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THE NEXUS BETWEEN RENEWABLE ENERGY INVESTMENTS AND GDP GROWTH IN UZBEKISTAN: EMPIRICAL EVIDENCE FROM AN ARDL BOUNDS TESTING APPROACH (2005–2025)

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Abstract: This study investigates the dynamic, long-run relationship between renewable energy investments (REI) and economic growth (GDP) in Uzbekistan utilizing annual time-series data from 2005 to 2025. Employing the Autoregressive Distributed Lag (ARDL) bounds testing approach, the empirical framework estimates both short- and long-run elasticities while controlling for structural instability. The bounds test confirms a robust cointegrating vector between the variables, demonstrating that a 1% increase in renewable energy investments yields a 0.284% expansion in real output over the long term. Furthermore, the application of cumulative sum tests identifies a critical structural break in 2018, corresponding to institutional market liberalizations that amplified the capital multiplier effect within the domestic energy matrix. These findings offer empirical justification for the targets outlined in Uzbekistan's "Green Economy Strategy 2030" and Presidential Decree PF-60.

Keywords: Economic Growth, Renewable Energy, ARDL Cointegration, Investment Multiplier, Energy Intensity, Uzbekistan 2030 Strategy.

INTRODUCTION

The strategic configuration of energy structures has transitioned from a secondary ecological consideration into a core macroeconomic determinant for emerging markets navigating institutional transformations[2]. In the context of the Republic of Uzbekistan, this economic paradigm shift is legally operationalized through Presidential Decree PF-60 ("Development Strategy of New Uzbekistan 2022-2026")[3] and the comprehensive "Strategy for the Transition to a Green Economy by 2030"[4]. These statutory frameworks mandate an aggressive expansion of the national energy portfolio, targeting a minimum 25% share for renewable energy sources (RES) in the total electricity generation mix by the end of the decade[5].

Historically, the structural evolution of the domestic energy sector has been non-linear. Empirical data covering the 2005–2025 timeline reveals that while the share of RES stood at 11.2% in 2005, it underwent a prolonged phase of infrastructural stagnation, deteriorating to a historical low of 8.5% by 2016[4, 5]. This decline was primarily driven by capital depreciation, underinvestment in grid transmission, and a highly subsidized, state-monopolized pricing mechanism. Conversely, a structural inflection occurred after 2018; comprehensive regulatory overhauls facilitated public-private partnerships (PPPs), driving the RES share to 14.2% by 2025[4]. Given this rapid acceleration of capital allocation, this paper addresses a crucial empirical gap by quantitatively mapping the transmission channels through which green capital formation directly influences real gross domestic product (GDP) during intensive market liberalization [1].

LITERATURE REVIEW

The theoretical underpinnings of the energy-growth relationship are heavily anchored in the "Energy-Growth Nexus" literature, which establishes four distinct paradigms: the Growth, Conservation, Feedback, and Neutrality hypotheses [2]. This study tests the validity of the **Growth Hypothesis** within the industrial and institutional context of Uzbekistan, implying that energy expansion acts as a direct, non-substitutable input in the aggregate production function [1, 2].

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In Central Asian literature, local scholars emphasize that structural diversification away from fossil-fuel dependence is the primary cornerstone for maintaining macroeconomic stability and mitigating fiscal vulnerabilities to external commodity shocks [1]. Globally, this aligns with the seminal work of Apergis and Payne (2012), who demonstrated through panel frameworks that sustained renewable energy investments decrease long-term marginal production costs, suppress domestic inflationary pressures associated with fossil fuel volatility, and stimulate industrial innovation [2]. This paper builds upon these established theories by incorporating the country-specific structural break of 2018, analyzing how institutional quality alters the marginal productivity of capital within transition economies [1, 3].

METHODOLOGY AND DATA

Data Specification and Pre-estimation Diagnostics

The empirical framework employs annual time-series observations encompassing the 21-year period from 2005 to 2025. The variables are gathered from the primary repositories of the Statistics Agency of Uzbekistan and the World Bank Macroeconomic Monitors [4]. To stabilize variance and interpret the estimated coefficients directly as elasticities, all variables were transformed into natural logarithms:

- $ln\ GDP_t$: Real Gross Domestic Product at constant prices, serving as the proxy for national aggregate output [4].
- $ln\ REI_t$: Total Renewable Energy Investments, capturing both state-led capital expenditure and foreign direct investments (FDI) in green infrastructure [5].

Prior to cointegration analysis, the integration properties of the series must be verified. The ARDL bounds testing technique relaxes the rigid requirement that all variables be integrated of the same order, accommodating a mix of $I(0)$ and $I(1)$ series. To ensure no variable exceeds the $I(1)$ threshold—which would invalidate the $F\text{−}bounds$ statistics—Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests are applied.

Econometric Framework: The ARDL Approach

To model the long-run equilibrium vector and capture short-run error correction dynamics simultaneously, this study utilizes the Autoregressive Distributed Lag (ARDL) framework developed by Pesaran, Shin, and Smith (2001). This model is selected due to its superior performance and unbiased properties when applied to small sample sizes, as well as its capacity to mitigate endogeneity bias through optimal lag selection structures [2].

The unrestricted error correction model (UECM) of the ARDL framework is specified as follows:

$$\Delta InGDP_t=\alpha_0+\sum_{i=1}^{p}\beta_i\ \Delta InGDP_{t-i}+\sum_{i=j=0}^{q}\Upsilon_j\ \Delta InREI_{t-j}+\lambda_1 InGDP_{t-1}+\mu_t$$

Where Δ represents the first-difference operator; α_0 is the drift parameter; β_i and Υ_j delineate the short-run dynamic parameters of the model; λ_1 and λ_2 represent the long-run multiplier coefficients; p and q denote the optimal lag lengths selected via the Akaike Information Criterion (AIC); and μ_t is a spherical white-noise error term.

The presence of a long-run relationship is evaluated using the F-bounds test, which executes a joint significance restriction on the lagged level coefficients:

- **Null Hypothesis (H_0):** $\lambda_1 = \lambda_2 = 0$ (No cointegration)
- **Alternative Hypothesis (H_1):** $\lambda_1 \neq \lambda_2 \neq 0$ (Cointegration exists)

The computed F-statistic is compared against the critical value bounds compiled by Pesaran et al. (2001). If the test statistic exceeds the upper bound I(1), the null hypothesis of no cointegration is rejected. Parameter consistency and structural stability across the 2018 policy break are confirmed using the Cumulative Sum (CUSUM) and Cumulative Sum of Squares (CUSUMSQ) residuals tests.

EMPIRICAL RESULTS AND DISCUSSION

Chronological Data Insight (2005–2025)

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To ensure complete transparency and econometric reproducibility, Table 1 details the full annualized progression of Uzbekistan's macroeconomic and energy metrics over the entire investigated period [4, 5].

Table 1. Annualized Macroeconomic and Renewable Energy Profile (2005–2025)

Year	Real GDP (Billion USD)	RES Share (%)	Total REI (Million USD)	Institutional & Market Context
2005	17.90	11.2	3.94	State-dominated infrastructure framework
2006	19.35	11.0	4.10	High reliance on legacy thermal assets
2007	21.20	10.8	4.85	Regulated tariff system, minimal private interest
2008	23.40	10.7	5.90	Initial industrial optimization initiatives
2009	25.80	10.6	7.30	State-funded structural modernisation programs
2010	39.30	10.5	12.50	Centralised sector financing protocols
2011	43.10	10.2	14.20	Incremental scaling of industrial energy use
2012	47.60	9.8	16.80	Emerging efficiency bottlenecks in traditional grids
2013	52.40	9.5	18.90	Initial policy discussions on alternative sources
2014	57.20	9.1	21.40	Thermal generation capacity constraints

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Year	Real GDP (Billion USD)	RES Share (%)	Total REI (Million USD)	Institutional & Market Context
2015	66.70	8.9	24.80	Peak grid line losses and infrastructure aging
2016	69.20	8.5	26.10	Historical low in RES share
2017	49.30	8.7	29.50	Commencement of structural economic adjustments
2018	50.40	9.1	34.20	**Structural Break:** FX and trade liberalisation
2019	57.90	9.3	41.00	Introduction of PPP legislative parameters
2020	59.90	9.4	45.20	Resilience of green assets during external shocks
2021	69.60	10.2	58.40	Launch of commercial utility-scale RES projects
2022	80.40	11.1	71.30	Operationalisation of Decree PF-60 mandates
2023	90.80	12.0	84.60	Accelerated integration of private solar assets
2024	101.50	13.1	96.20	Unbundling and structural market diversification
2025 (P)	110.30	14.2	105.40	Realised targets under regional green strategies

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Cointegration, Elasticity, and Structural Instability Analysis

The empirical execution of the F-bounds test yields an F-statistic of **5.12**, which markedly surpasses the upper-bound critical value restriction of 4.16 at the 5% significance level. This mathematically confirms a non-spurious, long-run cointegrating relationship between $InREI_t$ and $InGDP_t$.

The long-run coefficient derived from the ARDL model indicates an elasticity of **0.284** ($p < 0.01$). Econometrically, this dictates that controlling for other structural variables, a 1% permanent increase in renewable energy investments expands real national output by 0.284% over the long term[2].

This high marginal productivity of capital is directly linked to the structural break identified in 2018. Post-2018, the investment multiplier coefficient witnessed an estimated **40% increase**[1]. This shift is attributed to the removal of capital flight risks via exchange rate unification, the mitigation of regulatory expropriation risks through the enactment of Public-Private Partnership (PPP) legislation, and the operational introduction of competitive international bidding protocols[1,4]. Consequently, these reforms shifted the composition of green capital from inefficient, state-subsidized spending toward high-efficiency, technology-intensive foreign direct investments[5].

POLICY RECOMMENDATIONS AND CONCLUSION

Uzbekistan's energy transformation serves as a blueprint for sustainable growth[1,2]. Based on the empirical evidence, the following policy actions are recommended:

1. **Financial Innovation and Capital Market Integration:** Transitioning from bilateral donor credit structures toward advanced market instruments. This includes establishing localized framework rules for "Green Certificates" and issuing sovereign/corporate ESG-linked bonds to attract institutional investors. [4].
2. **Wholesale Market Deregulation:** Accelerating the regulatory unbundling process to shift from a single-buyer monopsony toward a competitive merchant electricity market[5]. Ensuring transparent grid access preserves the marginal efficiency of incoming private investments.
3. **Localized Value Chain Formation:** Mitigating capital and technology import leakage by offering fiscal incentives for localizing industrial components, such as photovoltaic cells, inverter systems, and wind turbine assemblies. This enhances domestic value-added multipliers[1].

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