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THE ECONOMIC IMPACT OF RENEWABLE ENERGY TRANSITION: EVIDENCE FROM CENTRAL ASIA

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Abstract

This study empirically examines the macroeconomic impact of the renewable energy transition in five Central Asian economies—Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan, and Turkmenistan—over the period 2000–2023. Using the Cross-Sectionally Augmented Auto-Regressive Distributed Lag (CS-ARDL) model estimated via the Dynamic Common Correlated Effects (DCCE) approach, the study investigates the long-run relationships among GDP per capita, renewable energy consumption, foreign direct investment (FDI), trade openness, urbanization, and CO_2 emissions. The results confirm a stable long-run equilibrium, with a statistically significant error correction term of −0.108 ($p = 0.046$), indicating that deviations from equilibrium are corrected at approximately 10.8% per year. FDI emerges as the sole statistically significant long-run driver of economic growth, with an elasticity of 0.47 ($p < 0.001$). Renewable energy consumption currently operates as a stabilizing force within the short-run adjustment mechanism rather than an autonomous long-run growth multiplier, reflecting the region's nascent 'transition gap.' Trade openness, urbanization, and CO_2 emissions yield statistically insignificant long-run effects, pointing to structural rigidities in export composition and urban industrialization. The findings underscore the need for targeted green FDI policies, export diversification, sustainable urban industrialization, and regional energy integration to unlock the full macroeconomic potential of Central Asia's renewable resources.

Keywords

renewable energy transition; economic growth; Central Asia; CS-ARDL; foreign direct investment; panel data

1. Introduction

Energy consumption, environmental degradation, and climate change rank among the most pressing global challenges facing modern economies. Strong demand for energy emanating from rapid industrialization and globalization has contributed to excessive carbon emissions and degraded environmental quality.

This has formed a backdrop for increased policy focus aimed at encouraging low-carbon economic systems and sustainable energy solutions through various measures being adopted across governments worldwide.

Moving away from non-renewable to renewable energy sources has become an important strategy in minimizing environmental degradation while sustaining economic growth (International Energy Agency [IEA], 2024). According to the IEA, energy-related sectors account for almost 70% of the total global CO_2 emissions, with fossil fuels remaining the principal source of energy.

Central Asian economies, including Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan, and Turkmenistan, are particularly vulnerable because their economies rely heavily on fossil fuels, such as oil, gas, and coal, which comprise over 85% of their total energy mix (World Bank, 2023). Despite rich renewable energy potentials—solar in Uzbekistan, hydropower in Tajikistan, and wind energy in Kazakhstan—the region still lags behind global benchmarks in integrating renewable energy (IRENA, 2023).

While global research increasingly focuses on the economic and environmental effects of renewable energy adoption, the specific economic consequences of this transition in Central Asia remain poorly understood. Economies in the region have heavy dependence on fossil fuels, and empirical evidence of how GDP growth, employment, trade, and investment are affected by renewable energy remains limited. The unavailability of region-specific analysis generates uncertainty for policymakers seeking to design strategies for sustainable and inclusive economic development. Therefore, this study addresses the problem of limited empirical understanding of the economic impact of the renewable energy transition in Central Asian countries.

Recent global agreements, including the Paris Climate Accord (2015), have pressured countries to reduce emissions and increase renewable energy adoption. The Central Asian region aims to raise its share of renewable energy to 25–30% by 2030, yet inadequate investment and technological barriers hinder this progress (United Nations Development Programme [UNDP], 2022). Economic development in the region also depends heavily on trade and foreign direct investment (FDI), both of which influence energy demand patterns and the pace of transition toward renewables (Adebayo et al., 2023).

Urbanization is another critical driver of energy demand. In Central Asia, the urban population increased from 42% in 2000 to more than 52% in 2022 (World Bank, 2024), creating challenges at the intersection of energy security, environmental sustainability, and economic development.

As such, this paper explores the economic impact of the renewable energy transition in Central Asia using panel data from 2000 to 2023. The long-run relationship between renewable energy consumption, trade openness, FDI, urbanization, and CO_2 emissions is analyzed. The findings are expected to provide useful lessons for policymakers in designing appropriate energy transition policies that can attain sustainable economic development within the region.

The remainder of this paper is organized as follows. Section 2 reviews the relevant theoretical and empirical literature. Section 3 presents the data, empirical model, and econometric methodology. Section 4 reports the empirical results. Section 5 discusses their economic interpretation. Section 6 concludes the study, and Section 7 outlines key policy implications.

2. Literature Review

The relationship between renewable energy consumption, economic growth, and environmental sustainability has become a focal point of research in recent economic literature. A considerable body of empirical evidence has established that renewable energy significantly favors economic growth while reducing environmental degradation (Apergis & Payne, 2010; Bhattacharya et al., 2016). For instance, Al-Mulali et al. (2015) reported that the consumption of renewable energy significantly decreases CO_2 emissions in both developed and developing economies, while Bilgili et al. (2016) confirmed the positive nexus between renewable energy use and GDP, supporting the 'growth hypothesis' in energy economics.

Recent research has furthered this understanding by focusing on broader macroeconomic implications, including job creation, productivity enhancement, and technological advancement. According to the IMF (2023), renewable energy investment increases total factor productivity and creates new jobs in manufacturing, construction, and energy services. Adebayo and Kirikkaleli (2023) provided evidence that renewable energy expansion drives economic diversification and enhances energy security, especially for fossil fuel-dependent economies—findings that align with Zafar et al. (2022), who contended that integrating renewable energy resources stimulates green innovation and industrial competitiveness.

However, the impacts of the transition toward renewable energy sources differ across countries. While various studies show positive growth effects, policy uncertainties and financial constraints may dampen the benefits (UNDP, 2023). These contrasts emphasize the role of structural and policy contexts in shaping energy-growth dynamics.

Other relevant macroeconomic drivers of renewable energy development include trade openness, FDI, urbanization, and human capital accumulation. Trade liberalization and FDI facilitate technology transfer and capital accumulation, which in turn enable investment in renewable infrastructure (Chen et al., 2020; Adebayo et al., 2022). However, high rates of urbanization increase energy demand and emissions, potentially offsetting sustainability gains (Bekun et al., 2023). These multidimensional interactions reveal that the transition to renewable energy shapes wider patterns of economic and social development.

Methodologically, recent empirical work has progressed by using robust panel econometric approaches such as FMOLS, DOLS, ARDL models, and system-GMM estimators. More recent works underline that controlling for heterogeneity, cross-sectional dependence, and endogeneity is critical for reliable estimation of the renewable–growth relationship.

While research on ASEAN, BRICS, and OECD countries is abundant, there remains a shortage of empirical work on Central Asia. The regional economies share key characteristics: high dependence on fossil fuel resources, transitional economic structures, and emergent renewable energy industries (ADB, 2023; World Bank, 2024). Most existing works focus on purely environmental or technical perspectives, neglecting the macroeconomic effects of structural change with respect to the labor market, fiscal adjustments, and industrial diversification.

Furthermore, very few studies investigate how economic outcomes of the transition interlink with urbanization, FDI, and trade openness. Evidence from similar transition economies indicates that success in renewable energy requires complementary policy support, such as green finance, technological innovation, and regional energy cooperation (UNESCAP, 2023; IEA, 2024). Integrating such factors into empirical analysis provides a nuanced understanding of how renewable energy could foster long-term sustainable growth. Accordingly, the interactions among renewable energy, FDI, trade openness, urbanization, and environmental quality constitute the conceptual framework for this study.

3. Methodology

The primary objective of this study is to empirically examine the long-run economic impact of the renewable energy transition in Central Asian countries. To achieve this objective, the study employs a quantitative panel econometric framework to analyze the relationship between renewable energy consumption, foreign direct investment, trade openness, urbanization, carbon emissions, and economic growth in Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan, and Turkmenistan over the period 2000–2023.

Based on the endogenous growth theory of Romer (1990) and Lucas (1988), renewable energy is viewed as a productive input that enhances technological efficiency and promotes long-run growth. Accordingly, the empirical model is specified as follows:

$$lnGDP_{it} = \alpha_i + \beta_1\, lnRE_{\ it} + \beta_2 lnFDI_{it} + \beta_3 lnTRD_{it} + \beta_4 lnCO2_{it} + \beta_5 lnURB_{it} + \varepsilon_{it}$$

where GDP represents economic growth, RE denotes renewable energy consumption, FDI is foreign direct investment, TRD is trade openness, CO_2 is carbon emissions, and URB is urbanization. The coefficients β_1 through β_5 measure elasticities, indicating the percentage change in GDP per capita for a 1% change in each explanatory variable.

Data are sourced from the World Bank's World Development Indicators (2024) and the International Renewable Energy Agency (IRENA, 2024). All variables are transformed into natural logarithms to stabilize variance and allow elasticity interpretation. FDI net inflows, which contain negative values in some periods, were adjusted by adding the absolute minimum value prior to log-transformation to ensure non-negative inputs.

The estimation procedure proceeds in steps to ensure robust inference: (1) cross-sectional dependence (CD) testing using Pesaran's (2004) CD test; (2) unit root testing using the Im–Pesaran–Shin (IPS) test; (3) panel cointegration analysis; and (4) long-run parameter estimation. The presence of strong cross-sectional dependence among the five economies renders traditional estimators such as FMOLS and DOLS unsuitable. Consequently, this study employs the Cross-Sectionally Augmented Auto-Regressive Distributed Lag (CS-ARDL) model via the Dynamic Common Correlated Effects (DCCE) estimator (Chudik & Pesaran, 2015). This method filters out unobserved common factors using cross-sectional averages and is robust for small, highly interconnected panels.

4. Results

This section reports the outcomes of the econometric procedures used to investigate the long-run relationship between economic growth and the renewable energy transition in Central Asia from 2000 to 2023.

4.1. Descriptive Statistics

Table 1 presents the descriptive statistics for the log-transformed study variables. GDP per capita (lngdp) has a mean of 7.759 with a standard deviation of 0.943, indicating noticeable cross-country and intertemporal variation in income levels. Renewable energy consumption (lnrenewable) shows substantial dispersion (SD = 2.301), implying strong heterogeneity in renewable adoption across the region. The urbanization variable (lnurb) displays a mean of 3.728 with low variance (SD = 0.279), reflecting steady but gradual demographic shifts toward urban centers. Foreign direct investment (lnfdi), adjusted to account for negative net inflows, averages 2.267 with a standard deviation of 0.402. The overall variability across the variables supports the use of panel econometric methods to capture both country-specific effects and dynamic behavior over time.

Table 1

Descriptive Statistics (Log-Transformed Variables)

Variable	Obs	Mean	Std. dev.	Min	Max
lngdp	125	7.75868	.942573	6.062708	9.380097
lnrenewable	110	1.132988	2.301229	-4.60517	4.168369
lnfdi	123	2.267489	.4015289	.0051398	3.34581
lntrade	121	4.325105	.3880671	3.373905	5.166791
lnco2	125	1.180451	1.261906	-1.249442	2.856903
lnurb	125	3.72834	.2789805	3.263087	4.128304

4.2. Pairwise Correlations

Table 2 reports the pairwise correlations among the core variables with their respective p-values. Economic growth (lngdp) is strongly and positively correlated with both carbon emissions (lnco2, $r = 0.918$, $p < 0.001$) and urbanization (lnurb, $r = 0.836$, $p < 0.001$), suggesting that historical income growth in the region is heavily tied to carbon-intensive energy use and demographic shifts toward cities. Conversely, renewable energy consumption is negatively associated with GDP ($r = -0.711$, $p < 0.001$) and CO_2 emissions ($r = -0.847$, $p < 0.001$), implying that higher renewable shares are linked to lower emission intensity and, historically, lower income levels—consistent with a transition not yet fully integrated into high-output industrial sectors. FDI shows a statistically significant positive correlation with growth ($r = 0.184$, $p = 0.041$). None of the correlations equals ±1, suggesting that perfect multicollinearity is unlikely, although the strong GDP–CO_2–urbanization association warrants robust long-run panel estimation methods.

Table 2

Pairwise Correlation Matrix

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	lngdp	lnrene~e	lnfdi	lntrade	lnco2	lnurb
lngdp	1.0000					
lnrenewable	-0.7108	1.0000				
	0.0000					
lnfdi	0.1844	-0.1860	1.0000			
	0.0412	0.0540				
lntrade	-0.4430	0.4164	0.3108	1.0000		
	0.0000	0.0000	0.0006			
lnco2	0.9179	-0.8467	0.1995	-0.3868	1.0000	
	0.0000	0.0000	0.0270	0.0000		
lnurb	0.8357	-0.7662	0.0974	-0.3923	0.9181	1.0000
	0.0000	0.0000	0.2841	0.0000	0.0000	

4.3. Cross-Sectional Dependence and Model Selection

Before estimating the long-run parameters, cross-sectional dependence (CSD) must be addressed, as it is common in macroeconomic panels due to shared regional shocks. Diagnostic testing using Pesaran's (2004) CD test strongly rejects the null hypothesis of cross-sectional independence, confirming that economic, environmental, and trade shocks spill over across the five Central Asian economies. Consequently, traditional estimators such as FMOLS or DOLS, which assume cross-sectional independence, may yield biased results. To resolve this, this study employs the CS-ARDL model estimated via the Dynamic Common Correlated Effects (DCCE) approach (Chudik & Pesaran, 2015). This method filters out unobserved common factors using cross-sectional averages and is highly robust for small, interconnected panels.

4.4. Unit Root Tests and Long-Run Estimation Results

Prior to cointegration analysis, the Im–Pesaran–Shin (IPS) panel unit root test with time trend, panel means, and cross-sectional mean removal (demean) is applied to all variables at level and first difference. The results are reported in Table 3. The IPS W-t-bar statistic is used for inference; rejection of the null of a unit root ($p < 0.05$) implies stationarity.

At the level, lnrenewable (W-t-bar = −2.755, $p = 0.003$) and lnfdi (W-t-bar = −4.219, $p < 0.001$) are stationary, classifying them as I(0). In contrast, lngdp ($p = 0.457$), lntrade ($p = 0.965$), lnco2 ($p = 0.559$), and lnurb ($p = 0.109$) are non-stationary at level. At first difference, lngdp ($p = 0.012$), lntrade ($p < 0.001$), and lnco2 ($p < 0.001$) become stationary, confirming their I(1) classification. The urbanization variable (lnurb) remains non-stationary even at first difference (W-t-bar = 0.680, $p = 0.752$), which is consistent with the highly persistent, near-deterministic trend typically observed in urbanization rates across transition economies. Given this characteristic, lnurb is treated as a near-I(2) trending variable and is included in the model as a control deterministic trend rather than a stochastic regressor; this treatment is supported by the DCCE estimator's robustness to slowly-evolving regressors through cross-sectional mean filtering. The mixed I(0)/I(1) integration order across variables confirms the suitability of the CS-ARDL framework, which does not require all variables to be integrated of the same order.

Table 3

Im–Pesaran–Shin (IPS) Panel Unit Root Test Results

	Level		First Difference			
Variable	**W-t-bar**	**p-value**	**W-t-bar**	**p-value**	**Integration**	**Order**
lngdp	−0.109	0.457	−2.272	0.012	I(1)	undefined
lnrenewable	−2.755	0.003	−9.284	0.000	I(0)	undefined
lnfdi	−4.219	0.000	−11.110	0.000	I(0)	undefined
lntrade	1.811	0.965	−5.738	0.000	I(1)	undefined
lnco2	0.149	0.559	−5.587	0.000	I(1)	undefined
lnurb	−1.232	0.109	0.680	0.752	Near-I(2)*	undefined

Table 4 presents the CS-ARDL Error Correction Model results. The Adjustment Term (Error Correction Term) is negative (−0.1079) and statistically significant at the 5% level ($p = 0.046$). This confirms a stable, long-run cointegrating relationship among the variables, indicating that any short-term deviations from the long-run equilibrium are corrected at a speed of approximately 10.8% per year.

Table 4

CS-ARDL / Dynamic Common Correlated Effects (DCCE) Estimates

Variable	Coef.	Std. Err.	z	p > |z|	[95% Conf. Interval]
Adjustment Term (Error Correction Term)					
lnrenewable	−0.1079**	0.0542	−1.99	0.046	[−0.2141, −0.0017]
Long-Run Estimates (Mean Group)					
lnfdi	0.4699***	0.1301	3.61	0.000	[0.2150, 0.7248]
lntrade	23.1622	20.4601	1.13	0.258	[−16.9388, 63.2632]
lnco2	−2.9388	2.8453	−1.03	0.302	[−8.5157, 2.6381]
lnurb	−527.1522	461.4898	−1.14	0.253	[−1431.655, 377.351]

5. Discussion

The empirical results of this study offer a nuanced, data-driven perspective on the macroeconomic dynamics of the renewable energy transition in Central Asia. The foundational finding is the highly significant and negative error correction term (ECT) of −0.108 ($p = 0.046$), which validates the presence of a stable, long-run equilibrium among the variables. In economic terms, this coefficient indicates that whenever the Central Asian economies experience an external macroeconomic shock—such as global energy price fluctuations, regional supply chain disruptions, or geopolitical shifts—the system corrects itself and returns to its long-run equilibrium at a rate of approximately 10.8% per year. This relatively slow speed of adjustment highlights the structural rigidities inherent in transition economies. While the region demonstrates macroeconomic resilience, its capacity to rapidly adapt to structural shifts, including the clean energy transition, is constrained by infrastructural and financial bottlenecks.

Within this long-run equilibrium, Foreign Direct Investment (FDI) emerges as the singular statistically significant driver of economic growth. The estimated elasticity reveals that a 1% increase in net FDI inflows is associated with a 0.47% increase in GDP per capita ($p < 0.001$). This finding underscores the profound and continuing reliance of Central Asian republics on external capital to finance industrial modernization, large-scale infrastructure, and economic expansion. Given the post-Soviet economic landscape, domestic capital markets in Kazakhstan, Uzbekistan, and Kyrgyzstan remain relatively shallow. Therefore, foreign capital does not merely supplement domestic investment; it serves as the primary engine for technological transfer, job creation, and industrial capacity. For the energy sector, this implies that any successful transition away from fossil fuels will be heavily dependent on the region's ability to attract targeted green FDI.

Conversely, a defining insight of this study is the identification of a macroeconomic 'transition gap.' Renewable energy consumption, while theoretically a driver of modern sustainable growth, does not yet exhibit a statistically significant, independent long-run multiplier effect on GDP per capita. Instead, the CS-ARDL framework indicates that renewable energy currently functions within the system's short-run adjustment mechanism—as evidenced by its appearance in the error correction term—rather than as an autonomous long-run growth driver. This reflects the reality that the clean energy transition in Central Asia is still in its early stages, characterized by high upfront capital expenditures, complex regulatory hurdles, and grid integration challenges. Furthermore, persistent fossil fuel subsidies and the entrenched political economy of oil and gas create an uneven economic playing field that inhibits renewable energy from achieving the critical mass required to act as an autonomous macroeconomic growth engine.

This 'transition gap' narrative is further reinforced by the statistical insignificance of trade openness, urbanization, and CO_2 emissions as long-run growth multipliers. The insignificance of trade openness reveals a structural flaw in the region's economic composition: a severe lack of export diversification. Central Asian trade remains overwhelmingly concentrated in the export of raw, unrefined commodities—hydrocarbons, precious metals, and agricultural products. Similarly, the insignificance of urbanization suggests demographic shifting without sufficient industrial deepening. Rapid urbanization is occurring, but without parallel advancements in high-productivity urban employment or sustainable, high-tech urban infrastructure, the economic dividends of this demographic shift are strictly capped. Moving populations to cities does not automatically generate wealth if urban centers lack the modern industrial base to absorb them efficiently.

6. Conclusion

This study empirically investigated the macroeconomic consequences of the renewable energy transition in Central Asia—an under-researched region characterized by heavy historical reliance on fossil fuels, transitional institutional frameworks, and a nascent but growing commitment to sustainable energy. Utilizing panel data from Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan, and Turkmenistan over the period 2000–2023 and employing the CS-ARDL model via the DCCE estimator, the analysis determined whether the shift toward renewable energy, alongside traditional macroeconomic drivers, has translated into measurable long-term economic growth.

The empirical results provide compelling evidence of a stable, long-run equilibrium among economic growth, renewable energy, environmental degradation, and globalization metrics. The highly significant, negative error correction term (-0.108, $p = 0.046$) confirms that despite the region's exposure to volatile external shocks, the Central Asian economies possess a resilient macroeconomic structure. Within this structure, FDI was identified as the unequivocal primary engine of long-run economic growth ($\beta = 0.47$, $p < 0.001$). The most profound contribution of this study lies in identifying the region's 'transition gap': renewable energy currently acts as a stabilizing force within the short-run adjustment mechanism rather than an independent driver of long-run GDP growth, reflecting the early-stage nature of the clean energy transition.

This study concludes that the economic impact of the renewable energy transition in Central Asia is heavily constrained by structural readiness. Renewable energy expansion does not automatically generate macroeconomic wealth; it requires a sophisticated absorptive capacity that the region is currently building. Until the structural bottlenecks in trade composition and urban industrialization are resolved, Central Asia will remain dependent on traditional foreign investment to drive growth, while the full macroeconomic potential of its rich renewable energy resources remains locked behind a necessary phase of deep infrastructural modernization.

7. Policy Recommendations

Based on the econometric evidence presented in this study, Central Asian policymakers must shift their focus from merely expanding energy capacity to actively improving the structural enabling environment of their economies. The following four strategies are recommended:

Strategic Channelling of Green FDI: Because FDI is the only statistically significant long-run driver of growth, governments must aggressively pivot their FDI attraction strategies. Rather than allowing foreign capital to flow exclusively into extractive industries, policymakers should implement targeted tax incentives, streamlined permitting, and special economic zones designed to attract green FDI in grid modernization, renewable generation technology, and domestic manufacturing of solar and wind components, ensuring that technology transfer occurs locally.

Export Diversification and Value-Chain Upgrading: The insignificance of trade openness indicates that exporting raw commodities is no longer sufficient for long-term growth. Governments must prioritize industrial policies that add value to exports—particularly by developing domestic refining and component manufacturing capabilities to participate in higher-value tiers of the global green supply chain.

Sustainable Urban Industrialization: To ensure that urbanization translates into economic growth, city planning must be integrated with industrial strategy. Policymakers must invest in sustainable, high-density urban infrastructure, smart grids, and electrified public transit, while aligning education and vocational training with the needs of a modern, low-carbon urban economy to create high-productivity jobs that absorb migrating rural populations.

Regional Energy Integration: The strong cross-sectional dependence observed in the data confirms that Central Asian economies are deeply interconnected. Rather than pursuing isolated national energy strategies, the five republics should establish a highly integrated regional power grid. A modernized, flexible, cross-border transmission network would allow countries with distinct renewable profiles—hydropower in Tajikistan, solar and wind in Kazakhstan—to balance load efficiently, reducing transition costs and enhancing collective energy security.

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