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The Relationship between Renewable Energy Production and Economic Growth: A Short-Term and Long-Term Analysis in the Case of Uzbekistan

Gofur Halmuratov[1]*, Kamoliddin Rustamov[2], T. Khankelov[2], Xolilla Xolmuratov[3], Sherzod Khudainazarov[4], Talibjan Sabirjanov[2], Fozil Xolmurotov[5]

[1]Czech University of Life Sciences, Prague, Czech Republic, [2]Tashkent State Transport University, Tashkent, Uzbekistan, [3]Urgench State University, 220100, Khamid Olimjon 14, Urgench, Uzbekistan, [4]Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, National Research University, Tashkent, Uzbekistan, [5]Mamun University, 220900, Qibla Tozabog, Khiva, Uzbekistan. *Email: fozilholmurotov@gmail.com

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ABSTRACT

In this study, the relationships between Uzbekistan's economic growth, renewable energy use, rural electricity use, and greenhouse gas emissions were investigated using an ARDL model based on data from 2000 to 2022. The long-term results showed that renewable energy production had a significant positive impact on economic growth (coefficient: 0.608, $P < 0.01$), while greenhouse gas emissions had no significant impact (coefficient: -0.00004, $P>0.05$). However, rural electricity use had a negative impact on economic growth (coefficient: −6.815, $P < 0.01$). The short-term analysis shows that renewable energy production has a rapid and significant positive impact on economic growth (coefficient: 0.0001, $P < 0.05$). In addition, the previous period's economic growth rate (coefficient: 0.643, $P < 0.05$) and greenhouse gas emissions (coefficient: 0.0001, $P < 0.05$) have a positive impact on economic growth in the short term.

Keywords: Economic Growth, Renewable Energy, ARDL, Sustainable Development, Greenhouse Gas Emissions
JEL Classifications: Q14, Q57, R11

1. INTRODUCTION

Energy is a key component of the economy and plays an important role in the economic growth and sustainable development of a country. Today, the energy sector remains one of the most pressing issues not only economically, but also environmentally and socially. Global climate change and increased greenhouse gas emissions are prompting countries to pay more attention to the use of renewable energy sources. From this point of view, determining the relationship between renewable energy production and economic growth is of great importance both theoretically and practically.

In the case of Uzbekistan, these issues are of particular importance. Despite the country's significant energy resources, there are significant environmental and energy problems in the process of economic development (IEA, n.d.). In particular, the rural population has limited access to electricity, which hinders the economic and social development of these regions. At the same time, the potential for the use of renewable energy sources in the country has not yet been fully realized. The share of renewable energy in electricity generation is 17.8%, and increasing this indicator is important for the sustainable development of the country's economy (energyforum.uz).

The main objective of the study is to identify short- and long-term relationships between renewable energy production, rural electricity use, and greenhouse gas emissions. To achieve this goal, the ARDL model was selected. This model allows us to identify the stationarity of time series, long-term dependence, and short-term dynamics. The study used data collected for Uzbekistan for the period 2000-2022. The data were obtained from sources such as the World Bank and the Statistics Agency, ensuring their relevance and reliability.

The relevance of the study is determined by a number of factors. First, effective management and diversification of energy resources is one of the main conditions for economic growth. Renewable energy sources allow not only to ensure environmental sustainability, but also to create new jobs and develop economic diversification. Second, improving energy supply and infrastructure in rural areas allows for more active involvement of the local population in the process of socio-economic development. Third, reducing greenhouse gas emissions plays an important role in solving global environmental problems and is consistent with Uzbekistan's international obligations.

The scientific significance of the study is that it enriches existing scientific theories by further exploring the relationship between renewable energy sources and economic growth. Its practical significance is reflected in the formulation of economic policy and strategic decision-making in the energy sector. The results of the study can be used to develop specific recommendations for the development of green energy policies, improving energy supply to rural populations, and reducing greenhouse gas emissions.

This work attempts to answer a number of questions: How does renewable energy production affect economic growth? How does rural electricity use affect economic development? What is the relationship between greenhouse gas emissions and economic growth? To answer these questions, the study used a number of methods and statistical tools. Important conclusions were drawn through statistical analysis and model estimation processes.

The results of the study showed that renewable energy production has a significant positive impact on economic growth. Expanding access to electricity in rural areas was found to be an important factor in supporting economic development. At the same time, the fact that greenhouse gas emissions did not have a significant impact on economic growth highlights the complexity of the relationship between economics and environmental policy.

This study provides new approaches to policy-making in the energy and economic sectors. In particular, it provides practical assistance in the development and implementation of strategies based on renewable energy sources. The results of the study will contribute to the sustainable development of the economy of Uzbekistan, as well as to solving global environmental problems. Thus, this work is of urgent importance not only at the national but also at the international level.

2. LITERATURE REVIEW

The link between renewable energy and economic growth has attracted the attention of many researchers globally. Research in this area has mainly focused on determining the impact of renewable energy sources on environmental sustainability and economic growth. The existing scientific literature substantiates the important role of renewable energy in the economy.

Investment in renewable energy has been shown to significantly boost economic growth by increasing energy security, creating jobs, and improving energy efficiency. This positive impact is particularly evident in developing countries, where investment in renewable energy is associated with higher GDP growth rates, employment levels, and per capita income (Ali and Zaighum, 2024). Switching to renewable energy sources like solar and wind not only reduces greenhouse gas emissions, but also reduces energy costs, contributing to a more sustainable and resilient economy (Padmanabhuni et al., 2024). Additionally, renewable energy projects support economic opportunities through job creation and rural electrification, which drives inclusive growth in underserved communities (Agbakwuru et al., 2024).

2.1. The Relationship between GDP Growth and Access to Electricity, Rural

The relationship between GDP growth and rural electricity access is a complex and multifaceted topic, and has been widely studied across regions and contexts. The general consensus is that there is a positive relationship between economic growth and increased access to electricity, particularly in rural areas. This relationship is influenced by a variety of factors, including economic policies, demographic characteristics, and existing energy infrastructure.

Economic growth has been shown to have a positive impact on rural electricity access. For example, in the West African Economic and Monetary Union (WAEMU), long-term economic growth significantly increases access to electricity, although this effect is more pronounced in the short term in some countries, such as Benin (Christian, 2022). In China, the Primary Rural Electrification Program led to a 5.3% increase in per capita GDP in pilot counties, demonstrating the economic benefits of rural electrification (Lin and Xu, 2023).

Electrification has significant welfare impacts, as evidenced by research in Bangladesh, where grid electrification increased household incomes by 9-30% and improved educational outcomes (Khandker et al., 2009a). In sub-Saharan Africa, access to electricity is crucial for economic growth, and energy poverty is a significant obstacle to development. Energy consumption in the region has increased by 45% since 2000, highlighting the importance of energy access for economic progress (Singh and Inglesi-Lotz, 2021).

Despite the positive impacts, problems remain, such as the uneven distribution of benefits. In Bangladesh, wealthy households benefit more from electrification than poor ones (Khandker et al., 2009b). The relationship between electricity use and economic growth is not always straightforward. Some studies identify short-term effects that suggest that other factors, such as credit constraints, may limit the benefits of electrification (Chakravorty and Pelli, 2022).

While the positive relationship between GDP growth and rural electricity access is well documented, the broader socio-economic context needs to be considered. Factors such as income inequality, infrastructure quality, and policy interventions play a role in determining the extent of these benefits. Furthermore, the transition to sustainable energy sources presents both opportunities and challenges for rural electrification and economic growth.

2.2. The Relationship between GDP Growth and Renewable Electricity Output

The relationship between GDP growth and renewable electricity generation is complex and varies across regions and economic contexts. Research has shown that renewable energy can positively impact economic growth by reducing greenhouse gas emissions and promoting sustainable development (Saribayevich et al., 2024). However, the strength and nature of this relationship may vary depending on factors such as the level of economic development, the structure of the energy market, and government policies.

Renewable energy consumption in G7 countries has a positive long-term relationship with economic growth, although this relationship is statistically insignificant in some cases (Guliyev, 2023). Renewable energy production in the EU-28 has a positive impact on GDP growth, with biomass energy having the highest impact (Armeanu et al., 2017). For developing countries, renewable electricity generation has a significant positive impact on economic growth in both the short and long term (Azam et al., 2021).

In China, a major consumer of renewable energy, renewable energy consumption has a significant positive impact on economic output, suggesting that increased investment in renewable energy can drive economic growth (Almozaini, 2020). In middle-income Asian countries, there is a trade-off between economic growth and environmental sustainability, suggesting that while renewable energy can support growth, it may require additional policies to improve energy efficiency (Maslyuk and Dharmaratna, 2013).

The renewable growth hypothesis suggests that renewable electricity can Granger cause economic growth, especially in countries with strong renewable manufacturing industries (Yang and Kim, 2020). There is evidence that there is a bidirectional causal relationship between renewable energy and economic growth in high-income countries in the short run and a unidirectional causal relationship from growth to renewable energy in the long run (Doğan et al., 2014).

While the positive relationship between renewable electricity generation and GDP growth is clear in many contexts, the strength and nature of this relationship can vary. Factors such as the level of economic development, energy market structure, and policy frameworks play a crucial role in shaping this dynamic. Furthermore, while renewable energy can stimulate economic growth, potential trade-offs with environmental sustainability need to be considered, especially in developing regions.

2.3. The Relationship between GDP Growth and Total Greenhouse Gas Emissions

The relationship between GDP growth and total greenhouse gas emissions, particularly CO_2, is complex and has been extensively studied across regions and time periods. The general consensus is that economic growth tends to increase CO_2 emissions, although the nature of this relationship can vary considerably depending on the context. This relationship is often analyzed through the lens of the Environmental Kuznets Curve (EKC), which suggests an inverted U-shaped relationship between economic growth and environmental degradation. However, this hypothesis does not hold true everywhere, as various studies have shown (Qodirov et al., 2024).

A number of studies confirm a positive correlation between GDP growth and CO_2 emissions (Xolmurotov et al., 2024). For example, Fu's research using data visualization techniques shows a direct relationship between economic growth and increasing emissions, suggesting that as economies expand, emissions also tend to increase (Fu, 2023). A long-run cointegration relationship has been found between economic growth and CO_2 emissions in the European Union, with a 1% increase in GDP leading to a 0.072% increase in emissions (Onofrei et al., 2022). The BRICS-T countries also show a positive relationship, with a 1% increase in economic growth leading to a 0.79% increase in carbon emissions (Erdoğan et al., 2019).

The EKC hypothesis, which suggests an inverted U-shaped relationship, is supported in some contexts, but not universally. For example, in Latin America and the Caribbean, monotonic positive relationships are observed, which contradicts the EKC hypothesis (Balza et al., 2024). The relationship is more complex in the G-7 countries, with different patterns (M-shaped, N-shaped) observed over a long historical period indicating several turning points in the growth-emissions relationship (Destek et al., 2020).

Some studies suggest that decoupling economic growth from emissions is beneficial, especially at higher income levels, but the evidence remains weak (Schröder and Storm, 2020). The need for effective environmental policies to manage emissions during periods of economic growth has been highlighted, as is evident in the European Union and Asian countries, where policy measures are crucial for sustainable development (Hồ et al., 2024).

While the relationship between GDP growth and greenhouse gas emissions is generally positive, the complexity and variability across regions and time periods highlight the importance of tailored policy interventions. The potential for decoupling growth from emissions remains an important area for further research and policy development. These comments suggest that further analysis of the relationship between renewable energy and economic growth is important, particularly in the context of Uzbekistan. The results of the study can play an important role in shaping the country's green energy policy.

3. METHODOLOGY AND RESULTS

This study uses the data in Table 1, selected for Uzbekistan for the period 2000-2022. The research question is to study the short- and long-term impact of rural electricity use, renewable electricity generation, and total greenhouse gas emissions on GDP growth. Therefore, we have chosen the ARDL model as the most appropriate model to study this process.

It is very important to have complete information about the variables during the analysis, because we can choose statistical tools and research methods based on these results (Fávero and Belfiore, 2019). Descriptive statistics provide us with a summary of the data that offers insights into the distribution, central tendency, and variability of the variables (Table 2).

According to the analysis, GDP_growth: The average annual growth rate is 5.96%. The minimum value is 1.7%, and the maximum value is 9.47%. This indicator reflects a stable pace of economic growth, but the standard deviation (1.98) indicates that there have been significant changes in the economy in some years.

Electricity_Access_Rural: The average coverage of access to electricity is 99.48%. The minimum value is 99.02%, and the maximum value is 100%, which indicates that there is almost full access to electricity.

The standard deviation is very small (0.33), which indicates the stability of this indicator.

Ren_elec_output: The average share of renewable sources in electricity generation is 17.81%. The minimum value is 12.54%, and the maximum value is 22.99%. The standard deviation (3.64) shows the variability of this indicator, which indicates that there are differences in the share of renewable energy over the years.

Total_greenhous_emis (Total greenhouse gas emissions): The average emission volume is 178,331.3 kt CO_2. The minimum value is 150,117.2, and the maximum value is 192,741.5 kt CO_2. The standard deviation (10,499.92) shows that this indicator also varies significantly.

Time series data analysis often begins with testing the stationarity of variables, as stationarity is a key property that affects the validity of many statistical methods used in time series analysis. Stationarity means that statistical properties of a time series, such as the mean and variance, remain constant over time, which is essential for reliable inference and prediction. Therefore, the results of the unit root test of the variables used in the study are presented in Table 3. According to the results of the table, all variables are stationary at the "at Level" level, some variables are stationary, some are not stationary, and at the "First-difference" level, all variables achieve stationarity. This result provides a basis for applying the ARDL model to analyze long-term relationships in time series.

Determining the appropriate lag values for variables is crucial in time series analysis, especially after testing for stationarity (Table 4). Lag selection criteria help determine the optimal number of prior observations to include in the model, which can significantly improve the predictive accuracy and interpretability of the model. Various methods and criteria are used to achieve this, each with its own strengths and limitations. Common criteria for lag selection include the Akaike Information Criterion (AIC), the Schwartz Information Criterion (SIC), and the Hannan-Quinn criterion. These criteria help in choosing the length of the lag by balancing the fit and complexity of the model (Cavaliere et al., 2011).

According to the results of the table, all indicators (AIC, HQIC, SBIC) have a minimum value for lag 4, which is selected as the optimal lag (indicated by the * symbol). The optimal lag of 4 means that enough lags are taken into account for the effective operation of the model.

The correct choice of lags increases the accuracy of the time series model. If the wrong lag is chosen, errors (overspecification or underspecification) may occur in the model (Surakhi et al., 2021).

Table 1: Variables, measurments and sources of data

Variables	Sources of data
GDP growth (annual %)	World Bank, Stat.uz
Access to electricity, rural (% of rural population)	World Bank, Stat.uz
Renewable electricity output (% of total electricity output)	World Bank, Stat.uz
Total greenhouse gas emissions (kt of CO_2 equivalent)	World Bank, Stat.uz

Table 2: Descriptive statistics

Variable	Obs	Mean	Standard deviation	Min	Max
GDP_growth	27	5.9621	1.9752	1.7	9.4730
Electricity_ Access_Rural	27	99.4813	0.3289	99.0158	100
Ren_elec_ output	27	17.8073	3.6381	12.5439	22.9959
Total_ greenhous_ emis	27	178331.3	10499.92	150117.2	192741.5

Table 3: Unit root test results (Intercept)

Variable name	ADF test		PP test	
	At level	First-difference	At level	First-difference
GDP_growth	−1.793 (0.3842)	−5.042 (0.0000)	−12.284 (0.0170)	−34.917 (0.0000)
Electricity_ Access_Rural	−0.722 (0.8409)	−2.706 (0.0429)	−0.645 (0.9222)	−24.526 (0.0000)
Ren_elec_ output	−1.411 (0.5769)	−4.359 (0.0004)	−4.806 (0.4151)	−39.374 (0.0000)
Total_ greenhous_emis	−3.556 (0.0067)	−3.199 (0.0201)	−10.052 (0.0111)	−30.095 (0.0000)

Table 4: Lag-order selection criteria

Lag	LL	LR	FPE	AIC	HQIC	SBIC
0	−338.501		1.0e+08	29.7827	29.8324	27.9802
1	−293.164	90.675	8.1e+06	27.2316	27.4799	28.219
2	−278.713	28.902	1.1e+07	27.3663	27.8133	29.1436
3	−254.312	48.801	7.9e+06	26.6358	27.2815	29.203
4	−217.858	72.909*	3.9e+06*	24.8572*	25.7015*	28.2143*

*Optimal lag, Endogenous: GDP_growth Electricity_Access_Rural Ren_elec_output Total_greenhous_emis

The ARDL model is a powerful tool for analyzing dynamic relationships between variables, especially when there is cointegration. The bound test is very important in this context because it determines the existence of a long-run equilibrium relationship between the variables under study (Table 5). This test is very important because it allows researchers to determine the presence of cointegration without requiring all variables to be integrated in the same order, thereby providing flexibility and robustness in empirical analysis. The bound test, proposed by Pesaran et al., is a widely used method for testing cointegration in ARDL models. It provides a way to test the existence of a long-run relationship between variables, even when they are integrated in different orders (I(0) or I(1))(Natsiopoulos and Tzeremes, 2022).

According to the test results, the F-statistic value is: 8.166. This value is greater than the upper bound, which indicates the presence of a long-term relationship. The t-statistic value is: −5.399. This value is also greater than the upper bound (weaker), which confirms the presence of a long-term relationship. Number of variables: k=3, i.e. there are 3 uncertain variables in the model.

The test results confirm the existence of a long-run relationship, as the F-statistic is above the critical values. This allows us to examine the long-run relationship between economic growth, electricity access, renewable energy share, and greenhouse gas emissions.

Table 6 presents the results of the ARDL (1,2,1,1) regression equation obtained in the study. According to the analysis results, R-squared = 0.7912: The explanatory power of the model is high, that is, 79.12% of the variables explain changes in economic growth. Adj R-squared = 0.6171: It shows that the explanatory power is significant even taking into account the number of model variables. Root MSE = 1.1157: It indicates the amount of average forecast errors of the model, and this value is significantly small.

Long-run relationship (LR). Electricity Access Rural: Coefficient: −6.8151, P < 0.01. Access to electricity has a negative impact on economic growth. This result suggests that energy distribution efficiency or other structural factors play a significant role. Renewable Electricity Output: Coefficient: 0.6080, P < 0.01. The share of renewable energy has a positive impact on economic growth. This result confirms the effectiveness of green energy

Table 5: ARDL bound test results

Bound test statistics		Critical F-values		Critical t-values	
Estimated values	**Critical levels**	**Lower bounds**	**Upper bounds**	**Lower bounds**	**Upper bounds**
	0.010	4.29	5.61	−3.43	−4.37
F-value=8.166	0.025	3.69	4.89	−3.13	−4.05
t-value=−5.399	0.050	3.23	4.35	−2.86	−3.78
k=3	0.100	2.72	3.77	−2.57	−3.46
accept if F <critical value for I (0) regressors					
reject if F >critical value for I (1) regressors					

k: # of non-deterministic regressors in long-run relationship, Critical values from Pesaran/Shin/Smith (2001)

Table 6: ARDL (1,2,1,1) regression results

Sample: 2000	Thru: 2022			Number of obs=23 R-squared=0.7912 Adj R-squared=0.6171	
Log likelihood=−27.672796				Root MSE=1.1157	
D.GDP_growth	**Coefficient**	**Standard error**	**t**	**P>t**	**[95% confidence interval]**
ADJ					
GDP_growth					
L1.	−1.8246	0.3379	−5.40	0.000	−2.561−1.088
LR					
Electricity_Access_Rural	−6.8151	0.7304	−9.33	0.000	−8.4066−5.2236
Ren_elec_output	0.6080	0.0615	9.88	0.000	0.4739 0.7421
Total_greenhous_emis	−0.00004	0.00002	−1.67	0.120	−0.0001 0.00001
SR					
GDP_growth					
LD.	0.6431	0.2521	2.55	0.025	0.0938 1.1923
Ren_elec_output					
D1.	−1.1063	0.2693	−4.11	0.001	−1.6929−0.5196
LD.	−0.7851	0.2210	−3.55	0.004	−1.2667−0.3036
L2D.	−0.7374	0.2283	−3.23	0.007	−1.2348−0.2400
L3D.	−0.3777	0.1624	−2.33	0.038	−0.7316−0.02393
Total_greenhous_emis					
D1.	0.0001	0.0001	2.33	0.036	9.17e-06 0.0002
_cons	1241.33	248.80	4.99	0.000	699.245 1783.42

policies or the importance of energy sector diversification for economic development. Total Greenhouse Emissions: Coefficient: −0.00004, P > 0.05. Greenhouse gas emissions did not have a significant impact on economic growth, indicating that the level of emissions is not directly related to economic activity.

Short-run relationship (SR). GDP Growth (L1): The indicator is positive and significant (P < 0.05), meaning that the economic growth rate in the previous period has a significant impact on the growth rate in the next period. Renewable Electricity Output: There is a positive effect even in the short run (0.0001), which indicates that the introduction of renewable energy contributes rapidly to economic growth. Total Greenhouse Emissions: Although there is a positive effect, the effect size is very small (P < 0.05). This result shows that emissions can be linked to economic activity in the short run.

In general, the positive effect of renewable energy production is consistent with the concept of a "green economy", which supports the principles of energy diversification and sustainable growth. The negative effect of electricity access indicates that attention should be paid to infrastructure and efficiency.

The reliability of the ARDL model can be assessed using several diagnostic tests. These tests are essential to ensure the adequacy and reliability of the model in capturing the underlying data dynamics. These diagnostic tests are Serial Correlation using the Breusch Godfrey (LM test), Heteroscedasticity using the Breusch-Pagan Godfrey/White test, Normality test using the Jarque-Bera test, Functional Form using the Ramsey Reset test, and Specification Error tests.

Table 7 presents the results of the Breusch-Godfrey LM test. The purpose of this test is to detect autocorrelation, that is, the interdependence between the residual series of the model (Rois et al., 2012). In this case, the H0 hypothesis: There is no autocorrelation, while the Alternative hypothesis is that there is autocorrelation. According to the results of the analysis, the Chi-square statistic (Chi-square): 0.099. The probability value (Prob > Chi-square): 0.7535. This value is higher than the 5% level, which means that there is no reason to reject the H0 hypothesis. So, there is no autocorrelation in the model. This means that there is no significant relationship between the residual errors and the model is working well.

The study also presents the results of the Durbin-Watson d-statistic. This test is used to detect autocorrelation, especially first-order autocorrelation (Albertson et al., 2002). Durbin–Watson d-statistic(11, 23) = 1.73175. According to the analysis results, the Durbin–Watson d-statistic is: 1.73175. If the Durbin–Watson value is close to 2, then autocorrelation is considered to be absent. Since the values of this result are in the range of 1.5–2.5, the absence of autocorrelation is confirmed. There is no autocorrelation in the residual errors of the model. This confirms the reliability of the results obtained in estimating the model parameters. This confirms that the variables in the model are consistent with the time series and that the residual errors are free from correlation, which indicates the stability of the estimation results and their suitability for economic analysis.

Table 8 presents the results of the Breusch-Pagan/Cook-Weisberg test for heteroskedasticity. This test is used to check for heteroskedasticity, that is, whether the variance of the residual errors is constant (constant variance) independent of the variables (Halunga et al., 2017). The presence of heteroscedasticity: This can compromise the effectiveness and reliability of the model estimation results. Here, H_0 (null hypothesis): The variance of the residual errors does not change, that is, there is homoscedasticity. H_1 (alternative hypothesis): The variance of the residual errors changes, that is, there is heteroscedasticity.

According to the analysis results, the Chi-square statistic (Chi-square): 0.40. Probability value (Prob > Chi-square): 0.5271. Since this value is greater than the usual 5% level (0.05), the null hypothesis (H_0) cannot be rejected. This means that the variance of the residual errors is independent of the variables and is stable. The model estimation results are reliable, and the variability of the residual errors during the analysis does not negatively affect the results.

The Table 9 shows the results of White's test. The White test is used to test for heteroscedasticity, that is, whether the variance of the residual errors is stable across variables. White's test is effective in detecting heteroscedasticity in a variety of regression models, including models with high-dimensional covariates. This is particularly emphasized by its robustness in scenarios where the number of covariates exceeds the sample size, as demonstrated in the context of high-dimensional linear regression (Shinkyu, 2023). In a comparative study, White's test was found to perform well alongside the Harrison-McCabe test in detecting heteroscedasticity in multiple linear regression models, especially for samples with fewer than 50 samples (Clement Onifade and Olanrewaju, 2020). The performance of the test can be affected by the presence of outliers. Research has shown that after removing outliers,

Table 7: Breusch-Godfrey LM test for autocorrelation

lags (p)	Chi-square	df	Prob >Chi-square
1	0.099	1	0.7535

H_0: No serial correlation

Table 8: Breusch–Pagan/Cook–Weisberg test for heteroskedasticity

Assumption: Normal error terms
Variable: Fitted values of D.GDP_growth
H0: Constant variance
Chi-square (1)=0.40
Prob>Chi-square=0.5271

Table 9: White's test results

H_0: Homoskedasticity
H_a: Unrestricted heteroskedasticity
Chi-square (9) = 4.99
Prob>Chi-square=0.8349
Cameron and Trivedi's decomposition of IM-test

Source	Chi-square	df	P-value
Heteroskedasticity	4.99	9	0.8349
Skewness	6.37	3	0.0951
Kurtosis	3.53	1	0.0603
Total	14.89	13	0.3145

White's test retains well-bounded sampling properties under symmetric error distributions, but may suffer from dimensionality distortions under asymmetric errors (Rico and Wilms, 2018). Unlike the Breusch-Pagan test, this test can also detect nonlinear heteroskedasticity. Here, H_0 (null hypothesis): Homoskedasticity exists (residual variance is constant). H_1 (alternative hypothesis): Heteroskedasticity exists (residual variance changes). Chi-square statistic: 4.99. Prob > Chi-square: 0.8349. This probability value is >5% (0.05) level, meaning that the H_0 hypothesis cannot be rejected. According to the test results, the residual error variance is constant and there is no heteroskedasticity. Cameron and Trivedi's decomposition: Heteroskedasticity: Chi-square = 4.99, P = 0.8349. Confirms the stability of the residual variance. Skewness: Chi-square = 6.37, P = 0.0951. This value indicates that the residual errors are close to a symmetric distribution. Kurtosis: Chi-square = 3.53, P = 0.0603. This result indicates that the residual errors are relatively close to a normal distribution. Total IM-test: Chi-square = 14.89, P = 0.3145. This indicator confirms that the residual errors are free from general structural distortion.

Overall, the White test results confirm the absence of heteroscedasticity and the stable distribution of residual errors. The model is shown to be statistically and economically robust.

In addition, the Jarque-Bera normality test results were also obtained to check the significance of the model. The Jarque-Bera (JB) test is a widely used statistical tool for assessing the normality of regression residuals. It tests the skewness and kurtosis of the residuals to see if they follow a normal distribution (Jarque and Bera, 1987). The test is especially important in linear regression models, where the assumption of normally distributed residuals is crucial for making reliable statistical inferences (Upendra et al., 2023). Importance of normal distribution: A normal distribution of residual errors is necessary to test statistical hypotheses and ensure the reliability of the model. Here, H_0 (null hypothesis): Residual errors have a normal distribution. H1 (alternative hypothesis): Residual errors do not have a normal distribution. According to the results, Chi-square statistic: 3.884. Prob > Chi-square: 0.1434. Since the probability value is >5% (0.05) level, the null hypothesis (H_0) cannot be rejected. This means that residual errors have a normal distribution.

Table 10 presents the results of the Ramsey RESET test for omitted variables. The Ramsey RESET test is a diagnostic tool used to detect omitted variables in regression models by assessing the functional form specification. It operates on the premise that the model is likely to be misfit if nonlinear combinations of explanatory variables can explain the dependent variable. This test is particularly sensitive to the degree of nonlinearity between the dependent and independent variables, which can significantly affect its power and efficiency in detecting omitted variables (Christodoulou-Volos and Tserkezos, 2023). This test assesses the accuracy of the model and whether its specification is correct (Leung and Yu, 2000). Hypotheses: H_0 (null hypothesis): There is no omitted variable in the model. H1 (alternative hypothesis): There is an omitted variable in the model. According to the results of the analysis, the F-statistic: 0.81. Prob > F: 0.5027. Since this probability value is greater than the usual 5% (0.05) level, the null hypothesis (H_0) cannot be rejected.

Table 10: Ramsey RESET test for omitted variables

Omitted: Powers of fitted values of GDP_growth
H_0: Model has no omitted variables
F (3, 20)=0.81
Prob>F = 0.5027

According to the test results, there are no significant omitted variables in the model. This result indicates that the variables used in the model are selected correctly, and additional omitted factors do not significantly affect the results.

4. CONCLUSIONS

This study analyzed the short- and long-run relationships between Uzbekistan's economic growth, renewable energy use, rural electricity use, and greenhouse gas emissions over the period 2000-2022. The study was conducted using the ARDL model and yielded several important results. Long-run relationship: Renewable energy production has a positive impact on economic growth, which indicates that green energy policies have a place in the economy. Greenhouse gas emissions did not significantly affect economic growth. Access to electricity: Rural electricity use has a negative impact on economic growth. This result indicates the need to address issues in infrastructure efficiency and the energy distribution system. Model fit and diagnostics: The analyzed diagnostic tests (autocorrelation, heteroscedasticity, normal distribution and functional fit test) confirmed the statistical reliability and suitability of the model.

Short-term correlation: Renewable energy production also makes a positive contribution to short-term growth, which indicates the economic efficiency of developing this sector.

Using the results obtained in the analysis, we can make the following recommendations. Develop a green energy strategy: To increase renewable energy production, it is necessary to attract public investments and the private sector. Expanding infrastructure based on sustainable energy sources can have a positive impact on economic growth. Improve energy efficiency: Infrastructure should be modernized to improve electricity use and increase efficiency. It is advisable to reduce negative economic impacts by optimizing access to electricity for the rural population. Reduce greenhouse gas emissions: To reduce emissions, it is necessary to accelerate the transition to alternative energy sources and strengthen environmental protection policies. Innovative technologies should be introduced to reduce the impact of greenhouse gas emissions on economic activity. Support scientific research: Scientific research and the database should be expanded to better understand the relationship between energy and economic growth. An evidence-based approach to decision-making in the energy sector should be developed. Strengthen regional policy: Efficiency can be achieved by differentiating economic strategies related to the share of electricity and renewable energy at the regional level. In particular, special programs should be developed to increase energy efficiency in rural areas. The results of the study are important for policymaking, in particular for the development of green energy policies and improving the energy distribution system. These recommendations will help ensure sustainable growth in Uzbekistan's economic development and support the country in its transition to an environmentally sustainable economy.

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