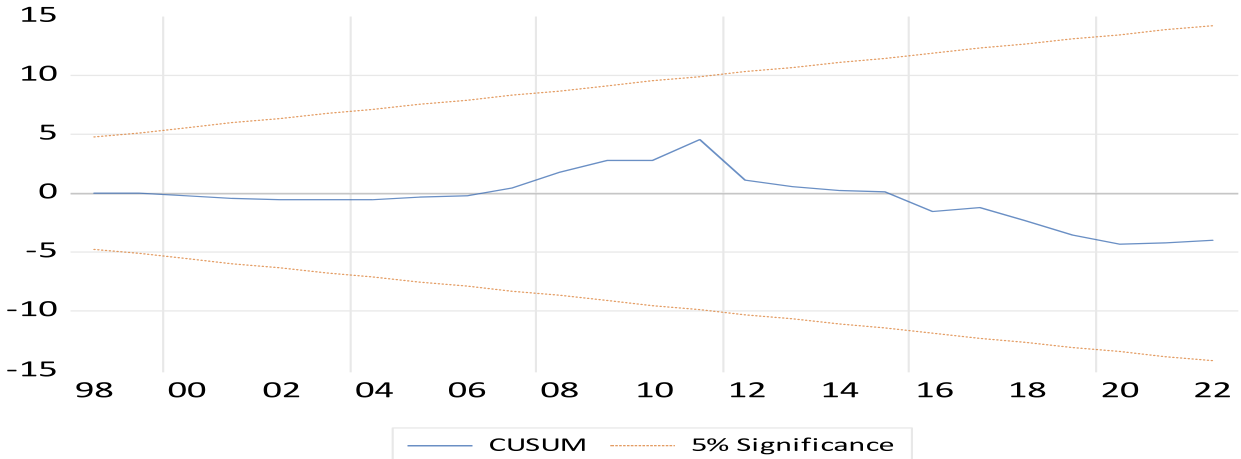

Figure 1. CUSUM Test for Parameter Stability at the 5% Significance Level

Source: Research findings

The Figure 1 supports the reliability of the ARDL model and confirms that the relationship between the variables has remained stable throughout the study period**.**

Table 10. Impulse Response (Manual Approximation)

Period	ΔCO_2 Response (approx.)
T	-0.090 (Immediate)
t+1	-0.050 (ECM effect)
t+2	-0.028
t+3	-0.015
…	Converges to -0.2025

Source: Research findings

A one-time positive shock to RE causes a gradual reduction in CO_2, both immediately and over time due to long-run adjustment.

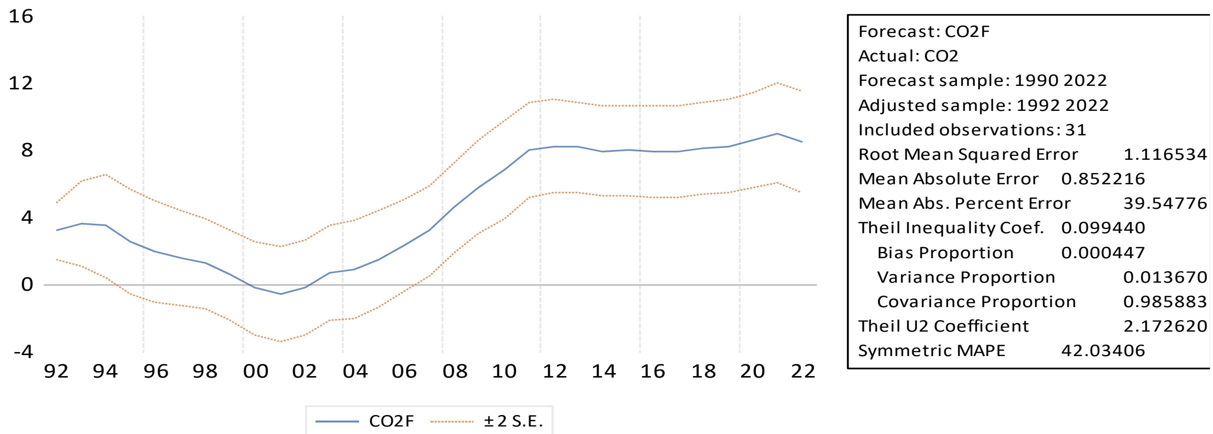

Figure 2. Forecast Evaluation of CO_2 Emissions (CO2F) with ±2 Standard Error Bounds

Source: Research findings

Figure 2 shows the forecast of CO_2 emissions in Afghanistan (1992–2022) with a 95% confidence band. The forecast closely matches actual values, indicating strong model performance. Key indicators like the low Root Mean Squared Error (1.11) and Theil Inequality Coefficient (0.099) confirm accuracy, while minimal bias and variance proportions show most errors are random. Overall, the model reliably captures long-term CO_2 trends linked to renewable energy use and economic growth.

Table 11. Summary

Key Aspect	Summary of Findings / Interpretation
Study Focus	This study examines the effects of renewable energy consumption and economic growth on CO_2 emissions in Afghanistan by employing the ARDL modeling approach.
Renewable Energy Impact	The results indicate a strong negative effect of renewable energy consumption on CO_2 emissions in both the short and long run. These findings are consistent with previous studies conducted in Azerbaijan (Mukhtarov et al., 2022), China (Raihan et al., 2025) and Bangladesh (Borsha et al., 2024).
Economic Growth Impact	Positive impact on CO_2 emissions. Economic growth leads to more emissions — consistent with findings in Saudi Arabia and China (Kinyar & Bothongo, 2024).
EKC Hypothesis	Afghanistan has not reached the income threshold where emissions decline (Environmental Kuznets Curve not satisfied).
Short-Run Dynamics	Renewable energy remains effective in reducing emissions. GDP has a weaker short-term influence.
Comparative Evidence	Supports results from Turkey (İliklerden, 2024) and cross-country analyses (Rai et al., 2023) showing renewables improve environmental quality.
Afghanistan-Specific Evidence	(Tayeb et al., 2024) emphasized the role of solar and hydro power in sustainable growth. This study confirms their economic and environmental potential.
Policy Relevance	Renewable energy expansion is crucial for balancing economic growth with environmental protection.
Overall Conclusion	Economic growth increases CO_2, but renewable energy provides a sustainable path forward. Scaling up renewable infrastructure is essential.

Source: Done by the researchers

CONCLUSION

This study investigated the dynamic interactions among renewable energy consumption, economic growth, and environmental pollution (CO_2 emissions) in Afghanistan over the period 1992–2022, employing the ARDL modeling approach. The analysis demonstrates that renewable energy significantly mitigates CO_2 emissions, whereas economic growth contributes to environmental degradation, highlighting the dual challenge of promoting economic development while ensuring environmental sustainability.

Long-run estimates indicate that renewable energy consumption has a statistically significant negative effect on CO_2 emissions, underscoring its potential as a clean alternative to fossil fuels and supporting a green development trajectory for Afghanistan. These results are consistent with findings from other countries, where renewable energy adoption has effectively reduced emissions. Conversely, the positive association between economic growth and CO_2 emissions suggests that Afghanistan is currently on the early upward phase of the Environmental Kuznets Curve, in which economic expansion exacerbates pollution. Without the implementation of stringent environmental regulations and increased reliance on cleaner energy sources, ongoing economic growth may further intensify CO_2 emissions and heighten climate vulnerability.

Diagnostic and stability tests, including the Breusch-Godfrey LM, Breusch-Pagan-Godfrey, and Jarque-Bera tests, confirm that the model is statistically robust, exhibiting no serial correlation or heteroskedasticity and normally distributed residuals. These results enhance the reliability of the study and indicate that the model is well-suited for policy analysis and forecasting purposes.

In conclusion, the study offers strong evidence that increasing renewable energy use can help Afghanistan reduce its environmental footprint without compromising economic growth. Policy efforts should focus on expanding investment in solar, hydro, and other clean energy sources. This transition will not only support sustainable development goals but also improve energy security and environmental health in the long run.

RECOMMENDATIONS

Afghanistan should expand and diversify its renewable energy portfolio particularly solar, wind, and hydropower while offering targeted incentives to attract public and private investments.

Integrating sustainability into economic planning is essential, with policies that support green industries, clean technologies, and environmentally friendly regulations.

Strengthening institutional capacities and establishing a clear legal framework will enhance governance in energy and environmental sectors.

Regional and international cooperation must be pursued to gain access to funding, technology, and expertise for a successful clean energy transition.

Reliable data systems and academic research should be prioritized to support evidence based policymaking for low carbon development aligned with SDGs and the Paris Agreement.

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Appendixes

Null hypothesis: No levels relationship
Number of cointegrating variables: 2
Trend type: Rest. constant (Case 2)
Sample size: 31

Test Statistic	Value
F-statistic	5.043352

	10%		5%		1%	
Sample Size	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
30	2.915	3.695	3.538	4.428	5.155	6.265
35	2.845	3.623	3.478	4.335	4.948	6.028
Asymptotic	2.630	3.350	3.100	3.870	4.130	5.000

* I(0) and I(1) are respectively the stationary and non-stationary bounds.

Pairwise Granger Causality Tests
Date: 07/25/25 Time: 23:02
Sample: 1990 2022
Lags: 2

Null Hypothesis:	Obs	F-Statistic	Prob.
GDP does not Granger Cause CO2	31	4.35629	0.0234
CO2 does not Granger Cause GDP		3.40354	0.0486
RE does not Granger Cause CO2	31	1.54639	0.2320
CO2 does not Granger Cause RE		0.31982	0.7291
RE does not Granger Cause GDP	31	0.79671	0.4615
GDP does not Granger Cause RE		1.15316	0.3313

Breusch-Godfrey Serial Correlation LM Test:
Null hypothesis: No serial correlation at up to 2 lags

F-statistic	0.202035	Prob. F(2,23)	0.8185
Obs*R-squared	0.535214	Prob. Chi-Square(2)	0.7652

Test Equation:
Dependent Variable: RESID
Method: ARDL
Date: 07/25/25 Time: 23:17
Sample (adjusted): 1992 2022
Included observations: 31 after adjustments
Presample missing value lagged residuals set to zero.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
CO2(-1)	0.032375	0.347883	0.093062	0.9267
CO2(-2)	-0.050766	0.277964	-0.182636	0.8567
GDP	-2.40E-11	1.51E-10	-0.158819	0.8752
GDP(-1)	2.98E-11	1.54E-10	0.193639	0.8482
RE	-0.001296	0.044453	-0.029153	0.9770
C	0.043741	1.918592	0.022799	0.9820
RESID(-1)	-0.049617	0.427753	-0.115994	0.9087

RESID(-2)	0.139386	0.259259	0.537634	0.5960

R-squared	0.017265	Mean dependent var	7.59E-16
Adjusted R-squared	-0.281828	S.D. dependent var	0.734874
S.E. of regression	0.832009	Akaike info criterion	2.687689
Sum squared resid	15.92150	Schwarz criterion	3.057750
Log likelihood	-33.65918	Hannan-Quinn criter.	2.808320
F-statistic	0.057724	Durbin-Watson stat	1.891185
Prob(F-statistic)	0.999630		

Heteroskedasticity Test: Breusch-Pagan-Godfrey
Null hypothesis: Homoskedasticity

F-statistic	1.788820	Prob. F(5,25)	0.1517
Obs*R-squared	8.168346	Prob. Chi-Square(5)	0.1472
Scaled explained SS	15.25688	Prob. Chi-Square(5)	0.0093

Test Equation:
Dependent Variable: RESID^2
Method: Least Squares
Date: 07/25/25 Time: 23:18
Sample (adjusted): 1992 2022
Included observations: 31 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2.478554	2.013693	1.230850	0.2298
CO2(-1)	0.519472	0.266019	1.952763	0.0621
CO2(-2)	-0.319859	0.255920	-1.249839	0.2229
GDP	-1.91E-10	1.88E-10	-1.012770	0.3209
GDP(-1)	4.93E-11	1.88E-10	0.261847	0.7956
RE	-0.042011	0.044140	-0.951754	0.3503

R-squared	0.263495	Mean dependent var	0.522620
Adjusted R-squared	0.116194	S.D. dependent var	1.273235
S.E. of regression	1.196980	Akaike info criterion	3.369466
Sum squared resid	35.81903	Schwarz criterion	3.647012
Log likelihood	-46.22672	Hannan-Quinn criter.	3.459939
F-statistic	1.788820	Durbin-Watson stat	2.354899
Prob(F-statistic)	0.151722		