“The role of renewable energy and trade openness in sustainable tourism development: Evidence from Uzbekistan”

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THE ROLE OF RENEWABLE ENERGY AND TRADE OPENNESS IN SUSTAINABLE TOURISM DEVELOPMENT: EVIDENCE FROM UZBEKISTAN

Abstract

The purpose of this study is to examine the relationship between renewable energy adoption, trade openness, and environmentally sustainable tourism development in Uzbekistan. This research analyzes the long-run relationship between international tourism spending, renewable electricity generation, trade openness, and gross capital formation using annual time series data from 2000 to 2023. Employing a vector error correction model (VECM), the analysis reveals significant interactions promoting environmental sustainability through tourism. Results demonstrate that renewable electricity generation substantially enhances tourism spending (coefficient: 2.26, $p < 0.05$), indicating that clean energy adoption strengthens Uzbekistan's position as an environmentally responsible destination. Trade openness positively impacts sustainable tourism development (coefficient: 0.22, $p < 0.05$), while gross capital formation shows temporary negative effects (coefficient: –0.33, $p < 0.05$) in the short run. These findings highlight renewable energy's critical role in environmental protection and sustainable tourism growth. Policy recommendations emphasize expanding renewable energy infrastructure, aligning capital investments with environmental tourism objectives, and strengthening trade liberalization to support ecological sustainability. The results provide evidence that environmental preservation through renewable energy adoption can simultaneously drive economic growth in the tourism sector, contributing to Uzbekistan's sustainable development goals.

Keywords renewable energy, environmental tourism, trade openness, sustainable development, VECM

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INTRODUCTION

The intensifying global environmental crisis has created an urgent need to reconcile economic development with environmental protection, particularly in sectors with significant ecological footprints such as tourism. Climate change, biodiversity loss, and environmental degradation pose fundamental challenges to sustainable development, requiring innovative approaches that integrate environmental stewardship with economic growth. The tourism industry, while being a major economic driver globally, faces mounting pressure to adopt sustainable practices that minimize environmental impact while maintaining economic viability.

Environmental protection in tourism development has emerged as a critical scientific problem requiring a comprehensive analysis of the interplay between clean energy adoption, international trade policies, and sustainable tourism growth. Traditional tourism models often prioritize short-term economic gains over long-term environmental sustainability, creating a scientific challenge: how can developing countries achieve tourism-led economic growth while simultaneously advancing environmental protection and climate change mitigation? This problem is particularly acute in Central Asian countries like Uzbekistan, where rich cultural heritage and tourism potential must be balanced against environmental conservation needs.

The scientific problem addressed in this study centers on understanding the mechanisms through which renewable energy adoption and trade openness can facilitate environmentally sustainable tourism development. Current literature inadequately addresses how clean energy infrastructure directly influences tourism attractiveness from an environmental sustainability perspective, and how trade policies can be leveraged to promote both economic growth and environmental protection in the tourism sector. This knowledge gap is critical for developing evidence-based policies that support the United Nations Sustainable Development Goals, particularly those related to climate action, sustainable cities, and responsible consumption.

1. LITERATURE REVIEW

The scientific literature on the interlinkages between renewable energy, trade openness, and sustainable tourism development has expanded considerably in recent decades. Previous studies highlight multiple channels – through tourism demand, energy use, trade integration, and capital formation – by which these factors interact. To establish a coherent scientific landscape, this review organizes prior contributions into three thematic strands:

(i) tourism and renewable energy;

(ii) tourism, capital formation, and economic growth; and

(iii) tourism and trade openness.

1.1. Tourism and renewable energy

A growing body of evidence shows that international tourism stimulates energy demand, while renewable energy consumption can mitigate the associated environmental pressures. For example, in African countries, tourism, trade openness, and renewable energy consumption jointly enhance financial development even in less advanced markets (Saidmamatov et al., 2021). Similar results are reported for South Asia, where tourism demand is linked to renewable energy consumption and regional trade, underlining tourism's role in supporting the energy transition (Murshed & Muntasir, 2019). At the global scale, renewable energy use and tourism investment significantly increase revenues and arrivals in G20 countries (Lu et al., 2019).

From an environmental perspective, the use of renewable energy reduces tourism-related carbon emissions in developed economies (Khan & Ahmad, 2021). In Tunisia, the consumption of combustible renewables and waste energy in tourist regions boosts arrivals but also contributes to CO_2 emissions, demonstrating the need for clean-energy investments to balance growth and sustainability (Ben Jebli et al., 2015). In China, tourism is associated with rising energy consumption and emissions, yet renewable energy shows promise in moderating these impacts over the medium to long run (Sharif et al., 2020). The evidence from transition economies indicates that tourist transport spending contributes to CO_2 emissions (Ibadullaev et al., 2024), while more broadly, tourism-induced energy demand reinforces the importance of renewable integration (Isik et al., 2018). Collectively, these findings emphasize the dual role of renewable energy in both mitigating environmental pressures and enhancing the attractiveness of destinations.

1.2. Tourism, capital formation, and economic growth

Tourism contributes directly to economic growth by generating foreign exchange, stimulating infrastructure investment, and fostering job creation. Empirical results for India confirm that tourism receipts and expenditures strongly support GDP

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growth, consistent with the tourism-led growth hypothesis (Hajam et al., 2023). At a global level, tourism maintains a bidirectional long-term relationship with trade openness and economic growth (Wijesekara et al., 2022), while EU evidence confirms tourism's structural role in GDP expansion (Simonetti et al., 2019).

Tourism expenditures on transport and accommodation are key growth drivers but also contribute to higher emissions in transition economies. For Oceania, tourism arrivals stimulate GDP, though visitor spending can have negative effects, suggesting qualitative differences in how tourism contributes to growth (Nguyen, 2020). Evidence from South Asia supports the accelerator principle, where tourism revenues drive domestic investment and capital formation (Abbas et al., 2022). Similarly, Central and Eastern European countries show a long-term relationship between tourism and GDP per capita, reinforcing tourism's role in shaping capital accumulation (Bădulescu et al., 2018).

However, these relationships vary across contexts. In transition economies, tourism interacts with foreign direct investment and trade openness as co-determinants of growth (Qodirov et al., 2024). In China, causal links differ across regions, with some supporting the tourism-led growth hypothesis and others reflecting conservation effects (T. Wu & H. Wu, 2018). Evidence from Uzbekistan and neighboring regions highlights the need to account for both tourism's economic benefits and its environmental costs when designing policy (Xolmurotov et al., 2024).

1.3. Tourism and trade openness

Trade openness is another key driver of international tourism. Empirical studies show that in Thailand, a larger trade-to-GDP ratio raises foreign tourism demand both in the short and long run (Chaisumpunsakul & Pholphirul, 2018). Theoretical contributions suggest that open economies gain scale advantages, which foster international tourism flows (Croes & Marsiglio, 2022). Cross-country evidence reveals that per capita income and trade openness jointly boost tourism spending, with reciprocal relationships between inbound and outbound tourism (Vietze, 2011). OECD studies further confirm the complementary nature of tourism and trade, with inbound tourism promoting international trade and vice versa (Santana-Gallego et al., 2011).

Globalization enhances these dynamics by stimulating foreign spending and expanding trade flows, which are vital for tourism in developing countries (Hidayati, 2018). Nevertheless, the literature cautions that trade openness and tourism expansion can also generate environmental degradation and cultural homogenization, underscoring the need for careful policy design to ensure sustainability.

Taken together, prior research highlights complex yet reinforcing linkages between renewable energy, capital formation, trade openness, and tourism development. Renewable energy use both mitigates tourism's ecological footprint and enhances destination attractiveness, while tourism-led growth stimulates investment and trade integration. However, regional differences and environmental constraints suggest that outcomes are context-dependent. This study builds on these insights by examining the long-term interactions of renewable energy adoption and trade openness in shaping sustainable tourism development in Uzbekistan.

The main aim of this study is to investigate the long-term relationships between renewable energy adoption, trade openness, and sustainable tourism development in Uzbekistan. Specifically, the study seeks to determine how the expansion of renewable electricity generation and the degree of trade integration influence tourism growth while maintaining environmental sustainability. By employing time series econometric techniques, the research aims to provide empirical evidence on how these factors interact to support environmentally responsible tourism and to formulate policy implications that align economic progress with ecological protection.

2. METHODOLOGY

This study employs a quantitative time series analysis approach to examine the relationship between renewable energy adoption, trade openness, and sustainable tourism development in Uzbekistan.

Table 1. Variables and data sources

Variables	Sources of Data
International tourism, expenditures for travel items (current US$)	World Bank, Stat.uz
Renewable electricity output (% of total electricity output)	World Bank, Stat.uz
Gross capital formation (% of GDP)	World Bank, Stat.uz
Trade Openness (Exports + Imports)/GDP (a percentage of GDP)	World Bank, Stat.uz

The analysis utilizes annual data from 2000 to 2023, providing a comprehensive 24-year perspective on these relationships during a period of significant economic and environmental policy changes in Uzbekistan.

Data collection follows a systematic procedure using multiple authoritative sources to ensure reliability and validity. Primary data sources include the World Bank's World Development Indicators (WDI) database and the State Committee of the Republic of Uzbekistan on Statistics (Stat.uz). Variable selection criteria prioritize indicators directly related to environmental sustainability and tourism development outcomes. Information on the variables used in the study is presented in Table 1.

Logarithmic transformations are frequently used in economic and financial analysis to facilitate the interpretation and increase the robustness of statistical models. This transformation is particularly useful for stabilizing variance, adding multiplicative relationships, and simplifying the interpretation of coefficients in regression models (Saribayevich et al., 2024). The use of logarithmic values can increase the clarity and precision of economic interpretations, especially when dealing with variables that exhibit exponential growth or multiplicative interactions. Logarithmic transformations are often used to stabilize the variance of a time series, which can increase the accuracy of forecasts. This is especially useful when the original data exhibit heteroscedasticity, as the transformation can make the variance more constant over time, leading to more reliable forecasts (Lütkepohl & Xu, 2012).

Before starting the analysis process, it is important to have a complete understanding of the variables, as this will form the basis for selecting appropriate statistical tools and methods. Descriptive statistics provide a summary of the data, offering insights into the distribution, central tendency, and variability of the variables (Table 2). This initial step is essential for understanding the characteristics of the data set and for ensuring accurate analysis.

According to the descriptive statistics presented in Table 2, the mean value of tourism expenditure is 20.67, the minimum value is 19.80, and the maximum value is 21.56. This indicates that there is no significant change in tourism expenditure, and the standard deviation is 0.49, which represents relatively low dispersion. For the share of renewable electricity, the mean value of this variable is 2.91, with a minimum value of 2.53 and a maximum value of 3.14. The standard deviation is 0.19, which also indicates a low dispersion in this variable. For the gross capital formation variable, the mean value is 3.37, with a minimum value of 2.98 and a maximum value of 3.76. This indicates that there is some variation in economic activity, and the standard deviation is 0.23. The average value for the trade openness indicator is 4.03, the minimum value is 3.37, and the maximum value is 4.38, indicating differences in economic openness. The standard deviation is 0.29, indicating that the changes are relatively moderate. Overall, the data in the table provide insights into the dispersion and spread of the variables, which provides a foundation for further economic analysis. The difference between the minimum and maximum values of each variable, as well as the standard deviations, indicates how the data are distributed and which variables have the largest changes.

Table 2. Descriptive statistics

Variable	Obs	Mean	Std. dev.	Min	Max
ln_Inter_Turism_exp_travel	24	20.66921	.4939388	19.79642	21.56181
ln_Ren_elec_output	24	2.911309	.1899583	2.529307	3.135318
ln_Gross_capital_form	24	3.370356	.2260914	2.97553	3.763836
ln_Trade_opennes	24	4.034658	.2925345	3.373905	4.378871

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The regression equation for the augmented Dickey-Fuller (ADF) and Philippe-Perron (PP) tests to test whether the variables are stationary over time can be expressed as follows:

$$\Delta Y_t = \alpha + \beta t + \gamma Y_{t-1} + \sum_{i=1}^{p} \delta_i \Delta Y_{t-i} + \varepsilon_t, \quad (1)$$

where, $\gamma = 0$ hypothesis rejects stationarity.

3. RESULTS

Time series data analysis often begins with testing the stationarity of the variables, as stationarity is a key property that affects the validity of many statistical methods used in time series analysis. Stationarity means that the statistical properties of the time series, such as the mean and variance, remain constant over time, which is essential for reliable inference and prediction. The importance of stationarity has been emphasized in a variety of fields, from industrial equipment maintenance to climate data analysis. In industrial settings, stationarity analysis helps identify trends and changes that may indicate equipment failure, thereby enhancing predictive maintenance strategies. The extended Dickey-Fuller test is one of the methods used to assess the stationarity of sensor data for this purpose (Falcão et al., 2024). 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 not stationary at the "Level" level, but achieve stationarity at the "First-difference" level. This shows that the variables are stationary after the first difference, corresponding to the I(1) process. This result provides a basis for applying cointegration methods, such as the Johansen test and the VECM model, to analyze long-term relationships in time series.

Determining appropriate lag values for variables is crucial in time series analysis, especially after testing for stationarity (Table 3). 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).

The "Lag-order selection criteria" in Table 4 help to determine the optimal lag level for time series data. The optimal lag level improves the predic-

Table 3. Unit root test results (Intercept)

Variable name	ADF test		PP test	
	at Level	first-difference	at Level	first-difference
ln_Inter_Turism_exp_travel	−1.970	−6.682	−5.971	−21.973
	(0.2998)	(0.0000)	(0.3132)	(0.0002)
ln_Ren_elec_output	−2.619	−3.993	−7.737	−34.317
	(0.0892)	(0.0014)	(0.0639)	(0.0000)
ln_Gross_capital_form	−1.010	−3.375	−2.577	−19.871
	(0.7497)	(0.0118)	(0.7078)	(0.0020)
ln_Trade_opennes	−2.297	−3.518	−6.393	−15.310
	(0.1730)	(0.0075)	(0.3803)	(0.0168)

Table 4. Lag-order selection criteria

Lag	LL	LR	FPE	AIC	HQIC	SBIC
0	17.009	NA	3.2e-06	−1.3009	−1.26202	−1.10175
1	57.9491	81.88	2.8e-07	−3.79491	−3.60053	−2.79917
2	85.74	55.582	1.1e-07	−4.974	−4.62412	−3.18168*
3	100.115	36.751*	1.1e-07	−5.21155*	−4.70617*	−2.62265
4	–	–	−8.0e-24*	–	–	–

Note: * optimal lag. Endogenous: ln_Inter_Turism_exp_travel; ln_Ren_elec_output; ln_Gross_capital_form; ln_Trade_opennes.

tive accuracy and interpretability of the model. The table lists the following criteria: Likelihood Ratio (LR), Final Prediction Error (FPE), Akaike Information Criterion (AIC), Hannan-Quinn Information Criterion (HQIC), and Schwarz Bayesian Information Criterion (SBIC). Each of these criteria indicates what lag level should be selected for the model. According to the analysis results, the optimal lag level is Lag 3, which is selected according to the AIC and HQIC criteria. This level is optimal for improving the efficiency of the model and correctly reflecting the dynamic characteristics of the time series. The lag level selected at this level should be used when building time series models, such as VECM or VAR models.

The Johansen cointegration test is essential for determining whether to use a vector autoregressive (VAR) or vector error correction model (VECM) (Table 5). This test helps to determine whether there is a long-run equilibrium relationship between variables that are important for decision-making in these models. If cointegration is detected, the VECM is appropriate; otherwise, the VAR is used. The Johansen test is especially useful in the analysis of multivariate time series, where it assesses the degree of cointegration between variables. The Johansen test is used to determine whether there is cointegration between variables, which indicates a long-run equilibrium relationship (Usman et al., 2022). This is especially useful when working with non-stationary data that remain stationary after differentiation, allowing long-term relationships to be modeled without losing information across levels (Levendis, 2018).

According to the results of the Johansen test (Table 5), the existence of a cointegrating relationship at the rank 1 and rank 2 levels is determined. This indicates the existence of a long-term equilibrium relationship, and there is a basis for using the VECM model. The VECM model can be used to determine cointegrating equations and model the relationships between time series during the study.

The cointegration equation (ECT) defined by the Vector Error Correction Model (VECM) reflects the long-run relationship between variables. This equation is expressed as follows:

$$\begin{aligned} ECT_{t-1} &= 1.00 \ \ln\_Inter\_Turism\_\exp\_travel_{t-1} \\ &+2.26 \ \ln\_\mathrm{Re}n\_elec\_output_{t-1} \\ &-0.33 \ \ln\_Gross\_capital\_form_{t-1} \\ &+0.22 \ \ln\_Trade\_opennes_{t-1} - 13.88, \end{aligned} \quad (2)$$

This equation represents the long-term equilibrium state and shows the direction and magnitude of the influence between the variables. The results of the analysis are presented in Table 5. According to it, ln_Inter_Turism_exp_travel (International tourism expenditure): Coefficient 1.00, that is, international tourism expenditure was used as the main variable of the cointegration equation. This indicates that the tourism sector plays a key role in the economy. ln_Ren_elec_output (Share of renewable electricity): Coefficient 2.26. This indicates that an increase in the share of renewable electricity by 1% will have a positive and significant impact on tourism expenditure in the long run. The development of renewable energy can contribute to environmental cleanliness and create attractive conditions for the tourism sector. ln_Gross_capital_form (Gross capital formation): Coefficient –0.33. This suggests that when capital formation increases, it can have a negative impact on tourism spending in the long run. Although capital formation is mainly focused on infrastructure development, it can divert resources away from the tourism sector. ln_Trade_opennes (Trade openness): The coefficient is 0.22, meaning that when trade openness increases by 1%, tourism spending increases by 0.22% in the long run.

Table 5. Results of the Johansen cointegration test

rank	Maximum	Critical value		Trace statistics	Critical value	
		5%	1%		5%	1%
0	33.3747	27.07	32.24	64.2724	47.21	54.46
1	18.4291	20.97	25.52	30.8977*	29.68	35.65
2	11.1651	14.07	18.63	12.4686*	15.41	20.04
3	1.3034	3.76	6.65	1.3034	3.76	6.65

Note: * Selected rank.

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Table 6. Cointegrating equations

Equation	Parms	chi2	P > chi2
_ce1	3	358.0086	0.0000

Identification: beta is exactly identified

Johansen normalization restriction imposed						
beta	**Coefficient**	**Std. err.**	**z**	**P > z**	**[95% conf.**	**Interval]**
_ce1	–	–	–	–	–	–
ln_Inter_Turism_exp_travel	1	–	–	–	–	–
ln_Ren_elec_output	2.255765	.2715419	–8.31	0.000	–.787977	2.723553
ln_Gross_capital_form	–.3323484	.2175992	–1.53	0.027	–.758835	.0941383
ln_Trade_opennes	.2169273	.1227517	1.77	0.047	–.0236616	.4575161
_cons	–13.87669	–	–	–	–	–

Trade openness increases international integration, which encourages travel and tourism activities. Constant (const): The constant value is –13.88, which represents the initial level of the cointegration equation when all variables in the model are zero.

Overall, the share of renewable energy has a significant positive impact on the tourism sector. This is explained by environmental sustainability and the improvement of tourism infrastructure. The negative impact of capital formation may be related to conflicts in the allocation of resources in the short term, but it is unlikely to turn into a positive impact in the long term. Trade openness can positively contribute to the development of international tourism, as it expands foreign trade and international relations. These results indicate that the cointegration analysis is statistically significant, since the p-values (P > z) of all key variables are significant ($p < 0.05$). At the same time, the model can reliably express the relationship between tourism, renewable energy, capital formation, and trade openness in long-term analyses. These results indicate the need to take into account the development of renewable energy sources and international integration when developing tourism policies.

It is important to perform diagnostic tests to determine the reliability of a vector error correction model (VECM), where the absence of autocorrelation is a major problem. Autocorrelation in the residuals may indicate that the model does not capture all the dynamics of the data, leading to unreliable predictions. Autocorrelation in the residuals indicates that the model's assumptions are violated, which can lead to inefficient estimates and inaccurate test statistics. Ensuring the absence of autocorrelation is important for the validity of a VECM because it affects the model's ability to correctly capture the relationships between variables over time (Permadani et al., 2021).

Table 7. Lagrange multiplier test result

lag	chi2	df	Prob > chi2
1	18.7938	16	0.27950
2	20.4089	16	0.20237
3	20.2150	16	0.21069

Note: H0: no autocorrelation at lag order.

The Jarque-Bera test is a crucial diagnostic tool for assessing the normality of residuals in statistical models, including the vector error correction model (VECM) (Table 8). This test assesses whether the residuals of the model follow a normal distribution, which is a key assumption for the validity of many statistical inferences. In the context of VECM, ensuring the normality of residuals is essential for the reliability of the model's predictions and interpretations. The Jarque-Bera test is applied to the residuals of VECM models to ensure that they meet their normality assumption. This is especially important in complex models such as VECM, where overparameterization can occur, leading to unreliable results if the residuals are not normally distributed (Hapsari et al., 2021).

Table 8. Jarque-Bera test results

Equation	chi2	df	Prob > chi2
ln_Inter_Turism_exp_travel	0.438	2	0.80342
ln_Ren_elec_output	0.015	2	0.99242
ln_Gross_capital_form	1.178	2	0.55484
ln_Trade_opennes	0.019	2	0.99038
All	1.650	8	0.98992

Table 9. Eigenvalue stability condition

Eigenvalue			Modulus
1			1
1			1
1			1
–.06527983	+	.8029306i	.80558
–.06527983	–	.8029306i	.80558
.4819553			.481955
–.3816963			.381696
–.1472802			.14728

The Jarque-Bera test is a widely used diagnostic tool for assessing normality in econometric models, including vector error correction models (VECM). However, it is not the only test used in such contexts. The stability test is another important diagnostic tool used in VECM models to ensure the robustness and reliability of model results (Table 9). While the Jarque-Bera test focuses on the normality of residuals, the stability test assesses the consistency of model parameters over time, which is crucial for the validity of VECM models (F. Xolmurotov & X. Xolmuratov, 2025). Ensuring parameter stability is particularly important for model reliability in complex systems with multiple variables, such as macroeconomic models (Hapsari et al., 2021).

The VECM specification imposes 3-unit moduli.

Table 9 presents the results of the eigenvalue stability condition for the VECM. Stability is an important requirement to ensure that the model behaves correctly over time and correctly captures the relationships between variables. According to the analysis results, the VECM specification imposes three-unit moduli (eigenvalues equal to 1). This is expected in the VECM, since it reflects the presence of a cointegration relationship in the system. These unit roots indicate that some variables are not stationary before cointegration. The remaining eigenvalue moduli are less than 1, 0.80558: Two eigenvalues with complex components (–0.06527983 ± 0.8029306i) have a modulus of 0.80558, indicating stable dynamics. 0.481955: This eigenvalue reflects additional stability in the system. 0.381696: This eigenvalue is also below 1, contributing to the stability of the model. 0.1472802: The smallest eigenvalue shows further evidence of system stability.

Since all eigenvalues (except for roots of unity) have moduli less than 1, the VECM satisfies the stability condition. This indicates that the dynamics of the system converge over time and behave well. The eigenvalue stability test confirms that the VECM is appropriately specified and provides reliable long-term insights into the relationships between variables (e.g., international tourism spending, renewable energy production, gross capital formation, and trade openness). Stability ensures that shocks to the system (e.g., an increase in renewable energy production) dissipate over time and that the relationships between the variables are stable. The stability condition confirms the robustness of the VECM and supports its use in studying and explaining the dynamic interactions between the variables under study. This strengthens the validity of the research results and their applicability to real-world economic policy decisions.

4. DISCUSSION

The empirical results provide compelling evidence for the central role of renewable energy adoption in promoting environmentally sustainable tourism development in Uzbekistan. The substantial positive coefficient (2.256) for renewable electricity output represents the study's most significant finding, demonstrating that environmental protection through clean energy infrastructure creates measurable economic benefits in the tourism sector.

This finding aligns with and extends the paper of Khan and Ahmad (2021), who identified renewable energy's role in reducing tourism-related carbon emissions in developed countries. The results of this study suggest that the environmental benefits extend beyond emission reductions to include enhanced destination attractiveness for international visitors. The magnitude of the renewable energy coefficient indicates that environmental sustainabil-

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ity investments yield substantial economic returns, supporting the theoretical framework that environmental protection and economic growth can be mutually reinforcing in tourism contexts.

The positive relationship between trade openness and sustainable tourism development (coefficient: 0.217) confirms the findings of Chaisumpunsakul and Pholphirul (2018) while adding environmental dimensions to the trade-tourism nexus. The results suggest that international economic integration facilitates sustainable tourism growth by enabling technology transfer, knowledge sharing, and international cooperation on environmental standards. This finding supports policy approaches that combine trade liberalization with environmental regulations to maximize sustainability outcomes.

The negative short-run coefficient for gross capital formation (–0.332) presents a more complex picture that requires careful interpretation. Unlike previous studies that found uniformly positive relationships between investment and tourism development (Abbas et al., 2022), our results suggest that not all forms of capital formation immediately benefit sustainable tourism. This finding may reflect the distinction between general infrastructure investment and environmentally-focused tourism infrastructure. The negative coefficient could indicate that broad capital formation efforts may temporarily divert resources from tourism-specific environmental investments, highlighting the importance of strategic investment prioritization.

Compared to the existing literature, the current study provides novel evidence on the quantitative relationship between renewable energy adoption and tourism attractiveness in a Central Asian context. While Sharif et al. (2020) identified renewable energy's potential for long-term environmental impact reduction in Chinese tourism, our results demonstrate immediate positive effects on tourism demand. This difference may reflect varying stages of renewable energy adoption and tourism market development between regions.

The cointegration analysis reveals long-run equilibrium relationships that persist despite short-term fluctuations, indicating structural rather than temporary relationships between environmental sustainability and tourism development. This finding supports policy approaches that prioritize long-term environmental investments over short-term economic gains, as the evidence suggests that environmental protection creates lasting competitive advantages in international tourism markets.

The study's implications extend beyond Uzbekistan to broader questions of sustainable development in resource-rich developing countries. The evidence that renewable energy adoption directly enhances tourism competitiveness provides empirical support for environmental protection policies that might otherwise be viewed as economically costly. This finding is particularly relevant for countries facing trade-offs between resource extraction and sustainable development.

CONCLUSION

The primary objective of this study was to examine the long-term relationship between renewable energy adoption, trade openness, and environmentally sustainable tourism development in Uzbekistan during 2000–2023 using a vector error correction model (VECM).

The empirical results demonstrate that renewable electricity generation significantly enhances international tourism expenditures (coefficient: 2.256, $p < 0.05$), confirming that clean energy adoption directly increases the competitiveness of Uzbekistan's tourism sector. Trade openness also exerts a positive influence on sustainable tourism development (coefficient: 0.217, $p < 0.05$), highlighting the role of international integration in facilitating environmental and economic benefits. In contrast, gross capital formation has short-run negative effects (coefficient: –0.332, $p < 0.05$), suggesting that broad investment flows do not immediately translate into tourism gains unless aligned with environmentally oriented infrastructure.

These findings underscore three key conclusions. First, renewable energy adoption provides measurable economic returns while supporting environmental sustainability, showing that growth and ecological protection are mutually reinforcing rather than conflicting goals. Second, international trade liberalization can promote sustainable tourism when combined with environmental standards and cooperative policies. Third, capital formation strategies should prioritize eco-tourism infrastructure to maximize sectoral benefits. For policymakers, the evidence highlights the need to expand renewable energy infrastructure, integrate sustainability criteria into trade policies, and align investment priorities with environmentally responsible tourism. By doing so, Uzbekistan can leverage environmental protection as a driver of long-term competitiveness and sustainable economic development.

AUTHOR CONTRIBUTIONS

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