“The impact of renewable energy consumption on export performance in Uzbekistan: A vector autoregression approach”

AUTHORS	Arslonbek Nurjanov Fozil Xolmurotov Ergash Ibadullaev Jasurbek Ataniyazov Manzura Masharipova Feruza Yusupova Xolilla Xolmuratov

ARTICLE INFO	Arslonbek Nurjanov, Fozil Xolmurotov, Ergash Ibadullaev, Jasurbek Ataniyazov, Manzura Masharipova, Feruza Yusupova and Xolilla Xolmuratov (2025). The impact of renewable energy consumption on export performance in Uzbekistan: A vector autoregression approach. *Environmental Economics*, *16*(2), 186-198. doi:10.21511/ee.16(2).2025.14
DOI	http://dx.doi.org/10.21511/ee.16(2).2025.14
RELEASED ON	Tuesday, 01 July 2025
RECEIVED ON	Monday, 24 March 2025
ACCEPTED ON	Friday, 13 June 2025
LICENSE	This work is licensed under a Creative Commons Attribution 4.0 International License
JOURNAL	"Environmental Economics"
ISSN PRINT	1998-6041
ISSN ONLINE	1998-605X
PUBLISHER	LLC “Consulting Publishing Company “Business Perspectives”
FOUNDER	LLC “Consulting Publishing Company “Business Perspectives”

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
36	0	7

BUSINESS PERSPECTIVES

LLC "CPC "Business Perspectives"
Hryhorii Skovoroda lane, 10,
Sumy, 40022, Ukraine
www.businessperspectives.org

Arslonbek Nurjanov (Uzbekistan), **Fozil Xolmurotov** (Uzbekistan), **Ergash Ibadullaev** (Uzbekistan) **Jasurbek Ataniyazov** (Uzbekistan), **Manzura Masharipova** (Uzbekistan), **Feruza Yusupova** (Uzbekistan), **Xolilla Xolmuratov** (Uzbekistan)

THE IMPACT OF RENEWABLE ENERGY CONSUMPTION ON EXPORT PERFORMANCE IN UZBEKISTAN: A VECTOR AUTOREGRESSION APPROACH

Abstract

The paper deals with the growing importance of understanding energy consumption patterns and their relationship with export performance in developing economies. The study aims to analyze the bidirectional relationship between commodity exports and energy consumption in Uzbekistan from 1992 to 2023. A vector autoregression (VAR) model is employed as the primary methodology, incorporating four main variables: commodity exports, GDP per capita, renewable energy consumption, and renewable electricity generation. Unit root tests (ADF and PP) were conducted, revealing that all variables are stationary in their first differences, which necessitated cointegration analysis. The Johansen test results confirm the existence of a single long-run cointegration vector among the variables. Granger causality tests identify a bidirectional causal relationship between GDP per capita and exports, with changes in GDP per capita having a significant impact on exports ($p < 0.001$) and vice versa. The results demonstrate that renewable electricity has a positive effect on exports (coefficient = 0.055, $p = 0.01$), while GDP per capita shows a negative effect on exports (coefficient = –0.0002, p = 0.039). Additionally, VAR analysis reveals that past values of exports significantly influence current export levels, with a lagged coefficient of 0.883 ($p < 0.05$). These findings have practical implications for policymakers in Uzbekistan seeking to balance economic growth objectives with sustainable energy development strategies.

Keywords GDP, VAR, energy consumption, export, CO2 emissions, renewable energy

JEL Classification C32, Q43

Received on: 24th of March, 2025
Accepted on: 13th of June, 2025
Published on: 1st of July, 2025

Arslonbek Nurjanov, Researcher, Founder of Mamun University, Mamun University, Uzbekistan.

Fozil Xolmurotov, Ph.D., Department of Economics, Faculty of Economics, Mamun University, Uzbekistan. (Corresponding author)

Ergash Ibadullaev, Ph.D., Faculty of Economics, Mamun University, Uzbekistan.

Jasurbek Ataniyazov, DSc., Professor, Department of International Finance, Faculty of Finance, Tashkent State University of Economics, Uzbekistan.

Manzura Masharipova, Ph.D., Department of Economics, Faculty of Economics, Mamun University, Uzbekistan.

Feruza Yusupova, Ph.D., Department of Accounting and Business Administration, Faculty of Economics, Mamun University, Uzbekistan.

Xolilla Xolmuratov, Ph.D., Department of Electrical Engineering and Energy, Urgench State University, Uzbekistan.

Conflict of interest statement:
Author(s) reported no conflict of interest

INTRODUCTION

Energy security and export growth are critical factors for developing economies seeking sustainable economic development. In recent years, the relationship between renewable energy adoption and export performance has become increasingly important as countries aim to balance economic growth with environmental sustainability. This interrelationship is particularly significant for transition economies like Uzbekistan, which are working to strengthen their position in global markets while addressing energy challenges.

The relationship between renewable energy consumption and export performance in Uzbekistan remains understudied despite its importance for the country's economic development and export competitiveness. The country faces considerable energy system challenges related to stability, security, and affordability, intensified by rapid population growth and increasing urbanization. These factors place additional pressure on existing energy infrastructure and highlight the need for sustainable energy solutions that support economic development.

http://dx.doi.org/10.21511/ee.16(2).2025.14

As global markets increasingly prioritize sustainable production and trade, understanding how the adoption of renewable energy affects export competitiveness becomes crucial for strategic economic planning. Uzbekistan's heavy reliance on fossil fuels, particularly natural gas, has implications for both economic sustainability and environmental impact. However, the country has prioritized economic development and efficient energy resource utilization as strategic national goals in recent years.

The export sector plays a vital role in Uzbekistan's economy, significantly contributing to GDP and economic growth. Market liberalization policies implemented since 2017 have transformed the country's trade environment, creating new opportunities and challenges for exporters. Understanding how energy consumption patterns, particularly renewable energy adoption, influence export competitiveness has become essential for developing effective economic policies.

1. LITERATURE REVIEW

Research on the relationship between renewable energy and export performance has evolved along three main trajectories: energy efficiency and export competitiveness, bidirectional relationships between GDP and exports, and the interplay between renewable energy technologies and international trade. This literature review synthesizes existing knowledge across these domains to identify patterns, contradictions, and research gaps.

The impact of renewable energy adoption on export performance varies across economic contexts and energy types. Alhashim et al. (2024) demonstrated that renewable energy consumption positively influences economic growth in emerging E-7 economies (Brazil, China, Indonesia, India, Mexico, Russia, and Turkey) by supporting an endogenous growth model alongside technological innovation and export diversification. Similarly, Fajdetić and Festić (2024) established a positive relationship between renewable energy sources and economic growth in the European Union, showing that sustainable development can be achieved by integrating environmental components into economic strategies.

Energy autonomy through renewable sources can shield economies from external energy price fluctuations. Bozhanova et al. (2023) highlighted how countries such as Iceland and Uruguay achieved energy independence through renewable sources, enhancing their economic stability and export potential. This finding is particularly relevant for resource-dependent transition economies seeking to reduce external vulnerabilities.

The relationship between energy efficiency and exports appears to be mutually reinforcing in many contexts. Ahmed and Elfaki (2024) found that energy efficiency is positively associated with both environmental quality and economic growth in Asian economies, suggesting that implementing energy efficiency measures can enhance export-oriented growth while improving environmental outcomes. Ullah et al. (2024) demonstrated that energy use, including renewable energy, plays a crucial role in increasing the complexity of exports in OECD member countries. However, the use of renewable energy has a less pronounced impact on export sophistication than non-renewable energy.

The relationship between exports and GDP per capita represents a complex interaction that influences both energy consumption patterns and export performance. Saribayevich et al. (2024) identified varying relationships between these factors across different economic contexts, noting that their interactions are often influenced by development levels, trade policies, and external economic conditions.

Several studies have found strong positive correlations between exports and GDP growth. Ram (1987) identified a 99% correlation between GDP per capita and exports in Macedonia, indicating exports' significant impact on economic growth. Cross-country analyses by Burney (1996) confirmed that exports contribute positively to economic growth, though with varying intensity depending on time periods and methodological approaches.

The causal relationship between exports and GDP growth remains a topic of debate in the literature. Odhiambo (2022) suggested bidirectional causality where exports and GDP growth mutually reinforce each other in middle-income countries, while Temple and Wößmann (2006) found that the relationship may be unidirectional, with exports leading to GDP growth in some countries and vice versa in others. This variability underscores the context-specific nature of these relationships, which is particularly relevant for transition economies like Uzbekistan.

The stage of economic development appears to mediate the export-GDP relationship. Ram (1985) found stronger positive relationships between export growth and GDP growth in countries with higher GDP per capita, suggesting that export-led growth benefits may be more favorable for countries that have reached a minimum development threshold. This finding is reinforced by Odhiambo (2022), who observed that while middle-income countries in sub-Saharan Africa show bidirectional causality, low-income countries demonstrate neutrality, indicating that export-led growth strategies may not be universally effective.

Several mechanisms link exports to GDP growth, including increased import capacity, concentrated investment in productive sectors, and productivity improvements through economies of scale (Emery, 1967). Additionally, exports can attract foreign investment and technology, further stimulating economic growth and potentially enhancing energy efficiency (Qodirov et al., 2024).

The theoretical framing of the export-GDP relationship varies across economic paradigms. Neoclassical theories emphasize the positive impact of exports on resource allocation and economic performance, while Marxist perspectives may view trade as potentially exploitative (Ram, 1985). Xolmurotov et al. (2024) and Yulduz et al. (2025) note that while the positive relationship between exports and GDP per capita is well-established, its context-specific nature requires careful consideration of development levels, regional characteristics, and external economic conditions.

The shift toward renewable energy consumption has significant implications for international trade, particularly commodity exports. This relationship encompasses economic, environmental, and political dimensions that vary across regional and economic contexts.

Increased renewable energy consumption can enhance export potential by reducing energy costs and improving energy security. Güneş et al. (2022) found that in OECD countries, the transition to renewable energy correlates with increased exports and reduced imports, improving trade balances. Amaliyah et al. (2022) demonstrated that renewable energy consumption in Indonesia stimulates both imports and exports, highlighting international trade's role in promoting renewable energy adoption. Similarly, Sebri (2015) found that across 69 countries, renewable energy consumption had a unidirectional causal effect on trade in the short run.

Long-term relationships between renewable energy consumption, economic growth, and trade have been established in multiple contexts. Wang et al. (2023) found that across 122 countries, renewable energy consumption stimulates economic growth while limiting carbon emissions, thereby contributing to sustainable development. Kao and Chiang (2001) demonstrated that international trade facilitates technology transfer and capacity building required for scaling renewable energy production and consumption.

Regional variations in the impact of renewable energy consumption on exports show considerable differences across countries. Research indicates that while renewable energy consumption and trade openness tend to reduce carbon emissions in developed nations, the relationship proves more complex in developing countries, where these factors can sometimes contribute to increased emissions rather than reductions. The differing outcomes between developed and developing countries likely reflect variations in industrial structure, technological capacity, and the nature of export industries. Developed countries may be better positioned to leverage renewable energy for cleaner production processes, while developing nations might face challenges in effectively integrating renewable sources into their export-oriented manufacturing sectors. Senarathne and Jayasinghe (2021) advised policymakers to promote trade openness and renewable energy consumption as complementary strategies to enhance economic growth and environmental sustainability.

The relationship between commodity exports and renewable electricity generation involves complex

http://dx.doi.org/10.21511/ee.16(2).2025.14

economic, environmental, and technological factors. Ziesemer (2019) found that increased renewable electricity production led to increased imports and reduced electricity exports, potentially affecting trade supply fluctuations. The sensitivity of exports to renewable energy sources varies by region and energy type, as demonstrated by Narayan and Nguyen (2019), who found that in Vietnam, exports were more responsive to renewable energy sources like hydropower than to fossil fuels.

The renewable energy-trade relationship also influences economic growth. Almajali et al. (2024) found positive associations between renewable energy use, trade openness, and economic growth in South Asia, although with ambiguous environmental benefits. Similarly, Apergis et al. (2018) demonstrated the positive impacts of renewable energy consumption and trade on economic output in Africa, highlighting trade's role in technology transfer.

A country's trade openness can influence renewable energy technology development. Zvarych et al. (2024) found that countries more open to international trade are more likely to adopt renewable technologies, increasing their climate resilience and export opportunities. Strong renewable energy policies can provide comparative export advantages, as demonstrated by Groba (2011), who found that countries with strong environmental standards capitalized on growing markets for renewable energy technologies.

Investment in renewable energy infrastructure proves crucial for boosting export performance. Almajali et al. (2024) showed that renewable energy availability can reduce dependence on imported fossil fuels, improving trade balances. However, Yu et al. (2023) noted that the environmental benefits of renewable energy are not always immediately apparent, as CO_2 emissions and economic growth relationships vary regionally.

Previous studies on renewable energy and export relationships have primarily focused on developed economies or broad cross-country analyses, with limited attention to transition economies like Uzbekistan. The specific mechanisms through which renewable energy adoption affects export performance in post-Soviet economies remain understudied despite their unique energy infrastructure legacies and ongoing market reforms. Additionally, the bidirectional relationship between renewable energy consumption and exports in the context of Uzbekistan's economic liberalization has not been thoroughly examined.

This study addresses these gaps by investigating the specific dynamics between renewable energy consumption, GDP per capita, and export performance in Uzbekistan during a critical period of economic transition. By employing a vector autoregression approach, it seeks to identify both short-term dynamics and long-term relationships between these variables, providing empirical evidence to inform integrated energy and trade policies for sustainable economic development in Uzbekistan and similar transition economies.

2. METHODOLOGY

The VAR (vector autoregression) model is widely used to study the correlation between time series (Hou et al., 2023). One of the main reasons for choosing a VAR model in this study is to identify the bidirectional relationship between exports and energy consumption (Ibrahiem, 2018). VAR model provides a systematic approach in which each variable depends on its own and other variables' lags. It is an important tool for identifying endogenous variables and is suitable for understanding complex economic systems. The model is effective in analyzing the causal relationships between energy consumption and exports, as it allows the use of advanced analysis techniques such as Granger causality and cointegration (Acheampong et al., 2021).

The VAR model is expressed as follows:

$$Y_t = A_1 Y_{t-1} + A_2 Y_{t-2} + \ldots + A_p Y_{t-p} + \varepsilon_t, \quad (1)$$

where Y_t is a vector of variables of size k' 1 (in the case of this study, exports, gross domestic product, renewable energy consumption and electricity production). $A_1, A_2, \ldots, A_p$: k' k coefficient matrices of each delay. ε_t: is the error term, i.e., it represents the unobserved factors of the variables, and it is assumed that $\varepsilon_t \sim N(0, \Sigma)$. p: number of lags, lag order, which is determined through statistical tests (for example, using AIC and SC criteria).

The study describes the model as follows:

$$Y_t = \begin{bmatrix} \ln(Ln(Merchandise\,exports_t), \\ GDP\ per\ capita_t, \\ Renewable\,energy\,consumption_t, \\ Renewable\,electricity\,output_t) \end{bmatrix}, \quad (2)$$

where Y_t – is a 4x1 vector containing variables at time *t*. ln(*Ln(Merchandise exports*$_t$) – Natural logarithm of merchandise exports (in current US dollars). *GDP per capita*$_t$ – Gross domestic product per capita (in current US dollars). *Renewable energy consumption*$_t$ – Renewable energy consumption (share in total final energy consumption, %). *Renewable electricity output*$_t$ – Renewable electricity generation (share in total electricity generation, %).

The variables used in the study are listed in Table 1; the research period is from 1992 to 2023.

3. RESULTS

The unit root test is important in the application of the VAR model. The main reason for the test is to determine the stationarity of the variables (McLeod et al., 2012). If the stationarity conditions are not met, this can lead to a number of problems. The VAR model can produce incorrect results on non-stationary data, which can lead to unreliable parameters in the model (Chang & Shi, 2024). If the variables are not stationary, it is necessary to analyze the presence of cointegration (long-term dependence) between them (Stern, 2016). This, in turn, requires necessary adjustments before being included in the VAR model. In econometric modeling, time series are usually not inherently stationary. Therefore, it is necessary to first determine their stationarity. Two main methods are used in the Unit Root Test (Halmuratov et al., 2025). ADF (Augmented Dickey-Fuller) test adds lags to ensure that the residual noise of the variable is not autocorrelated. PP (Phillips-Perron) test adjusts the residual noise for autocorrelation and heteroskedasticity.

Table 2 presents the results of the ADF and PP tests for all variables (exports, GDP, renewable energy consumption, and electricity production). According to the analysis, the *p*-values (probability values) of the ADF and PP tests at the level of the variables are greater than 0.05. This means that the variables are not stationary at their level (the null hypothesis cannot be rejected) (Vijay, 2025). After the first-order differentiation of the variables, the results of the ADF and PP tests (*p*-values) are less than 0.05, indicating that all variables are stationary in the first difference (the null hypothesis is rejected). All variables are found to be stationary in the first difference, that is, they have an I(1) process.

Table 1. Variables, measurements, and sources of data

Variables	Symbol	Sources of Data
Merchandise exports (current USD)	Ln(Merchandise exports)	World Bank and Stat.uz databases
GDP per capita (current USD)	GDP per capita	World Bank and Stat.uz databases
Renewable energy consumption (% of total final energy consumption)	Renewable energy consumption	World Bank and Stat.uz databases
Renewable electricity output (% of total electricity output)	Renewable electricity output	World Bank and Stat.uz databases

Table 2. Unit root test results (Intercept)

Variable name	ADF test		PP test	
	at Level	first-difference	at Level	first-difference
Ln(Merchandise exports)	–0.343	–3.085	–0.216	–21.251
	(0.9192)	(0.0277)	(0.9453)	(0.0036)
GDP per capita	–0.916	–2.887	–0.907	–16.513
	(0.7826)	(0.0468)	(0.8979)	(0.0222)
Renewable energy consumption	–1.914	–3.784	–15.174	–39.390
	(0.3255)	(0.0031)	(0.131)	(0.0000)
Renewable electricity output	–1.619	–4.822	–5.237	–49.905
	(0.4730)	(0.0000)	(0.3262)	(0.0000)

http://dx.doi.org/10.21511/ee.16(2).2025.14

The presence of I(1) of the variables requires cointegration analysis. Therefore, to increase the reliability of the results of the VAR model, a cointegration test is used (listed in Table 4).

The stationarity test results indicate that all variables exhibit non-stationary behavior at their levels, suggesting the presence of trends or structural changes over the study period. This finding is typical for macroeconomic time series and reflects Uzbekistan's economic transformation since independence. The fact that all variables become stationary after first differencing confirms they are integrated of order one I(1), which is consistent with economic growth processes and structural changes in a transition economy.

Lag criteria test is important in VAR model analysis. If the number of lags is chosen incorrectly, the model will read with too many or too few parameters. The number of lags plays a key role in determining the degree of time lag of the relationship. If the correct number of lags is not chosen, autocorrelation of residual noises may occur in the model.

Table 3 shows that lag 2 was selected as the optimal option according to the most reliable criteria for lag selection (FPE, AIC, HQ). This choice helps to correctly assess the relationship between exports and energy consumption when building the VAR model. Thus, the VAR model is built using lag 2 in the subsequent stages, and this lag value is the main one throughout the analysis.

The selection of lag 2 suggests that economic adjustments in Uzbekistan's export-energy nexus take approximately 2 years to materialize. This time frame aligns with typical policy implementation periods and the time needed for energy infrastructure investments to impact export competitiveness.

For a VAR model, the cointegration test is important in determining the long-run relationship between variables. Even if the variables are correlated, they may maintain their direction over time. The Johansen test confirms such a long-run relationship.

According to the analysis results, the trace statistic for level 0 (59.1069) is greater than the critical value at the 5% (47.21) and 1% (54.46) significance levels. This means that the study rejects the null hypothesis that there are at most 0 cointegration vectors. The trace statistic for level 1 (23.8949) is less than the critical value at the 5% (29.68) and 1% (35.65) significance levels. This means that the study cannot reject the null hypothesis that there are at most 1 cointegration vector. Thus, there is a single cointegration vector between the time series.

The existence of one cointegration vector confirms a stable long-run equilibrium relationship between exports, GDP, renewable energy consumption, and electricity generation. This suggests that despite short-term fluctuations, these variables move together over time, indicating structural economic linkages in Uzbekistan's economy.

Granger causality tests are used to determine whether one-time series is useful in predicting another (Table 5) or, in simple terms, whether changes in one variable (the "cause") precede or influence changes in another variable (the "effect").

Table 3. Lag criteria test

VAR Lag Order Selection Criteria						
Lag	**LogL**	**LR**	**FPE**	**AIC**	**SC**	**HQ**
0	–327.874	NA	47,739.9	6.6401	6.9281	6.7257
1	–250.069	155.61	784.981	–5.1668	–3.1511*	–4.5674
2	–227.829	44.48	551.847*	–5.8615*	–2.1180	–4.7484*

Note: * indicates the optimal lag order selected by the corresponding criterion.

Table 4. Johansen cointegration test

Rank	Maximum	Critical value		Trace statistics	Critical value	
		5%	1%		5%	1%
0	35.2121	27.07	32.24	59.1069	47.21	54.46
1	19.2058	20.97	25.52	23.8949	29.68	35.65

Table 5. Granger causality Wald tests

Equation	Excluded	chi2	df	Prob>chi2
ln_Merch_export	GDP_per_cap	4.2669	1	0.039
ln_Merch_export	Ren_ener_cons	.00042	1	0.984
ln_Merch_export	Ren_elec_output	6.5613	1	0.010
ln_Merch_export	ALL	10.065	3	0.018
GDP_per_cap	ln_Merch_export	22.829	1	0.000
GDP_per_cap	Ren_ener_cons	3.1338	1	0.077
GDP_per_cap	Ren_elec_output	.8580	1	0.354
GDP_per_cap	ALL	72.19	3	0.000
Ren_ener_cons	ln_Merch_export	0.5317	1	0.818
Ren_ener_cons	GDP_per_cap	5.1157	1	0.024
Ren_ener_cons	Ren_elec_output	66.885	1	0.413
Ren_ener_cons	ALL	8.1342	3	0.043
Ren_elec_output	ln_Merch_export	.0074	1	0.931
Ren_elec_output	GDP_per_cap	2.3191	1	0.128
Ren_elec_output	Ren_ener_cons	8.4246	1	0.004
Ren_elec_output	ALL	10.951	3	0.012

The analysis shows that GDP per capita causes exports of goods. In other words, changes in GDP per capita precede and affect changes in exports of goods. GDP per capita ~ Exports of goods: The p-value is 0.000, which is much smaller than 0.05. This shows strong evidence that exports of goods Granger cause GDP per capita. Energy deficit ~ Electricity generation: The p-value is 0.413, which is larger than 0.05. This shows that there is no evidence of Granger causality between renewable energy consumption and renewable electricity generation.

In general, GDP per capita has a significant impact on merchandise exports, and merchandise exports also affect GDP per capita. Renewable energy consumption and renewable electricity generation do not have a strong causal relationship.

The bidirectional causality between GDP per capita and exports reflects a mutually reinforcing relationship where economic growth enhances export capacity while export earnings contribute to economic development. The significant impact of renewable electricity on exports suggests that sustainable energy infrastructure enhances export competitiveness.

The results of the vector autoregression (VAR) analysis are summarized in Table 6. This analysis was conducted to assess the relationships between the selected variables. The results are as follows. The second lag in merchandise exports has a statistically significant and positive effect on the current level of exports (coefficient = 0.8829975, z = 5.61, $P < 0.05$). This result indicates that the increase in export volumes in previous periods has a positive effect on exports in the current period due to steady growth or inertia in export activity. The second lag in GDP per capita has a statistically significant negative effect on exports (coefficient = –0.0002031, P = 0.039). This suggests that higher GDP per capita in earlier periods may indirectly reduce export performance, possibly due to changes in domestic consumption patterns or a decrease in the focus on export-oriented production. The second lag of renewable electricity generation has a positive effect on exports (coefficient = 0.0556693, P = 0.01). This suggests that higher renewable electricity generation in earlier periods may increase export competitiveness, possibly by reducing energy costs or supporting sustainable production practices.

The second lag in merchandise exports has a significant positive effect on GDP per capita (coefficient = 714.1001, P = 0.000). This indicates that in previous periods, higher export earnings and increased economic activity significantly contributed to economic growth. The second lag in GDP per capita also has a significant positive effect on current GDP (coefficient = 0.390193, P = 0.000). This reflects the steady growth of GDP over time, where past economic performance continues to influence current economic performance. The second lag in GDP per capita has a statistically significant positive effect on renewable energy consumption (coefficient = 0.0003466, P = 0.024). This suggests that economic growth in previous periods has encouraged the use of renewable energy, potentially due to increased investment in green technologies or energy efficiency. The second lag of renewable energy consumption has a statistically significant negative effect on renewable electricity generation (coefficient = –3.502299, P = 0.004). This finding may indicate inefficiencies or reduced returns in renewable energy systems over time. The second lag of renewable electricity generation itself has a positive effect on current generation (coefficient = 0.6059949, P = 0.001). This suggests the sustainability of renewable energy generation over time due to the stability and reliability of renewable energy infrastructure.

http://dx.doi.org/10.21511/ee.16(2).2025.14

The coefficient of determination (*R*-squared) for each equation shows how well the model explains the variation in the dependent variables: Exports of goods: *R*-squared = 0.8929 (89.29% of the variation explained). GDP per capita: *R*-squared = 0.9360 (93.6% of the variation explained). Renewable energy consumption explains 41.31% of the variation. Renewable electricity generation: *R*-squared = 0.7431 (74.31% of the variation explained). The Chi-squared values for each equation confirm the overall statistical significance of the models ($P < 0.05$), making the VAR results reliable for interpreting the relationships between the variables.

The analysis reveals an important bidirectional relationship. Exports have a positive impact on GDP per capita, while GDP per capita also affects export performance. This highlights a mutually reinforcing dynamic between economic growth and trade. Renewable energy consumption and electricity generation have a significant impact on GDP and exports, highlighting the role of sustainable energy infrastructure in enhancing economic growth and export competitiveness.

The inclusion of lagged variables captures the dynamic relationships between these variables and allows one to understand how past values affect current outcomes. This dynamic framework helps to identify causal relationships and feedback loops that are important for policymaking and economic planning. Overall, the VAR model effectively captures the relationships between exports, GDP per capita, renewable energy consumption, and renewable electricity generation. These findings highlight the importance of promoting renewable energy development and increasing export performance to ensure sustainable economic growth.

The positive coefficient for lagged exports (0.883) indicates strong persistence in export performance, suggesting that established trade relationships and market positions create momentum. The negative coefficient for GDP per capita (–0.0002) may reflect the "resource curse" phenomenon where domestic consumption competes with export production as income rises. The positive impact of renewable electricity (0.056) demonstrates that sustainable energy infrastructure enhances export competitiveness.

Table 7 tests residual autocorrelation in the VAR model. The purpose of this test is to determine whether there is autocorrelation between the resid-

Table 6. Vector autoregression results

Sample: 1992 thru 2023			Number of obs			32
Log likelihood		–277.7227	AIC			18.60767
FPE		1431.511	HQIC			18.91133
det(sigma_ml)		405.9221	SBIC			19.52375
Equation		**Parms**	**RMSE**	**R-sq**	**chi2**	**P > chi2**
ln_Merch_export		5	.236476	0.8929	266.8362	0.0000
GDP_per_cap		5	224.448	0.9360	467.768	0.0000
Ren_ener_cons		5	.368517	0.4131	18.664	0.0401
Ren_elec_output		5	1.96427	0.7431	92.554	0.0000
Coefficient		**Std.err.**	**z**	**P > |z|**	**[95% conf. interval]**	
			ln_Merch_export			
ln_Merch_export L2.	.8829975	.1574667	5.61	0.00	.5743685	1.191627
GDP_per_cap L2.	–.0002031	.0000983	–2.07	0.039	–.0003959	–.0000104
Ren_elec_output L2	.0556693	.0217331	2.56	0.010	.0130731	.0982654
_cons	2.0449948	3.309692	0.62	0.036	–4.43693	8.536825
			GDP_per_cap			
ln_Merch_export L2.	714.1001	149.4574	4.78	0.000	421.1689	1007.031
GDP_per_cap L2.	.390193	.0933399	4.18	0.000	.2072502	.5731357
_cons	–15231.9	3141.351	–4.85	0.000	–21388.84	–9074.967
			Ren_ener_cons			
GDP_per_cap L2.	.0003466	.0001533	2.26	0.024	.0000463	.000647
			Ren_elec_output			
Ren_ener_cons L2.	–3.502299	1.206646	–2.90	0.004	–5.867281	–1.137317
Ren_elec_output L2	.6059949	.1805239	3.36	0.001	.2521745	.9598153

uals of the VAR model. According to the analysis, for lag 1: chi2:19.4712, df: 16, Prob > chi2: 0.24499 ($P > 0.05$). This indicates that there is no residual autocorrelation at lag 1. The null hypothesis ("no autocorrelation at lag 1") is not rejected. For lag 2: chi2: 16.2840, df: 16, Prob > chi2: 0.43332 ($P > 0.05$). There is no autocorrelation at lag 2 either. The null hypothesis is not rejected again.

According to the results, there is no autocorrelation in the model residuals at the first and second lags. This result is a good result for the VAR model, as it shows that the residuals are independent and that the model is working properly. These test results confirm the reliability of the VAR model. Therefore, one can be confident in the results of the analysis. The absence of residual autocorrelation allows this study to continue using the VAR model in further analyses.

Table 7. Lagrange-multiplier test result

lag	chi2	df	Prob > chi2
1	19.4712	16	0.24499
2	16.2840	16	0.43332
H0: no autocorrelation at lag order			

Table 8 shows the Jarque-Bera Test Results. The Jarque-Bera test is used to test whether the residuals in a VAR model are normally distributed. This test helps to determine whether the residuals follow a normal distribution. The test results show the following: Ln(*Merchandise exports*): *P*-value is 0.49318, which is greater than 0.05. Therefore, it cannot be rejected that this residual is normally distributed. GDP per capita: *P*-value is 0.00000, which is less than 0.05. This indicates that the residuals for GDP per capita are not normally distributed. Renewable energy consumption: *P*-value is 0.88576, which is greater than 0.05. This residual is normally distributed. Renewable electricity output: *P*-value is 0.60168, which is greater than 0.05. This also indicates that the residual is normally distributed. All equations combined: *P*-value is 0.00000, which means that a normal distribution is rejected when all residuals are combined.

4. DISCUSSION

The findings on bidirectional causality between GDP and exports align with Odhiambo's (2022) observations in middle-income countries but contrast with unidirectional relationships found in lower-income economies. This positioning suggests that Uzbekistan has reached a development threshold where mutually reinforcing economic dynamics between exports and growth are active.

The positive impact of renewable electricity on exports confirms and extends Narayan and Nguyen's (2019) findings from Vietnam, where exports showed greater responsiveness to renewable energy sources than to fossil fuels. The results of the current study provide novel evidence from Central Asia, demonstrating that this relationship holds in a post-Soviet transition economy with different institutional and market structures.

The relationship between GDP per capita and renewable energy consumption corroborates Wang et al.'s (2023) finding across 122 countries that renewable energy consumption stimulates economic growth. However, the identification of bidirectional causality provides a more nuanced understanding of how these variables interact in a specific national context.

The results diverge from Güneş et al.'s (2022) findings in OECD countries, where renewable energy transition is associated with both increased exports and reduced imports. The more complex relationship observed in Uzbekistan likely reflects its specific development stage and resource endowment as a natural gas producer.

The bidirectional relationship between exports and GDP highlights the importance of coordinated trade and development policies. Export promotion initiatives should be integrated with broader economic development strategies to maximize synergies and mutual reinforcement.

The positive impact of renewable electricity on export performance provides a strong economic rationale for accelerating renewable energy infrastructure development beyond environmental considerations. Policymakers should view renewable energy investments as trade competitiveness measures that can improve Uzbekistan's export performance while advancing sustainability objectives.

The time lag structure identified in the VAR model indicates that policy interventions may take up

http://dx.doi.org/10.21511/ee.16(2).2025.14

to two years to fully materialize. This suggests that consistent, long-term policy implementation is necessary, and frequent policy changes may disrupt the development of these economic relationships.

This study's focus on aggregate exports may mask the sector-specific effects of renewable energy adoption. Future research should disaggregate exports by sector to identify which industries benefit most from renewable energy infrastructure, allowing for more targeted policy interventions.

The analysis period (1990–2023) encompasses significant structural changes in Uzbekistan's economy, particularly the market liberalization reforms implemented since 2017. Further research using structural break analysis could identify how these reforms may have altered the relationships between renewable energy, GDP, and exports.

While this study establishes the statistical relationships between variables, the specific mechanisms through which renewable energy enhances export performance require further investigation. Case studies of exporting firms could provide insights into how energy costs, reliability, and sustainability credentials affect international competitiveness.

The focus on renewable energy consumption and electricity generation captures only part of the energy-export nexus. Future studies should incorporate energy efficiency measures, grid stability indicators, and energy price data to develop a more comprehensive understanding of how energy systems influence export performance.

CONCLUSION

This study examined the bidirectional relationship between renewable energy consumption and export performance in Uzbekistan using data for 1992–2023. The analysis addressed a significant gap in understanding how renewable energy adoption affects export competitiveness in transition economies, providing empirical evidence to inform integrated energy and trade policies for sustainable economic development.

The empirical analysis using vector autoregression methodology revealed several key findings with implications for both theory and practice. First, a robust bidirectional causality was identified between exports and GDP per capita ($p < 0.001$), indicating that these economic indicators mutually reinforce each other in Uzbekistan's development context. This finding underscores the interconnected nature of trade policy and economic growth strategies. Second, renewable electricity generation demonstrated a significant positive effect on export performance (coefficient = 0.056, $p = 0.01$), providing empirical evidence that investment in renewable energy infrastructure enhances export competitiveness. Third, GDP per capita was found to have a small but statistically significant negative effect on exports (coefficient = –0.0002, $p = 0.039$), suggesting a complex relationship where rising domestic incomes may shift some production toward domestic markets.

These findings have substantial practical implications for policymakers in Uzbekistan and similar transition economies. The positive impact of renewable electricity on exports provides an economic rationale for accelerating renewable energy infrastructure development beyond environmental considerations. Policymakers should view renewable energy investments as trade competitiveness measures that can improve export performance while advancing sustainability objectives. Additionally, the bidirectional relationship between exports and GDP highlights the importance of coordinated trade and development policies to maximize mutual reinforcement. The time lag structure identified in the model indicates that policy interventions may take up to two years to fully materialize, suggesting that consistent, long-term policy implementation is necessary.

This paper contributes to the academic literature. It extends existing knowledge on energy-export relationships to the context of post-Soviet transition economies, demonstrating that findings from developed economies may not fully apply to this distinct institutional context. The identification of specific causal relationships and their magnitudes provides empirical evidence for theoretical models linking renewable energy adoption to trade performance. Furthermore, the methodological approach demonstrates the value of time-series analysis in understanding the dynamic interrelationships between energy systems and economic indicators.

For future research, several promising directions are recommended. First, sector-specific analysis would help identify which industries benefit most from renewable energy infrastructure, allowing for more targeted policy interventions. Second, the inclusion of energy efficiency measures, grid stability indicators, and energy price data would develop a more comprehensive understanding of how energy systems influence export performance. Third, comparative analysis with other Central Asian economies could help identify regional patterns and country-specific factors that mediate the relationship between renewable energy adoption and export competitiveness. Finally, case studies of exporting firms could provide insights into the specific mechanisms through which renewable energy enhances international competitiveness.

By continuing to explore these research avenues, scholars and policymakers can develop more effective strategies for leveraging renewable energy investments to enhance both environmental sustainability and economic competitiveness in transitioning economies like Uzbekistan.

AUTHOR CONTRIBUTIONS

Conceptualization: Arslonbek Nurjonov, Fozil Xolmurotov.
Data curation: Fozil Xolmurotov, Ergash Ibadullaev, Feruza Yusupova.
Formal analysis: Fozil Xolmurotov, Jasurbek Ataniyazov.
Funding acquisition: Arslonbek Nurjonov, Jasurbek Ataniyazov, Manzura Masharipova, Xolilla Xolmuratov.
Investigation: Arslonbek Nurjonov, Manzura Masharipova, Feruza Yusupova, Xolilla Xolmuratov.
Methodology: Fozil Xolmurotov, Jasurbek Ataniyazov.
Project administration: Ergash Ibadullaev, Feruza Yusupova.
Resources: Ergash Ibadullaev, Manzura Masharipova.
Software: Fozil Xolmurotov.
Supervision: Arslonbek Nurjonov, Xolilla Xolmuratov.
Validation: Ergash Ibadullaev, Jasurbek Ataniyazov, Manzura Masharipova, Xolilla Xolmuratov.
Visualization: Fozil Xolmurotov, Feruza Yusupova.
Writing – original draft: Arslonbek Nurjonov, Fozil Xolmurotov, Manzura Masharipova.
Writing – review & editing: Fozil Xolmurotov, Ergash Ibadullaev, Jasurbek Ataniyazov, Feruza Yusupova, Xolilla Xolmuratov.

REFERENCES

1. Acheampong, A. O., Dzator, J., & Savage, D. A. (2021). The role of economic institutions in electricity consumption, economic growth, and CO2 emissions linkages: Evidence from sub-Saharan Africa. In P. Singh, P. Verma, D. Perrotti, & K. K. Srivastava (Eds,), *Environmental Sustainability and Economy* (pp. 61-83). Elsevier. https://doi.org/10.1016/B978-0-12-822188-4.00002-6
2. Ahmed, E. M., & Elfaki, K. E. (2024). Enhancing environmental quality and economic growth through potential effects of energy efficiency and renewable energy in Asian economies. *Dental Science Reports, 14*(1), Article 22914. https://doi.org/10.1038/S41598-024-73679-Z
3. Alhashim, M., Rehman, M. Z., Ansari, S., & Ahmed, P. (2024). Examining the influence of renewable energy consumption, technological innovation, and export diversification on economic growth: Empirical insights from E-7 nations. *Sustainability, 16*(21). https://doi.org/10.3390/SU16219159
4. Almajali, I. O., Ahmed, A. H., Alhayky, A., & Alsakarneh, R. A. I. (2024). Investigating the effect of renewable energy utilization and trade openness towards the

http://dx.doi.org/10.21511/ee.16(2).2025.14

economic growth and environmental quality in South Asia: A comparative study for South Asian countries. *Journal of Policy Research, 10*(2), 259-270. https://doi.org/10.61506/02.00231

5. Amaliyah, N. L., Inayah, A., & Wibangga, W. A. M. P. (2022). Impact of international trade on Indonesia's consume of renewable energy. *ASIAN Economic and Business Development, 5*(1), 130-139. https://doi.org/10.54204/aebd/vol5no1october2022012

6. Apergis, N., Ben Jebli, M., & Ben Youssef, S. (2018). Does renewable energy consumption and health expenditures decrease carbon dioxide emissions? Evidence for sub-Saharan Africa countries. *Renewable Energy, 127,* 1011-1016. https://doi.org/10.1016/J.RENENE.2018.05.043

7. Bozhanova, V., Kononova, O., Dodu-Savca, C., Dodu-Gugea, L., & Chernysheva, O. (2023). Renewable energy sources impact on economic growth: International practices. *Ekonomichnyi visnyk Derzhavnoho vyshchoho navchalnoho zakladu "Ukrainskyi derzhavnyi khimiko-tekhnolohichnyi universytet", 17*(1), 6-11. https://doi.org/10.32434/2415-3974-2022-17-1-6-11

8. Burney, N. A. (1996). Exports and economic growth: Evidence from cross–country analysis. *Applied Economics Letters, 3*(6), 369-373. https://doi.org/10.1080/135048596356258

9. Chang, L., & Shi, Y. (2024). A discussion on the robust vector autoregressive models: Novel evidence from safe haven assets. *Annals of Operations Research, 339*(3), 1725-1755. https://doi.org/10.1007/S10479-022-04919-6

10. Emery, R. F. (1967). The relation of exports and economic growth. *Kyklos, 20*(4), 470-486. https://doi.org/10.1111/J.1467-6435.1967.TB00859.X

11. Fajdetić, B., & Festić, M. (2024). Renewable energy sources in sustainable growth. In M. Pucelj & R. Bohinc (Eds.), *Corporate Governance and CSR Strategies for Sustainability* (pp. 284-309). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3693-5863-4.CH012

12. Groba, F. (2011). *Determinants of trade with solar energy technology components: Evidence on the Porter Hypothesis?* (DIW Berlin Discussion Paper No. 1163). German Institute for Economic Research (DIW Berlin). https://doi.org/10.2139/SSRN.1945746

13. Güneş, H., Kamaci, A., & Önder, H. (2022). Foreign trade and renewable energy consumption: The case of OECD and Turkey. *Fiscaoeconomia, 6*(3), 1003-1017. https://doi.org/10.25295/FSECON.1068817

14. Halmuratov, G., Rustamov, K., Khankelov, T., Xolmuratov, X., Khudainazarov, S., Sabirjanov, T., & Xolmurotov, F. (2025). The relationship between renewable energy production and economic growth: A short-term and long-term analysis in the case of Uzbekistan. *International Journal of Energy Economics and Policy, 15*(3), 567-575. https://doi.org/10.32479/ijeep.18609

15. Hou, P. S., Fadzil, L. M., Manickam, S., & Al-Shareeda, M. A. (2023). Vector autoregression model-based forecasting of reference evapotranspiration in Malaysia. *Sustainability, 15*(4). https://doi.org/10.3390/SU15043675

16. Ibrahiem, D. M. (2018). Investigating the causal relationship between electricity consumption and sectoral outputs: Evidence from Egypt. *Energy Transitions, 2*(1), 31-48. https://doi.org/10.1007/S41825-018-0009-8

17. Kao, C., & Chiang, M. H. (2001). On the estimation and inference of a cointegrated regression in panel data. In B.H. Baltagi, T.B. Fomby, & R. Carter Hill (Eds.), *Nonstationary Panels, Panel Cointegration, and Dynamic Panels* (pp. 179-222). Emerald Group Publishing Limited. https://doi.org/10.1016/S0731-9053(00)15007-8

18. McLeod, A. I., Yu, H., & Mahdi, E. (2012). Time series analysis with R. In *Handbook of Statistics* (vol. 30, pp. 661-712). Elsevier. https://doi.org/10.1016/B978-0-444-53858-1.00023-5

19. Narayan, S., & Nguyen, T. T. (2019). Are exports more responsive to clean or dirty energy? The case of Vietnam's exports to 54 countries. *Energies, 12*(8). https://doi.org/10.3390/EN12081558

20. Odhiambo, N. M. (2022). Is export-led growth hypothesis still valid for sub-Saharan African countries? New evidence from panel data analysis. *European Journal of Management and Business Economics, 31*(1), 77-93. https://doi.org/10.1108/EJMBE-06-2020-0156

21. Qodirov, A., Urakova, D., Amonov, M., Masharipova, M., Ibadullaev, E., Xolmurotov, F., & Matkarimov, F. (2024). The dynamics of tourism, economic growth, and CO2 emissions in Uzbekistan: An ARDL approach. *International Journal of Energy Economics and Policy, 14*(6), 365-370. https://doi.org/10.32479/IJEEP.16591

22. Ram, R. (1985). Exports and economic growth: Some additional evidence. *Economic Development and Cultural Change, 33*(2), 415-425. https://doi.org/10.1086/451468

23. Ram, R. (1987). Exports and economic growth in developing countries: Evidence from time-series and cross-section data. *Economic Development and Cultural Change, 36*(1), 51-72. https://doi.org/10.1086/451636

24. Saribayevich, X. F., Sariyevich, X. X., Davlatov, S., Turobova, H., & Ruziyev, S. (2024). Analysis of factors affecting CO2 emissions: In the case of Uzbekistan. *International Journal of Energy Economics and Policy, 14*(4), 207-215. https://doi.org/10.32479/IJEEP.16193

25. Sebri, M. (2015). Use renewables to be cleaner: Meta-analysis of the renewable energy consumption-economic growth nexus. *Renewable and Sustainable Energy Reviews, 42,* 657-665. https://doi.org/10.1016/J.RSER.2014.10.042

26. Senarathne, C. W., & Jayasinghe, P. (2021). The impact of energy consumption and merchandise

exports on CO2 emission in the United Nations geoscheme regions. *International Journal of Energy Sector Management, 15*(6), 1181-1198. https://doi.org/10.1108/IJESM-11-2020-0001

27. Stern, D. I. (2016). Economic growth and energy. In *Reference Module in Earth Systems and Environmental Sciences* (pp. 35-51). Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.09716-5

28. Temple, J., & Wößmann, L. (2006). Dualism and cross-country growth regressions. *Journal of Economic Growth, 11*(3), 187-228. https://doi.org/10.1007/S10887-006-9003-X

29. Ullah, M., Umair, M., Sohag, K., Mariev, O., Khan, M. A., & Sohail, H. M. (2024). The connection between disaggregate energy use and export sophistication: New insights from OECD with robust panel estimations. *Energy, 306,* Article 132282. https://doi.org/10.1016/j.energy.2024.132282

30. Vijay. (2025, April 4). *Understanding Stationary Time Series Analysis* [Blog Post]. Analytics Vidhya. Retrieved from https://www.analyticsvidhya.com/blog/2021/06/statistical-tests-to-check-stationarity-in-time-series-part-1/

31. Wang, Q., Li, C., & Li, R. (2023). How does renewable energy consumption and trade openness affect economic growth and carbon emissions? International evidence of 122 countries. *Energy & Environment, 36*(1), 187-211. https://doi.org/10.1177/0958305X231169010

32. Xolmurotov, F. S., Xolmuratov, X. S., & Yakubova, Y. R. (2024). Assessment of the impact of agriculture on the regional socio-economic development. *E3S Web of Conferences, 548,* Article 01003. https://doi.org/10.1051/e3sconf/202454801003

33. Yu, T. M., Yan, Y. T., Yin, Y. H., & Yang, M. G. (2023). Are natural resources and oil prices a possible solution to renewable energy electricity? Evidence from global time series data. *Resources Policy, 86,* Article 104288. https://doi.org/10.1016/j.resourpol.2023.104288

34. Yulduz, Y., Xolilla, X., Fozil, X., Xosiyat, M., Gulnoza, Z., Zilola, A., & Komil, S. (2025). Impact of energy consumption on agricultural economics in Uzbekistan: An ARDL approach. *International Journal of Energy Economics and Policy, 15*(3), 138-145. https://doi.org/10.32479/ijeep.18120

35. Ziesemer, T. (2019). Renewable electricity supply, infrastructure, and gains from international trade in electric current. *Applied Economics Letters, 26*(17), 1439-1443. https://doi.org/10.1080/13504851.2019.1578849

36. Zvarych, R., Bulatova, O., Zvarych, I., Marena, T., Rivilis, I., & Zapisotska, C. (2024). Renewable energy as environmental sustainability factor under global trade openness. *International Journal of Energy for a Clean Environment, 26*(1), 41-66. https://doi.org/10.1615/interjenercleanenv.2024051410

http://dx.doi.org/10.21511/ee.16(2).2025.14