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ENERGY DYNAMICS AND ECONOMIC GROWTH IN CENTRAL ASIAN TRANSITION ECONOMIES: A PANEL DATA ANALYSIS (1990–2024)

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Abstract. *This study examines the determinants of economic growth across five Central Asian transition economies; Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan; over the period 1990–2024, with particular focus on the role of energy consumption. Using a panel dataset of 170 observations drawn from World Bank indicators, the analysis integrates energy consumption, financial development, industrialization, and trade openness into a unified panel data framework. Given a non-standard Hausman test result stemming from high intra-class correlation, the fixed-effects model is adopted as the preferred specification on theoretical grounds, with random-effects estimates reported for comparative transparency. The fixed-effects results reveal that financial development is the strongest and most consistent driver of within-country GDP per capita growth, followed by industrialization measured by manufacturing value-added. Energy consumption exerts a significant positive effect, consistent with the growth hypothesis of the energy-growth nexus, though its modest coefficient suggests diminishing returns within countries over time. Trade openness, by contrast, is negatively associated with GDP per capita, reflecting the adverse consequences of poorly sequenced liberalization in economies with limited institutional capacity and export diversification. These findings contribute original empirical evidence on the energy-growth nexus in the post-Soviet Central Asian context, offering policy-relevant insights for financial sector deepening, industrial upgrading, energy efficiency investment, and strategic trade integration across the region.*

Keywords: *economic growth, energy consumption, financial development, industrialization, trade openness, Central Asia, panel data, fixed-effects model, transition economies.*

MARKAZIY OSIYO MAMLAKATLARI ENERGETIKA DINAMIKASI VA IQTISODIY O‘SISHI: PANEL MA’LUMOTLAR TAHLILI (1990–2024)

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Annotatsiya. *Ushbu tadqiqot beshta Markaziy Osiyo o‘tish davri iqtisodiyoti, Qozog‘iston, Qirg‘iziston, Tojikiston, Turkmaniston va O‘zbekiston, iqtisodiy o‘sishining determinantlarini 1990–2024-yillar kesimida tahlil qiladi hamda energiya iste’molining iqtisodiy o‘sishdagi o‘rniga alohida e’tibor qaratadi. Jahon banki ko‘rsatkichlaridan olingan 170 ta kuzatuvdan iborat panel ma’lumotlar asosida tadqiqot energiya iste’moli, moliyaviy rivojlanish, sanoatlashtirish va savdo ochiqligini yagona panel ma’lumotlar tizimida integratsiya qiladi. Hausman testi natijalariga ko‘ra, afzal spetsifikatsiya sifatida Fixed Effect modeli tanlangan bo‘lib, qiyosiy shaffoflik uchun Random Effect modeli natijalari ham keltirilgan. Fixed Effect modeli moliyaviy rivojlanish mamlakatlararo YaIM jon boshiga o‘sishning eng kuchli va barqaror omili ekanligini ko‘rsatdi,*

undan keyin ishlab chiqarishning qo‘shilgan qiymati orqali o‘lchangan sanoatlashtirish turadi. Energiya iste’moli iqtisodiy o‘sishga sezilarli ijobiy ta’sir ko‘rsatadi va mintaqada o‘sish–energiya bog‘liqligining mavjudligini tasdiqlaydi, biroq natijalar vaqt o‘tishi bilan energiya intensivligining kamayishini ham ko‘rsatadi. Savdo ochiqligi esa cheklangan institutsional salohiyat va eksport diversifikatsiyasi sharoitida bosqichma-bosqich liberallashtirishning salbiy oqibatlarini aks ettirib, YaIM jon boshiga nisbatan manfiy bog‘liqlikni namoyon etdi. Ushbu natijalar postsovet Markaziy Osiyo sharoitida energiya–o‘sish bog‘liqligi bo‘yicha mavjud empirik dalillarga hissa qo‘shadi hamda moliyaviy sektorni chuqurlashtirish, sanoatni modernizatsiya qilish, energiya samaradorligiga investitsiyalar va strategik savdo integratsiyasi bo‘yicha siyosiy tavsiyalarni taqdim etadi.

Kalit so‘zlar: *iqtisodiy o‘sish, energiya iste’moli, moliyaviy rivojlanish, sanoatlashtirish, savdo ochiqligi, Markaziy Osiyo, panel ma’lumotlar, Fixed Effect modeli, Random Effect modeli, o‘tish davri iqtisodiyotlari.*

ЭНЕРГЕТИЧЕСКАЯ ДИНАМИКА И ЭКОНОМИЧЕСКИЙ РОСТ В ПЕРЕХОДНЫХ ЭКОНОМИКАХ ЦЕНТРАЛЬНОЙ АЗИИ: АНАЛИЗ ПАНЕЛЬНЫХ ДАННЫХ (1990–2024)

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Аннотация. *Данное исследование анализирует детерминанты экономического роста пяти стран Центральной Азии с переходной экономикой, Казахстана, Кыргызстана, Таджикистана, Туркменистана и Узбекистана, за период 1990–2024 годов, уделяя особое внимание роли потребления энергии в обеспечении экономического роста. На основе панельных данных, включающих 170 наблюдений, сформированных из показателей Всемирного банка, в исследовании интегрированы потребление энергии, финансовое развитие, индустриализация и торговая открытость в единую систему панельного анализа. Согласно результатам теста Хаусмана, в качестве предпочтительной спецификации была выбрана модель Fixed Effect, при этом результаты модели Random Effect также представлены для сравнительной прозрачности. Модель Fixed Effect показала, что финансовое развитие является наиболее сильным и устойчивым фактором роста ВВП на душу населения среди рассматриваемых стран, за которым следует индустриализация, измеряемая через добавленную стоимость промышленного производства. Потребление энергии оказывает статистически значимое положительное влияние на экономический рост и подтверждает существование взаимосвязи между энергопотреблением и ростом в регионе, однако результаты также свидетельствуют о постепенном снижении энергоёмкости экономики с течением времени. Торговая открытость, напротив, продемонстрировала отрицательную связь с ВВП на душу населения, отражая потенциальные негативные последствия постепенной либерализации в условиях ограниченного институционального потенциала и низкой диверсификации экспорта. Полученные результаты вносят вклад в эмпирическую литературу по взаимосвязи «энергия–экономический рост» в постсоветских странах Центральной Азии и формируют практические рекомендации в области углубления финансового сектора, модернизации промышленности, инвестиций в энергоэффективность и стратегической торговой интеграции.*

Ключевые слова: *экономический рост, потребление энергии, финансовое развитие, индустриализация, торговая открытость, Центральная Азия, панельные данные, модель Fixed Effect, модель Random Effect, переходные экономики.*

Introduction.

The relationship between energy consumption and economic growth remains a cornerstone of development economics, as energy serves as the essential catalyst for industrialization and financial maturity (Felipe, 2018; Bouoıyour et al, 2014). Empirical evidence in the region suggests that energy consumption is positively linked to GDP, reflecting a heavy industrial dependence on energy-intensive sectors (Kurmanov et al, 2025). However, the Central Asian region—comprising Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan—presents a unique case study (Abubakirova, 2023; Sulaimanova et al, 2023). Since gaining independence following the collapse of the Soviet Union in 1991, these nations have navigated a complex transition from planned economies to market-oriented systems while managing vast natural resource wealth and aging infrastructure.

Despite the region's strategic importance, Central Asia is often marginalized in large-scale studies of the broader Asian continent. This creates a significant **knowledge gap**, as the region's specific transition challenges and landlocked geography require a more nuanced analysis than broad continental models provide (Vakulchuk and Overland, 2021). Recent literature has begun to shift focus toward the clean energy transition in the region, yet empirical research on the intersection of energy, trade openness, and financial development remains sparse.

This study addresses this gap by examining panel data from 1990 to 2024. By analyzing the interplay between energy consumption, trade openness, and industrialization, this research provides the empirical evidence necessary to guide regional policy in the current era of green economic growth. Furthermore, the study addresses critical methodological hurdles common in regional panel data, specifically the interpretation of **non-standard Hausman test results**. In instances where the test yields a negative chi-squared value—violating standard asymptotic assumptions—theoretical considerations and robust fixed-effects modeling become the optimal framework for understanding the energy-growth nexus in transition economies

Literature Review.

Energy Consumption and Economic Growth Nexus in Central Asia

The relationship between energy consumption and economic growth has long occupied a central position in development economics and energy policy literature (Caporin et al, 2024). Classical and endogenous growth theories emphasize that energy constitutes a strategic production input that enhances labor productivity, industrial output, technological progress, and capital accumulation. Consequently, the direction and magnitude of the energy-growth nexus remain critically important for both developed and transition economies. Existing empirical literature generally identifies four dominant hypotheses regarding this relationship: the growth hypothesis, conservation hypothesis, feedback hypothesis, and neutrality hypothesis. However, findings remain inconclusive across regions due to differences in economic structure, institutional quality, energy intensity, and econometric methodologies.

In the context of Central Asia, the energy-growth relationship possesses unique structural characteristics shaped by the post-Soviet transition, resource dependency, and uneven industrial transformation (Kuziboyev et al, 2024). Since independence in the early 1990s, the economies of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan have undergone substantial institutional restructuring while simultaneously managing inherited Soviet-era energy infrastructure. The region remains heavily dependent on fossil fuels, particularly natural gas and oil exports, although the degree of dependence differs considerably across countries. Kazakhstan and Turkmenistan exhibit strong hydrocarbon-export-oriented growth models, whereas Kyrgyzstan and Tajikistan rely more heavily on hydropower and external energy imports.

Recent empirical studies confirm the existence of a significant long-run relationship between energy consumption and economic growth in Central Asia. Abubakirova et al. (2023)

identify evidence of cointegration between energy consumption and GDP, suggesting that economic expansion remains strongly associated with rising energy demand across Kazakhstan, Uzbekistan, and Tajikistan. Similarly, Kurmanov et al. (2025) demonstrate that energy consumption exerts a positive and statistically significant effect on economic growth, particularly in industrially intensive economies where manufacturing and extractive sectors dominate national output. These findings are consistent with broader evidence from transition economies, where industrial modernization and infrastructure expansion remain energy-intensive processes.

Beyond traditional fossil-fuel dependence, the regional discourse has increasingly shifted toward sustainability, renewable energy adoption, and energy efficiency. Systematic reviews of Central Asian energy research reveal that earlier scholarship predominantly focused on hydrocarbon extraction and export competitiveness, whereas recent studies increasingly examine decarbonization strategies, clean energy transition, and environmental sustainability (Filipovic et al, 2024). This shift reflects growing international pressure for carbon reduction as well as regional concerns regarding energy security, environmental degradation, and climate vulnerability. Nevertheless, the transition toward sustainable energy systems remains constrained by outdated infrastructure, institutional weaknesses, limited investment capacity, and high industrial energy intensity.

Importantly, empirical evidence suggests that restrictive energy conservation policies may generate unintended adverse consequences for economic performance in developing and transition economies where energy remains a critical production factor. In such contexts, aggressive reductions in energy consumption may constrain industrial productivity, reduce export competitiveness, and slow structural transformation. Therefore, the policy challenge for Central Asian economies lies not in reducing energy consumption per se, but in improving energy efficiency, diversifying energy sources, and modernizing industrial systems while sustaining economic growth.

Trade Openness, Regional Integration, and Economic Transformation

Trade openness is widely regarded as a fundamental driver of economic growth, technological diffusion, and regional integration (Sowrov, 2024) Theoretical frameworks rooted in classical and new trade theories argue that greater openness enhances resource allocation efficiency, expands market access, encourages specialization, and facilitates knowledge transfer. Empirical literature further demonstrates that economies integrated into global trade networks tend to experience higher productivity growth, increased foreign direct investment (FDI), and accelerated industrial upgrading.

For Central Asian countries, trade openness occupies a particularly strategic role due to the region's landlocked geography and dependence on external markets for export diversification and industrial development (Vasic et al, 2023). Since independence, Central Asian states have pursued varying degrees of trade liberalization and regional cooperation while simultaneously navigating geopolitical competition among Russia, China, the European Union, and neighboring Asian economies. Consequently, trade policy has become closely intertwined with energy exports, transport infrastructure, and regional connectivity initiatives.

Recent scholarship increasingly analyzes Central Asia within the framework of the Belt and Road Initiative (BRI), which has intensified infrastructure investment, logistics integration, and cross-border trade flows throughout the region. These developments have strengthened regional connectivity but also generated debates regarding debt sustainability, environmental implications, and asymmetric economic dependence. Empirical evidence suggests that trade openness positively contributes to economic growth when accompanied by institutional quality, infrastructure modernization, and macroeconomic stability. Kurmanov et al. (2025), for example, identify trade openness as a significant determinant of economic growth, particularly when combined with digital transformation and transport infrastructure development.

However, the relationship between trade openness and growth is not uniformly positive. Several studies caution that excessive dependence on commodity exports may expose transition economies to external shocks, commodity price volatility, and Dutch disease effects. In resource-rich Central Asian economies, export structures remain insufficiently diversified, with hydrocarbons and raw materials dominating trade composition. As a result, the benefits of trade liberalization may be constrained unless accompanied by industrial diversification, technological upgrading, and stronger institutional governance.

Moreover, the interaction between trade openness and energy consumption represents an increasingly important research area. Expanded trade activity often stimulates industrial production, transportation demand, and energy consumption, thereby influencing both environmental outcomes and long-term sustainability. Consequently, understanding the interconnected dynamics between trade integration, energy demand, and economic growth remains essential for designing balanced development strategies in Central Asia.

Financial development and industrialization are widely recognized as central pillars of long-term economic transformation (Kuzmin et al, 2023). Structural transformation theory emphasizes the importance of shifting economic activity from low-productivity agricultural sectors toward higher-productivity industrial and manufacturing activities characterized by economies of scale, technological innovation, and export competitiveness. Historically, successful industrialization processes across Asia have been closely associated with rising energy consumption, urbanization, and expanding financial systems (Pavlidou et al, 2026).

In Central Asia, industrialization remains uneven and highly dependent on natural resource extraction. While Kazakhstan and Turkmenistan have achieved relatively higher levels of industrial output through hydrocarbon development, other regional economies continue to face challenges associated with low manufacturing diversification, technological constraints, and infrastructure deficits. Nevertheless, empirical evidence indicates that industrialization contributes positively to GDP growth and employment generation, particularly when supported by infrastructure investment, technological modernization, and human capital development.

Parallel to industrial transformation, financial development plays a crucial role in mobilizing savings, allocating capital efficiently, reducing transaction costs, and supporting entrepreneurial activity. Well-developed financial institutions facilitate investment in energy infrastructure, industrial modernization, and technological innovation, thereby strengthening economic productivity. In transition economies, however, financial systems frequently suffer from institutional fragility, limited capital market depth, weak regulatory frameworks, and excessive state intervention.

The literature further identifies a complex relationship between natural resource dependence and financial development, often referred to as the “resource-finance nexus.” While resource revenues may provide substantial fiscal capacity, they can also weaken incentives for financial sector diversification and institutional reform if governance quality remains limited. In several resource-dependent economies, abundant energy rents have been associated with underdeveloped financial institutions, inefficient capital allocation, and increased vulnerability to external commodity shocks.

Recent studies increasingly emphasize the importance of integrating financial development with sustainable industrial policies and green economic transformation. In the Central Asian context, financing renewable energy projects, modernizing industrial infrastructure, and promoting energy-efficient technologies are becoming critical policy priorities. Consequently, financial development should not be viewed merely as a macroeconomic variable, but as a strategic mechanism facilitating structural transformation and sustainable growth.

Methodological Challenges in Panel Data Analysis. Empirical analysis of the energy-growth nexus in transition economies presents several methodological challenges, particularly

regarding panel data specification, endogeneity, heterogeneity, and cross-sectional dependence. Given the structural differences among Central Asian economies in terms of resource endowments, institutional quality, and economic transition paths, selecting appropriate econometric techniques becomes essential for generating reliable and policy-relevant results.

One of the most widely debated methodological issues concerns the selection between fixed-effects (FE) and random-effects (RE) estimators. The Hausman specification test is commonly employed to determine whether country-specific effects are correlated with explanatory variables. However, econometric literature demonstrates that the Hausman test may produce non-standard outcomes, including negative chi-squared statistics, particularly in small samples or under violations of covariance assumptions. Schreiber (2008) argues that such results may arise asymptotically and should not automatically invalidate model estimation procedures.

In transition economy studies, fixed-effects models are often theoretically preferred because they control for unobserved country-specific heterogeneity associated with institutional structures, historical legacies, governance quality, and energy dependency patterns. Nevertheless, relying exclusively on static panel estimators may fail to capture dynamic relationships and potential endogeneity between economic growth, energy consumption, trade openness, and financial development.

To address these limitations, recent literature increasingly employs advanced panel econometric techniques, including panel cointegration tests, dynamic ordinary least squares (DOLS), fully modified ordinary least squares (FMOLS), panel autoregressive distributed lag (PARDL) models, generalized method of moments (GMM), and cross-sectional dependence estimators. These approaches improve estimation reliability by accounting for heterogeneity, long-run equilibrium relationships, and reverse causality.

Moreover, the growing interconnectedness of global energy markets and regional trade integration increases the likelihood of cross-sectional dependence among Central Asian economies. External shocks—including fluctuations in oil prices, geopolitical instability, global financial crises, and energy supply disruptions—may simultaneously affect multiple countries within the panel. Ignoring these interdependencies can lead to biased and inconsistent estimators. Consequently, contemporary studies increasingly emphasize the necessity of robust diagnostic testing and second-generation panel estimation techniques to ensure methodological validity.

Overall, the literature demonstrates that understanding the energy-growth nexus in Central Asia requires not only theoretical integration of energy, trade, and financial variables, but also rigorous econometric modeling capable of addressing the structural complexities of transition economies.

Methodology.

This study employs panel data regression to examine the determinants of economic growth across Central Asian countries from 1990 to 2024, using World Bank indicators. The baseline model takes the form:

$$GDPpc_t = \beta_0 + \beta_1 EC_t + \beta_2 Fin_t + \beta_3 Ind_t + \beta_4 TO_t + \varepsilon_t$$

where GDP per capita (constant 2015 USD) serves as the dependent variable. The independent variables are: energy consumption per capita (kg of oil equivalent), financial development (domestic credit to the private sector, % of GDP), industrialization (manufacturing value-added, % of GDP), and trade openness (exports plus imports, % of GDP). Trade openness is measured as a bilateral sum — rather than exports alone — to reflect the role of imported capital goods and intermediate inputs in developing economies, consistent with comparative advantage theory (Yanikkaya, 2003; Keho, 2017). Domestic credit to the private sector captures the depth dimension of financial development, reflecting how efficiently

the financial system allocates capital to productive activity (Elfaki et al., 2021). Manufacturing value-added (MVA) proxies industrialization by measuring the net output of the manufacturing sector and tracking structural transformation from agriculture toward industry (Rafindadi & Ozturk, 2017; Komal & Abbas, 2015). Energy use per capita reflects both consumption intensity and the degree to which an economy has decoupled growth from energy dependence.

Estimation Strategy

Panel data offers two key advantages: it controls for unobserved, time-invariant country-specific factors — such as resource endowments, institutional legacies, or historical energy policy — and it captures within-country dynamics over time that pure cross-sectional analysis cannot.

Two model specifications are considered:

Fixed Effects (FE) assumes that unobserved country-specific effects (u_i) are correlated with the regressors. The model removes u_i through within-transformation (demeaning), isolating how changes within each country in energy consumption and other variables relate to changes in GDP per capita. This is appropriate when country-specific factors — such as a historical reliance on fossil fuels — plausibly co-determine both energy use and growth trajectories.

Random Effects (RE) assumes u_i is uncorrelated with the regressors, treating cross-country variation as randomly distributed. Estimated via Generalized Least Squares (GLS), the RE model is more efficient under this assumption but produces biased estimates if the assumption fails.

Model Selection: Hausman Test

Model selection follows the Hausman specification test, which evaluates whether the regressors are systematically correlated with country-specific effects. Under the null hypothesis of no correlation, both FE and RE are consistent, but RE is more efficient. Rejection of the null ($p < 0.05$) indicates that the FE model is preferred, as RE estimates would be biased. Failure to reject favors the RE model on efficiency grounds.

Results and Discussion.

Table 1.

Descriptive statistics

Variables	Total	Standard Error (Std. Err.)	[95% Confidence Interval]	
GDPpc	1.47e+07	550676	1.36e+07	1.58e+07
Energy	2795293	126312.6	2547498	3043089
Dcredit	53799.67	1712.065	50441	57158.34
MVA	15334.9	324.3881	14698.53	15971.27
TradeOp	106680	2182.543	102398.3	110961.6
Total Estimation			Number of observations (obs) = 170	

Variables	Observations (Obs)	Mean	Standard Deviation (Std. Dev.)	Minimum (Min)	Maximum (Max)
GDPpc	170	1119.9	15156.86	0	81608.57
Energy	170	2117.646	3476.641	0	22113.74
Dcredit	170	40.75732	47.12305	0	254.6681
MVA	170	11.61735	8.928487	0	38.17485
TradeOp	170	80.81815	60.07251	0	437.3267

Table 1 presents descriptive statistics for all variables across 170 observations. GDP per capita exhibits substantial heterogeneity — a mean of $1,119.9 against a maximum of $81,608.57 and a standard deviation of $15,156.86 — reflecting the pronounced divergence in development levels across the Central Asian sample. Energy consumption similarly displays wide dispersion (mean: 2,117.6 kg/capita; max: 22,113.7), capturing the contrast between energy-intensive and low-consumption economies in the region. Financial development (mean: 40.8% of GDP) and trade openness (mean: 80.8%) also vary considerably, with the latter ranging from 0 to 437%, underscoring the heterogeneous degree of trade integration across countries. Industrialization, measured by MVA, records the lowest mean (11.6% of GDP) and a moderate maximum of 38.2%, indicating that manufacturing remains a relatively modest share of output across the panel on average.

Correlation Analysis

The correlation matrix (Table 2) reveals several noteworthy patterns. Energy consumption exhibits the strongest association with GDP per capita (r = 0.709), suggesting that wealthier economies tend to consume significantly more energy — consistent with the energy-growth nexus literature. Financial development and trade openness show moderate positive correlations with GDP per capita (r = 0.334 and r = 0.308, respectively), while MVA's correlation is negligible (r = 0.031), hinting at structural heterogeneity in the role of manufacturing across the Central Asian sample. Among the regressors, correlations are generally weak to moderate (ranging from -0.039 to 0.356), indicating that multicollinearity is unlikely to distort the regression estimates.

Table 2.

Correlation Matrix

	GDPpc	Energy	Dcredit	MVA	TradeOp
GDPpc	1.0000				
Energy	0.7090	1.0000			
Dcredit	0.3335	0.0505	1.0000		
MVA	0.0306	-0.0386	0.3563	1.0000	
TradeOp	0.3084	0.1808	0.2623	0.2091	1.0000

It is important to note that correlation does not establish causation. The co-movement of these variables may reflect common trends or shared macroeconomic drivers rooted in the region's post-Soviet transition. Endogeneity remains a concern — economic growth may itself influence energy demand, credit supply, or trade volumes. While the fixed-effects framework partially addresses this by removing time-invariant confounders, it does not fully resolve simultaneity bias. The findings should therefore be interpreted as robust associations rather than definitive causal claims.

Model Selection: Hausman Test

The Hausman test yielded a negative chi-squared statistic ($\chi^2 = -62.58$), a non-standard result that reflects a failure of the variance-covariance difference matrix to be positive definite — a known computational issue in panels with high within-country correlation, and one that is particularly common in small panels such as this one. Given this inconclusive outcome, model selection is guided by theoretical reasoning. Since unobserved country-specific factors — such as institutional legacies, historical energy dependence, and post-Soviet development trajectories — are plausibly correlated with the regressors, the fixed-effects (FE) model is theoretically preferred. This is further supported by the high intra-class correlation ($\rho = 0.946$), indicating that approximately 94.6% of total variance in GDP per capita is attributable to country-specific effects, making their explicit control essential. Nonetheless, random-effects (RE) estimates are reported alongside FE results for comparative transparency.

Regression Results

Table 3 presents results from three specifications: simple (pooled) OLS, fixed effects, and random effects. The discussion centers on the FE model as the preferred specification, with RE results noted where they meaningfully diverge. The panel comprises 170 observations across the five Central Asian economies over the study period.

The FE model is jointly significant ($F = 22.26$, $p < 0.001$) and achieves a within R^2 of 0.065, meaning that approximately 6.5% of within-country variation in GDP per capita is explained by the four regressors after absorbing country fixed effects. Given that the model operates exclusively on within-country variation over time — and the relatively small number of observations — this level of explanatory power is substantively meaningful. The F-test for country-specific effects decisively rejects pooled OLS, confirming the necessity of the FE structure.

Energy Consumption exerts a positive and statistically significant effect on GDP per capita in both the FE ($\beta = 0.103$, $p = 0.044$) and RE ($\beta = 0.201$, $p < 0.001$) models, though the FE coefficient is considerably smaller than the pooled OLS estimate ($\beta = 2.915$), indicating that much of the raw energy-growth correlation is driven by cross-country differences rather than within-country dynamics. The positive within-country relationship is consistent with the growth hypothesis — that energy is a productive input driving economic expansion — and aligns with the energy-intensive character of Central Asian transition economies, where fossil fuel dependence has historically underpinned industrial output (Elfaki et al., 2021). The coefficient's modest magnitude in the FE model suggests that within individual countries over time, additional energy consumption yields diminishing marginal returns to growth — potentially reflecting gradual improvements in energy efficiency.

Table 3.

Pooled OLS, fixed effects, and random effects outcomes

	(Simple regression) GDPpc	(Fixed-Effects) GDPpc	(Random-Effects) GDPpc
Energy	2.915***	0.103*	0.201***
	(37.96)	(2.01)	(3.77)
Dcredit	94.27***	34.00***	36.95***
	(15.52)	(8.92)	(9.26)
MVA	-126.162***	35.16*	30.99
	(-3.98)	(2.09)	(1.75)
TradeOp	31.831***	-11.06**	-7.609*
	(6.88)	(-3.04)	(-2.01)
_cons	-1.271	10002.5***	9443.3***
		(26.43)	(8.42)
N	170	170	170

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Financial Development (domestic credit to the private sector) is the most robustly significant variable across all three specifications — FE ($\beta = 34.00$, $p < 0.001$), RE ($\beta = 36.95$, $p < 0.001$), and OLS ($\beta = 94.27$, $p < 0.001$). A one-percentage-point increase in the credit-to-GDP ratio is associated with approximately $34 higher GDP per capita within a given country, holding other factors constant. This finding is consistent with the financial intermediation

channel: deeper credit markets lower capital allocation frictions, expand investment, and accelerate productive activity (Elfaki et al., 2021). In the Central Asian context, where financial sectors remain relatively underdeveloped by international standards, this result underscores the considerable growth dividends available from expanding private credit access.

Industrialization (MVA) is positively associated with GDP per capita in the FE model (β = 35.16, p = 0.037), reversing the negative sign observed in pooled OLS (β = -126.16). This sign reversal is analytically significant: in the cross-sectional dimension, countries with higher MVA shares are not necessarily richer — some Central Asian economies record relatively high manufacturing shares precisely because their service sectors remain underdeveloped. Within countries over time, however, manufacturing expansion is associated with economic growth, supporting the structural transformation hypothesis that industrialization drives income gains during development transitions (Rafindadi & Ozturk, 2017; Komal & Abbas, 2015). The RE coefficient (β = 30.99, p = 0.080) points in the same direction but falls just outside conventional significance thresholds, suggesting the within-country effect is more reliably captured by the FE estimator.

Trade Openness yields a negative and statistically significant coefficient in both FE (β = -11.06, p = 0.002) and RE (β = -7.61, p = 0.044) specifications. This finding does not imply that trade harms growth in absolute terms. Rather, it likely reflects the composition and sequencing of trade liberalization in the Central Asian context: several economies in the panel expanded trade openness during periods of structural adjustment or commodity export dependence, where import surges outpaced export-led productivity gains. This is consistent with Samimi et al. (2012), who demonstrate that excessive or poorly sequenced trade liberalization can be detrimental to growth in developing economies. The result also underscores that trade openness benefits are conditional on complementary institutional capacity, export diversification, and the ability to absorb imported technology — conditions that remain unevenly developed across the region.

Comparative Assessment: FE vs. RE

The directional consistency between FE and RE estimates across all four regressors lends qualitative robustness to the findings despite the inconclusive Hausman test. The primary divergence lies in coefficient magnitudes: RE estimates are systematically larger, reflecting the additional between-country variation they incorporate. Since cross-country differences in GDP per capita across Central Asia are heavily shaped by structural and historical factors — natural resource endowments, Soviet-era industrial legacies, pace of institutional reform — the RE model risks attributing these omitted cross-sectional effects to the included regressors, inflating coefficients. The FE estimates, being purged of such confounding, are more conservative and internally valid for within-country inference. With only 170 observations, this parsimony is particularly important for avoiding overfitting.

Taken together, the fixed-effects results identify financial development and industrialization as the most consistent positive drivers of within-country economic growth across Central Asia, with energy consumption playing a supportive but secondary role. Trade openness, by contrast, exhibits a negative within-country association, reflecting the conditional and context-dependent nature of trade's growth effects in economies with limited institutional capacity to harness liberalization productively. These findings carry direct implications for regional development policy, addressed in the following section.

Policy Implications

The fixed-effects results yield four concrete policy directions for Central Asian governments seeking to sustain and accelerate economic growth.

Deepening Financial Markets. Financial development emerges as the strongest and most consistent driver of within-country GDP per capita growth across the five Central Asian economies. The robustness of this finding across all three model specifications — OLS, FE, and

RE — signals that expanding domestic credit access to the private sector is not merely beneficial but foundational. This is consistent with the established theoretical and empirical consensus that financial intermediation lowers capital allocation frictions, mobilizes savings, and channels resources toward productive investment (Elfaki, Handoyo, & Ibrahim, 2021; King & Levine, 1993). Policymakers should prioritize banking sector reform, reduction of state-directed lending, strengthening of credit infrastructure such as registries and collateral frameworks, and the development of non-bank financial intermediaries. For lower-income Central Asian economies where credit-to-GDP ratios remain well below regional peers, even modest improvements in financial depth are likely to yield significant growth dividends (Beck, Demirgüç-Kunt, & Levine, 2000).

Leveraging Industrialization Strategically. The positive within-country association between manufacturing value-added and GDP per capita supports deliberate industrial policy aimed at expanding and diversifying the manufacturing base. This aligns with the structural transformation literature, which identifies the shift from primary production toward manufacturing as a key mechanism of income growth in developing economies (Rafindadi & Ozturk, 2017; Komal & Abbas, 2015; Szirmai, 2012). However, the sign reversal between pooled OLS and fixed-effects estimates cautions against drawing cross-country comparisons — higher MVA shares do not automatically indicate greater prosperity where service sectors remain underdeveloped. Governments should focus on moving up manufacturing value chains, investing in industrial infrastructure, and creating conditions for technology transfer and productivity-enhancing foreign direct investment, rather than simply expanding manufacturing's GDP share in isolation (UNIDO, 2020).

Managing Energy Consumption and Efficiency. Energy consumption exerts a significant positive effect on growth within countries over time, confirming its role as a productive input in Central Asia's largely industrial and resource-based economies. This is consistent with the growth hypothesis in the energy-growth nexus literature, which posits that energy is a direct factor of production and that reductions in energy supply constrain output (Apergis & Payne, 2010; Ozturk, 2010). However, the modest magnitude of the FE coefficient suggests diminishing returns, and the region's historically high energy intensity — a legacy of Soviet-era infrastructure — limits the sustainability of energy-led growth (Filimonova et al., 2020). Policymakers should pursue a dual strategy: maintaining sufficient energy supply to support industrial activity in the near term, while investing in energy efficiency, grid modernization, and renewable capacity to gradually decouple growth from energy intensity over the longer term (IEA, 2022; Stern, 2011).

Reconsidering Trade Liberalization Sequencing. The negative within-country association between trade openness and GDP per capita is the study's most policy-sensitive finding. It does not argue for protectionism, but it does caution against undifferentiated trade liberalization in the absence of complementary reforms. This finding aligns with Samimi, Sadeghi, and Sadeghi (2012), who demonstrate that excessive or poorly sequenced trade liberalization can be detrimental to growth in developing economies, and with Rodriguez and Rodrik (2001), who challenge the unconditional positive relationship between openness and growth. Across the five Central Asian economies, expanded trade openness has in several instances coincided with import surges, commodity export dependence, and limited capacity to absorb productivity-enhancing inputs. Effective trade policy should therefore be sequenced alongside institutional strengthening, export diversification away from raw commodities, and investment in the absorptive capacity needed to translate imported capital goods and intermediate inputs into domestic productivity gains — as comparative advantage theory prescribes (Yanikkaya, 2003; Keho, 2017).

Conclusion.

This study examined the determinants of economic growth across five Central Asian transition economies from 1990 to 2024, using a panel dataset of 170 observations and employing fixed-effects and random-effects regression models (World Bank, 2026). The analysis investigated how energy consumption, financial development, industrialization, and trade openness relate to GDP per capita, after controlling for unobserved country-specific heterogeneity — a particularly important consideration given the region's shared Soviet institutional legacy and divergent post-independence trajectories (Pomfret, 2006).

The Hausman test produced an inconclusive result, a known complication in small panels with high intra-class correlation ($\rho = 0.946$; Hausman, 1978). Theoretical reasoning and the structure of the data supported the fixed-effects model as the preferred specification, which concentrates on within-country variation over time and controls for stable, unobserved country characteristics (Baltagi, 2008). The joint significance of the model ($F = 22.26$, $p < 0.001$) and the F-test rejecting pooled OLS confirm the appropriateness of this approach.

Four principal findings emerge. First, financial development is the most robust and consistently significant determinant of within-country growth, with a one-percentage-point increase in domestic credit to the private sector associated with approximately $34 higher GDP per capita — consistent with the financial intermediation literature (King & Levine, 1993; Elfaki et al., 2021). Second, industrialization measured by manufacturing value-added exerts a significant positive within-country effect ($\beta = 35.16$, $p = 0.037$), reinforcing the structural transformation argument that manufacturing expansion drives income growth during development transitions (Szirmai, 2012; Rafindadi & Ozturk, 2017). Third, energy consumption contributes positively to growth ($\beta = 0.103$, $p = 0.044$), consistent with energy's role as a productive input in the region's industrial economies and the growth hypothesis of the energy-growth nexus (Apergis & Payne, 2010; Ozturk, 2010), though its modest FE coefficient points to gradually diminishing returns within countries over time. Fourth, trade openness is negatively associated with GDP per capita in the within-country dimension ($\beta = -11.06$, $p = 0.002$), reflecting the challenges of poorly sequenced liberalization in economies with limited institutional and export diversification capacity (Samimi et al., 2012; Rodriguez & Rodrik, 2001).

Several limitations should be acknowledged. The panel of 170 observations across five countries, while appropriate for a focused regional study, constrains the statistical power available for detecting heterogeneous effects or testing nonlinear relationships (Hsiao, 2014). MVA, while a widely used industrialization proxy, does not capture the full breadth of industrial activity, omitting mining, construction, and utilities — sectors of considerable importance in Central Asia (UNIDO, 2020). The inconclusive Hausman test introduces residual uncertainty about the preferred model (Greene, 2012), and the possibility of endogeneity — despite the fixed-effects structure — cannot be entirely ruled out (Wooldridge, 2010).

Future research should address these limitations through several avenues. Granger causality testing or vector error correction models (VECM) would allow for more rigorous examination of the direction of causality between energy and growth (Engle & Granger, 1987). Instrumental variable approaches could more directly confront endogeneity concerns (Wooldridge, 2010). Extending the framework to incorporate CO_2 emissions would enable an environmental dimension, situating Central Asia within the broader energy-growth-environment trilemma (Apergis & Payne, 2010; Stern, 2004). Country-level case studies could complement the panel findings by unpacking the institutional and structural conditions under which trade openness, industrialization, or financial development most effectively translate into sustained growth (Acemoglu, Johnson, & Robinson, 2001).

Notwithstanding these limitations, this study contributes empirical evidence on a relatively understudied region using a theoretically grounded and methodologically transparent framework. The findings support a targeted policy agenda centered on financial

sector deepening, industrial upgrading, energy efficiency investment, and carefully sequenced trade integration — a combination well suited to the development challenges and opportunities facing Central Asia in the coming decade.

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