



IQTISODIYOT & TARAQQIYOT

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THE ROLE OF DIGITAL INFRASTRUCTURE IN PROMOTING GREEN ECONOMIC GROWTH: EVIDENCE FROM CENTRAL ASIAN ECONOMIES

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Abstract. Digital infrastructure has emerged as a critical driver of economic transformation and sustainable development in both developed and developing economies. However, empirical evidence regarding its contribution to green economic growth remains limited, particularly in the context of Central Asia. This study examines the impact of digital infrastructure on green economic growth in four Central Asian economies over the period 2006–2021. A composite Digital Infrastructure Index (DII) is constructed using Principal Component Analysis based on Internet usage, mobile subscriptions, and broadband penetration indicators. Green economic growth is measured through adjusted net savings, which captures the sustainability dimension of economic development by accounting for investments in human capital, natural resource depletion, and environmental damages. The analysis employs panel econometric techniques, including fixed-effects and random-effects estimators, with model selection guided by the Hausman specification test. The empirical results indicate that the random-effects model is the most appropriate specification. The findings reveal that digital infrastructure exerts a statistically significant negative effect on adjusted net savings, suggesting that the current phase of digital expansion in Central Asia has not yet translated into improvements in sustainable economic performance. GDP growth and trade openness also demonstrate significant negative effects on adjusted net savings, while foreign direct investment does not exhibit a statistically significant impact. These results imply that digital transformation alone is insufficient to promote green economic growth unless accompanied by effective environmental policies, resource-efficient technologies, and sustainability-oriented development strategies. The study contributes to the growing literature on digitalization and sustainability by providing new evidence from an underexplored region and highlighting the complex relationship between technological advancement and sustainable development.

Keywords: digital infrastructure; green economic growth; adjusted net savings; Central Asia; sustainable development; panel data analysis.

Annotatsiya. Raqamli infratuzilma rivojlangan va rivojlanayotgan iqtisodiyotlarda iqtisodiy transformatsiya hamda barqaror rivojlanishning muhim omiliga aylanmoqda. Biroq uning yashil iqtisodiy o'sishga qo'shayotgan hissasi bo'yicha empirik dalillar, ayniqsa, Markaziy Osiyo sharoitida hali yetarli darajada o'rganilmagan. Ushbu tadqiqotda 2006–2021-yillar davrida to'rtta Markaziy Osiyo mamlakatida raqamli infratuzilmaning yashil iqtisodiy o'sishga ta'siri o'rganilgan. Internetdan foydalanish, mobil aloqa abonentlari soni va keng polosali internetga ulanish ko'rsatkichlari asosida asosiy komponentlar tahlili usuli yordamida kompozit Raqamli infratuzilma indeksi shakllantirilgan. Yashil iqtisodiy o'sish ko'rsatkichi sifatida inson kapitaliga investitsiyalar, tabiiy resurslarning kamayishi va ekologik zararlarni hisobga oluvchi tuzatilgan sof jamg'armalar ko'rsatkichi qo'llanilgan. Tahlilda Hausman spetsifikatsiya testi asosida model tanlovi amalga oshirilib, panel ekonometrik usullar, jumladan, qat'iy effektlar va tasodifiy effektlar modellari qo'llanilgan. Empirik natijalar tasodifiy effektlar modeli eng maqbul spetsifikatsiya ekanligini ko'rsatdi. Tadqiqot natijalariga ko'ra, raqamli infratuzilma tuzatilgan sof jamg'armalarga statistik jihatdan ahamiyatli salbiy ta'sir ko'rsatadi. Bu esa Markaziy Osiyoda raqamli kengayishning hozirgi



bosqichi hali barqaror iqtisodiy natijalarni yaxshilashga to'liq olib kelmaganini anglatadi. YaIM o'sishi va savdo ochiqligi ham tuzatilgan sof jamg'armalarga sezilarli salbiy ta'sir ko'rsatgan bo'lsa, to'g'ridan-to'g'ri xorijiy investitsiyalar statistik jihatdan ahamiyatli ta'sir ko'rsatmagan. Ushbu natijalar raqamli transformatsiyaning o'zi yashil iqtisodiy o'sishni ta'minlash uchun yetarli emasligini, bu jarayon samarali ekologik siyosat, resurs tejamkor texnologiyalar va barqarorlikka yo'naltirilgan rivojlanish strategiyalari bilan uyg'unlashishi zarurligini ko'rsatadi. Tadqiqot raqamlashtirish va barqaror rivojlanish bo'yicha ilmiy adabiyotlarga Markaziy Osiyo misolida yangi empirik dalillarni kiritadi hamda texnologik taraqqiyot va barqaror rivojlanish o'rtasidagi murakkab bog'liqlikni yoritib beradi.

Kalit so'zlar: raqamli infratuzilma; yashil iqtisodiy o'sish; tuzatilgan sof jamg'armalar; Markaziy Osiyo; barqaror rivojlanish; panel ma'lumotlar tahlili.

Аннотация. Цифровая инфраструктура становится важным фактором экономической трансформации и устойчивого развития как в развитых, так и в развивающихся экономиках. Однако эмпирические данные о её вкладе в зелёный экономический рост остаются ограниченными, особенно в контексте Центральной Азии. В данном исследовании рассматривается влияние цифровой инфраструктуры на зелёный экономический рост в четырёх странах Центральной Азии за период 2006–2021 годов. Композитный индекс цифровой инфраструктуры сформирован с использованием метода главных компонент на основе показателей использования интернета, количества абонентов мобильной связи и проникновения широкополосного доступа. В качестве показателя зелёного экономического роста использованы скорректированные чистые сбережения, отражающие устойчивый характер экономического развития с учётом инвестиций в человеческий капитал, истощения природных ресурсов и экологического ущерба. В анализе применены панельные эконометрические методы, включая модели с фиксированными и случайными эффектами, а выбор модели осуществлён на основе спецификационного теста Хаусмана. Эмпирические результаты показывают, что наиболее подходящей спецификацией является модель со случайными эффектами. Полученные результаты свидетельствуют о том, что цифровая инфраструктура оказывает статистически значимое отрицательное влияние на скорректированные чистые сбережения. Это указывает на то, что текущий этап цифрового расширения в Центральной Азии пока не привёл к улучшению устойчивых экономических результатов. Рост ВВП и открытость торговли также оказывают значимое отрицательное влияние на скорректированные чистые сбережения, тогда как прямые иностранные инвестиции не демонстрируют статистически значимого воздействия. Данные результаты показывают, что одной лишь цифровой трансформации недостаточно для стимулирования зелёного экономического роста без эффективной экологической политики, ресурсосберегающих технологий и стратегий развития, ориентированных на устойчивость. Исследование вносит вклад в развивающуюся научную литературу по цифровизации и устойчивому развитию, предоставляя новые эмпирические данные по недостаточно изученному региону и подчёркивая сложный характер взаимосвязи между технологическим прогрессом и устойчивым развитием.

Ключевые слова: цифровая инфраструктура; зелёный экономический рост; скорректированные чистые сбережения; Центральная Азия; устойчивое развитие; анализ панельных данных.

INTRODUCTION

The rapid expansion of digital technologies has transformed economic systems worldwide, creating new opportunities for productivity growth, innovation, and sustainable development. Digital infrastructure, encompassing Internet connectivity, mobile communication networks, and broadband access, has become a fundamental component of modern economic development. Governments and international organizations increasingly view digitalization as a key driver of economic competitiveness and social progress. Growing attention to environmental sustainability, resource efficiency, and climate-related challenges has increased interest in development models that reconcile economic growth with environmental sustainability. Within this context, the concept of green economic growth has gained significant prominence among policymakers and researchers seeking to promote long-term prosperity while preserving natural capital.

The relationship between digital infrastructure and green economic growth has emerged as an important area of academic inquiry. On the one hand, digital technologies can improve energy efficiency, facilitate environmental monitoring, optimize resource allocation, and accelerate the diffusion of green innovations. The development of digital infrastructure enables businesses and households to adopt more efficient production and consumption practices, potentially reducing environmental pressures while supporting economic expansion. On the other hand, the construction and operation of digital infrastructure require substantial investments in physical capital, energy consumption, and technological equipment, which may be associated with additional



environmental and resource-related pressures, particularly in developing economies where institutional and technological capacities are still developing. Consequently, the overall impact of digital infrastructure on green economic growth remains theoretically ambiguous and empirically contested.

This issue is particularly relevant for Central Asia, a region characterized by ongoing economic transformation, increasing digitalization, and growing sustainability challenges. Countries such as Kazakhstan, Kyrgyzstan, Tajikistan, and Uzbekistan have implemented various strategies aimed at expanding digital connectivity and promoting digital transformation as part of their long-term development agendas. Simultaneously, these economies continue to address important sustainability-related issues, including efficient resource use, water management, environmental protection, and gradual diversification from resource-intensive sectors. As digital infrastructure expands throughout the region, understanding its implications for sustainable economic development has become increasingly important for both policymakers and researchers.

Despite the growing body of literature examining the digitalization–sustainability nexus, empirical evidence for Central Asia remains limited. Existing studies have predominantly focused on advanced economies, China, or large panels of developing countries, while relatively little attention has been devoted to Central Asian economies. Furthermore, many previous studies rely on broad measures of digitalization and conventional indicators of economic performance, providing limited insights into the sustainability dimension of growth. The use of comprehensive measures that capture both economic and environmental aspects of development remains relatively scarce in the literature.

To address these gaps, this study investigates the impact of digital infrastructure on green economic growth in four Central Asian economies during the period 2006–2021. A composite Digital Infrastructure Index (DII) is constructed using Principal Component Analysis based on Internet usage, mobile subscriptions, and broadband penetration indicators. Green economic growth is measured through adjusted net savings, which reflects the sustainability of economic development by accounting for investments in human capital, depletion of natural resources, and environmental damages. Using panel econometric techniques, including fixed-effects and random-effects estimators, the study evaluates the extent to which digital infrastructure contributes to sustainable economic performance in the region. By focusing on Central Asia and employing a multidimensional measure of digital infrastructure, this research contributes to the emerging literature on digital transformation and sustainable development while providing policy-relevant evidence for developing economies seeking to balance technological advancement with environmental sustainability.

LITERATURE REVIEW

The relationship between digital infrastructure and green economic growth has attracted increasing scholarly attention over the past decade, particularly in the context of sustainable development and digital transformation. A growing body of literature argues that digital infrastructure facilitates resource efficiency, technological innovation, environmental monitoring, and productivity improvements, thereby contributing to green growth outcomes. Recent studies have examined this nexus in various contexts, including China, developing economies, and regional economic blocs. For example, Yu et al. (2025), Liu et al. (2025), Dong et al. (2025), and Khan and Sun (2026) provide empirical evidence that digital infrastructure and digital economy development contribute positively to green growth, the renewable energy transition, and environmental sustainability. Similarly, research focusing on Central Asia highlights the growing importance of digitalization for economic development and sustainability (Kurmanov et al., 2025; Ure, 2021). Consequently, the relationship between digital infrastructure and sustainable economic development has become an increasingly debated topic in both environmental economics and development economics literature.

Despite the growing number of studies, several important limitations remain. First, many existing studies focus on large economies such as China or broad cross-country samples, while empirical evidence from Central Asia remains scarce. Second, previous research often measures green development using indicators such as green investment, green total factor productivity, renewable energy consumption, or inclusive green growth indices (Kozhakhmetova et al., 2025; Liu et al., 2025; Dong et al., 2025). In contrast, limited attention has been paid to the use of Adjusted Net Savings as a comprehensive measure of green economic growth and sustainability. Third, most studies employ conventional indicators of digitalization or aggregate digital economy indices, whereas the present study constructs a Digital Infrastructure Index (DII) using Principal Component Analysis based on Internet usage, mobile subscriptions, and broadband penetration. Furthermore, this research utilizes recent data covering the period 2006–2021 for four Central Asian economies, providing updated evidence for a region that remains underrepresented in the literature.

Methodologically, previous studies have employed a wide range of econometric approaches to investigate the digitalization–green growth nexus. Time-series and panel-based studies frequently utilize Autoregressive

Due to high correlations among the three digital indicators, Principal Component Analysis (PCA) was employed to construct a single composite index.

Step 1: Diagnostic Tests for Factor Analysis

Kaiser-Meyer-Olkin (KMO) Measure: Overall $KMO = 0.6187$ (acceptable, as values > 0.6 are considered suitable). Individual KMO values ranged from 0.5714 to 0.7409 .

Bartlett's Test of Sphericity: $\chi^2(3) = 127.93, p < 0.001$, confirming the correlation matrix is not an identity matrix.

Step 2: *Principal Component Extraction*. Using the principal-component factors (PCF) method and the Kaiser criterion (eigenvalue > 1), one component was retained. This component explains **80.04%** of the total variance in the three indicators (see Table 4 and Figure 1 – Scree Plot).

Step 3: *Standardization*. All variables were standardized to have zero mean and unit variance:

$$Z_{j,it} = \frac{X_{j,it} - \bar{X}_j}{S_j}$$

where $X_{j,it}$ is the raw value of indicator j for country i at time t , \bar{X}_j and S_j are the sample mean and standard deviation (Table 1).

Step 4: *Index Construction*. The Digital Infrastructure Index is computed using the scoring coefficients (normalized eigenvectors) from Table 5:

$$DII_{it} = 0.6176 * Z_{internet_{it}} + 0.5238Z_{mobile_{it}} + 0.5867Z_{broadband_{it}}$$

This index captures the common underlying dimension of digital infrastructure development across the sample.

3.5 Panel Unit Root Tests

To determine the order of integration of the variables, three complementary panel unit root tests were applied:

- Levin–Lin–Chu (LLC) test
- Im–Pesaran–Shin (IPS) test
- Fisher-type Augmented Dickey–Fuller (ADF) test

Tests were conducted on variables in levels and first differences. The results presented in Table 6 indicate that most variables are either stationary in levels or become stationary after first differencing, supporting the validity of regression analysis in levels.

3.6 Diagnostic Tests

3.6.1 *Multicollinearity*. Pairwise Pearson correlation analysis (Table 2) shows that no explanatory variables have excessively high correlations ($|r| > 0.80$). Thus, multicollinearity is not a serious concern.

3.6.2 *Model Selection: Fixed Effects vs Random Effects*. Both Fixed Effects (FE) and Random Effects (RE) models were estimated (Table 7). The Hausman specification test was used to choose between them:

$$H_0: \text{Difference in coefficients is not systematic (RE is consistent)}$$

Result: $\chi^2(4) = 2.83, p\text{-value} = 0.5859 \rightarrow \text{Failure to reject } H_0$. Therefore, the Random Effects model is preferred.

3.7 Econometric Model Specification

The baseline model is specified as follows:

$$adj_net_savings_{it} = \beta_0 + \beta_1 DII_{it} + \beta_2 gdp_growth_{it} + \beta_3 trade_gdp_{it} + \beta_4 fdi_inflow_{it} + u_i + \varepsilon_{it}$$

where:

i =country (1 to 4), t = time period (1 to 16)

u_i =country-specific random effect (unobserved heterogeneity)

ε_{it} =idiosyncratic error term, assumed to be independently and identically distributed (i.i.d.)

3.8 Estimation Technique

The model is estimated using random-effects Generalized Least Squares (GLS). To address potential heteroskedasticity and intra-country serial correlation, cluster-robust standard errors at the country level are employed. The final estimation results are presented in Table 9.

3.9 Software Used

All data processing, index construction, diagnostic tests, and regressions were performed using Stata 17



statistical software.

ANALYSIS AND RESULTS

Table 1. Summary statistics of key variables (N = 64, 4 countries × 16 periods)

Variable	Obs	Mean	Std. Dev.	Min	Max
adj_net_savings	64	8.098	7.644	-8.815	27.895
internet_users	64	35.627	25.976	3.268	90.924
mobile_subs	64	94.782	37.577	9.477	174.709
broadband_subs	64	4.304	5.441	0.032	21.894
gdp_growth	64	3.704	3.100	-9.032	9.768
trade_gdp	64	80.015	31.529	29.192	146.106
fdi_inflow	64	4.519	3.974	-4.855	17.131

Table 1 presents the descriptive statistics of the variables employed in the analysis. The average value of adjusted net savings is 8.10%, indicating a generally positive level of sustainable wealth accumulation across the selected Central Asian economies during the study period. However, the wide range, from -8.82% to 27.90%, suggests substantial variation in sustainability performance across countries and years. Regarding digital infrastructure indicators, Internet usage exhibits considerable dispersion, ranging from 3.27% to 90.92% of the population, reflecting the heterogeneous pace of digital transformation within the region. Similarly, broadband subscriptions and mobile penetration demonstrate notable differences across observations. Among the control variables, GDP growth averaged 3.70%, while trade openness accounted for approximately 80% of GDP on average, indicating the relatively open nature of Central Asian economies. The variation observed across all variables suggests sufficient heterogeneity for panel econometric estimation.

Table 2. Pairwise Correlation Matrix of the Study Variables

Variables	-1	-2	-3	-4	-5
(1) Adjusted Net Savings	1.000				
(2) Digital Infrastructure Index (DII)	-0.035	1.000			
(3) GDP Growth	-0.017	-0.436	1.000		
(4) Trade (% GDP)	-0.357	-0.337	-0.011	1.000	
(5) FDI Inflow (% GDP)	-0.282	-0.176	0.089	0.513	1.000

Note: The table reports pairwise Pearson correlation coefficients. None of the explanatory variables exhibit excessively high pairwise correlations ($|r| < 0.80$), suggesting that multicollinearity is unlikely to be a serious concern in the regression analysis.

Table 2 reports the pairwise Pearson correlation coefficients among the variables. The Digital Infrastructure Index (DII) exhibits a weak negative correlation with adjusted net savings ($r = -0.035$), indicating that the simple bivariate relationship between digital infrastructure and green economic growth is not immediately apparent. Trade openness and FDI inflows are negatively correlated with adjusted net savings, with coefficients of -0.357 and -0.282 , respectively. Furthermore, DII is moderately negatively associated with GDP growth ($r = -0.436$) and trade openness ($r = -0.337$). Importantly, none of the explanatory variables display correlation coefficients exceeding the commonly accepted threshold of 0.80, suggesting the absence of severe multicollinearity problems. Therefore, the variables can be included simultaneously in the regression model without compromising estimation reliability.

Table 3. Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity

Measure	Value
Overall KMO	0.6187
<i>internet_users</i>	0.5714
<i>mobile_subs</i>	0.7409
<i>broadband_subs</i>	0.6056
Bartlett's test (LR test)	$\chi^2(3) = 127.93, *p* < 0.001$

Note: KMO values above 0.6 are considered acceptable for factor analysis. Bartlett's test rejects the null hypothesis that the correlation matrix is an identity matrix ($*p* < 0.001$), confirming factorability.

Table 3 evaluates the suitability of the digital infrastructure indicators for factor analysis. The overall KMO statistic of 0.6187 exceeds the minimum threshold of 0.60, indicating acceptable sampling adequacy. Among the individual indicators, mobile subscriptions exhibit the highest KMO value (0.7409), suggesting a strong contribution to the common factor structure. In addition, Bartlett's test of sphericity is highly significant ($\chi^2 = 127.93, p < 0.001$), rejecting the null hypothesis that the correlation matrix is an identity matrix. These findings confirm that the selected indicators are sufficiently correlated and appropriate for dimension reduction through factor analysis.

Table 4. Principal Component Factor Analysis Results (Unrotated)

Variable	Factor Loading (Comp1)	Uniqueness (1 - h ²)
<i>internet_users</i>	0.9570	0.0842
<i>mobile_subs</i>	0.8117	0.3412
<i>broadband_subs</i>	0.9092	0.1734
Eigenvalue	2.40122	—
Variance explained (%)	80.04%	—
Cumulative (%)	80.04%	—

Note: Extraction method: principal-component factors (PCF). One factor retained based on eigenvalue > 1 criterion. Factor loadings represent correlations between variables and the retained component. Uniqueness = proportion of variance not explained by the common factor.

The principal component factor analysis results demonstrate that a single factor adequately captures the common variation among the digital infrastructure indicators. All factor loadings exceed 0.80, indicating strong associations between the observed variables and the extracted component. Internet usage exhibits the highest loading (0.9570), followed by broadband subscriptions (0.9092) and mobile subscriptions (0.8117). The first component has an eigenvalue of 2.40 and explains approximately 80.04% of the total variance, substantially exceeding the conventional eigenvalue threshold of one. Therefore, the extracted component effectively summarizes the digital infrastructure characteristics of the selected economies and can be used to construct a composite Digital Infrastructure Index.

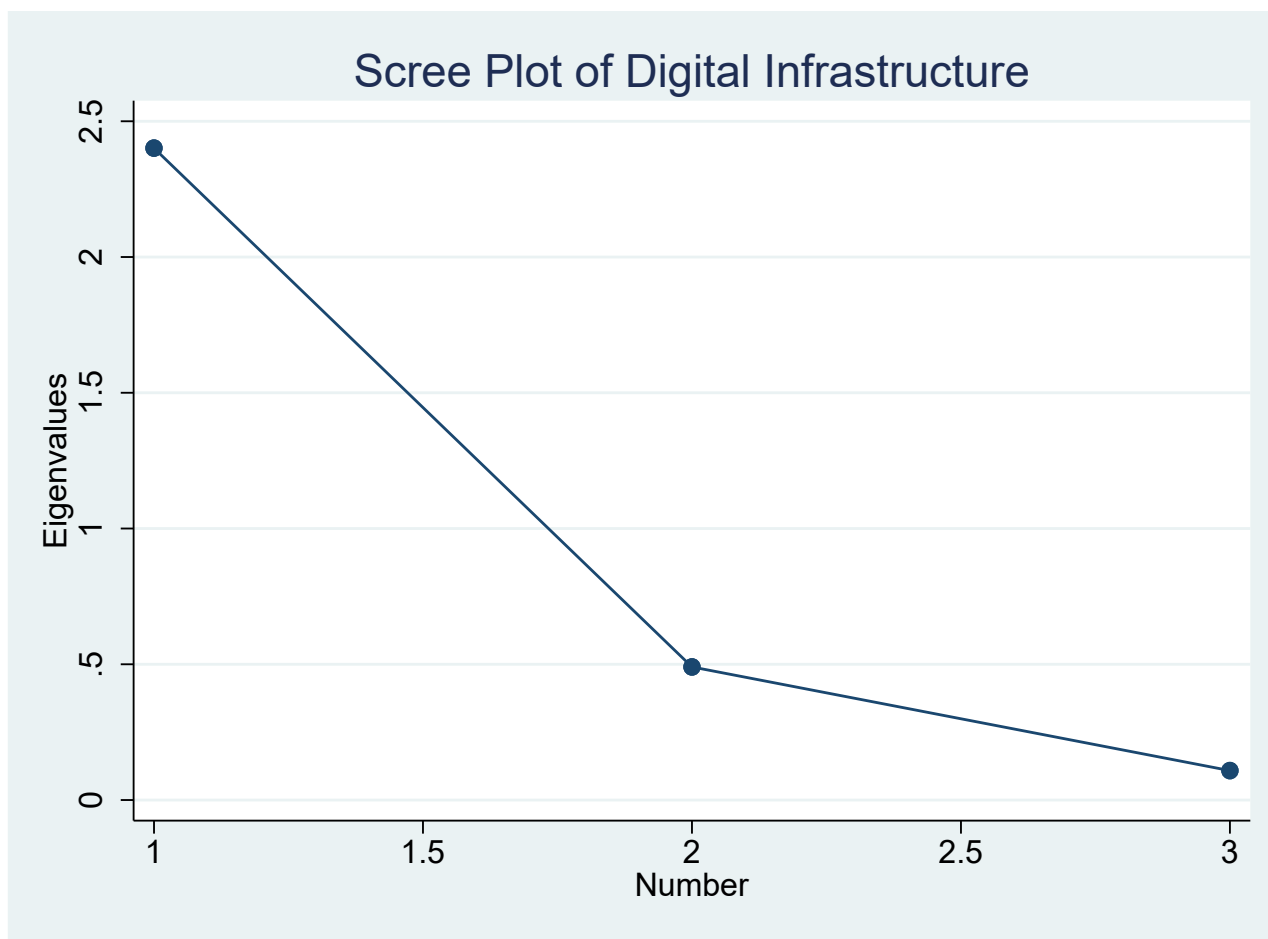


Figure 1. Scree Plot of Eigenvalues for Digital Infrastructure Indicators

Figure 1 illustrates the eigenvalue distribution obtained from Principal Component Analysis. The scree plot reveals a sharp decline in eigenvalues after the first component, while subsequent components have eigenvalues substantially below one. This pattern confirms the existence of a dominant underlying factor and supports the retention of a single component according to the Kaiser criterion. Consequently, the scree plot provides additional graphical evidence supporting the construction of a one-dimensional Digital Infrastructure Index.

Table 5. Component Scoring Coefficients (for Index Construction)

Variable	Comp1 Score Coefficient
<i>internet_users</i>	0.6176
<i>mobile_subs</i>	0.5238
<i>broadband_subs</i>	0.5867

*Note: Coefficients are normalized eigenvectors (sum of squares = 1). The Digital Infrastructure Index (DII) is computed as: $DII = 0.6176 * (internet_users) + 0.5238 * (mobile_subs) + 0.5867 * (broadband_subs)$ using standardized variables. The index explains 80.04% of the total variance.*

Table 5 presents the scoring coefficients used to construct the Digital Infrastructure Index. The coefficients indicate the relative contribution of each standardized indicator to the composite measure. Internet usage receives the largest weight (0.6176), followed by broadband subscriptions (0.5867) and mobile subscriptions (0.5238). The relatively balanced distribution of coefficients suggests that all three indicators contribute meaningfully to the measurement of digital infrastructure development. Since the resulting index captures more than 80% of the total variance, it provides a comprehensive and statistically robust measure of digital infrastructure across Central Asian economies.

Table 6. Results of Panel Unit Root Tests at Level and First Difference

Variable	LLC Test		IPS Test		Fisher-ADF Test	
	Level	First Difference	Level	First Difference	Level	First Difference
<i>adj_net_savings</i>	1.3178 (0.9062)	-1.1032 (0.1350)	-2.3710*** (0.0089)	-3.7929*** (0.0001)	7.2631 (0.5085)	21.6918*** (0.0055)
<i>DII</i>	-0.7355 (0.2310)	-1.8368** (0.0331)	0.9479 (0.8284)	-1.0137 (0.1554)	8.9615 (0.3456)	14.2281* (0.0760)
<i>gdp_growth</i>	-1.8358** (0.0332)	-2.8643*** (0.0021)	-3.3171*** (0.0005)	-4.5245*** (0.0000)	24.3344*** (0.0020)	74.6366*** (0.0000)
<i>trade_gdp</i>	-4.5698*** (0.0000)	-3.2865*** (0.0005)	-0.2025 (0.4198)	-2.6452*** (0.0041)	26.3193*** (0.0009)	29.5884*** (0.0002)
<i>fdi_inflow</i>	-2.3315*** (0.0099)	-4.5210*** (0.0000)	-2.2991** (0.0107)	-4.1049*** (0.0000)	10.8272 (0.2117)	43.6958*** (0.0000)

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 6 reports the results of the LLC, IPS, and Fisher-ADF panel unit root tests. The findings indicate mixed orders of integration among the variables. GDP growth, trade openness, and FDI inflows appear stationary in levels according to most test statistics, whereas the Digital Infrastructure Index becomes stationary after first differencing. Adjusted net savings also exhibits evidence of stationarity primarily after differencing. The consistency of results across multiple panel unit root tests strengthens the reliability of the stationarity assessment. Overall, the findings suggest that the variables do not exhibit problematic non-stationary behavior that would invalidate the subsequent panel regression analysis.

Table 7. Comparison of Fixed-Effects and Random-Effects Estimates

Variables	Fixed Effects	Random Effects
<i>DII</i>	-0.2469 (0.9061)	-1.1339 (0.7008)
<i>GDP Growth</i>	-0.3451 (0.3605)	-0.2719 (0.3318)
<i>Trade (% GDP)</i>	-0.0476 (0.0595)	-0.0906** (0.0357)
<i>FDI Inflow</i>	-0.1691 (0.3046)	-0.2332 (0.2665)
<i>Constant</i>	13.9499*** (4.3858)	17.4107*** (3.1131)
<i>Observations</i>	64	64
<i>Countries</i>	4	4
<i>Within R²</i>	0.0686	0.0544
<i>Between R²</i>	0.6811	0.9116
<i>Overall R²</i>	0.1337	0.1776

Note: Standard errors are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 7 compares the coefficient estimates obtained from fixed-effects and random-effects models. Although coefficient magnitudes differ somewhat between specifications, the overall direction of the estimated relationships remains relatively stable. In both models, digital infrastructure, GDP growth, trade openness, and FDI inflows exhibit negative coefficients. The random-effects model indicates a statistically significant negative



effect of trade openness on adjusted net savings, whereas the corresponding coefficient is insignificant under fixed effects. These differences motivate the need for a formal model selection procedure through the Hausman specification test.

Table 8. Hausman Specification Test

Test Statistic	Value
<i>Chi-square (4)</i>	2.83
<i>p-value</i>	0.5859
<i>Decision</i>	Random Effects Preferred

Table 8 reports the results of the Hausman specification test used to determine the appropriate panel estimator. The test statistic of $\chi^2(4) = 2.83$ yields a p-value of 0.5859, which is substantially above the conventional significance level of 0.05. Consequently, the null hypothesis that the random-effects estimator is consistent cannot be rejected. This result indicates that the random-effects specification is more efficient and appropriate for the present analysis. Therefore, subsequent interpretation is based on the random-effects model.

Table 9. Random-Effects Regression Results with Cluster-Robust Standard Errors

Variables	Coefficient	Robust S.E.	z-statistic	p-value
<i>DII</i>	-1.1339***	0.3868	-2.93	0.003
<i>GDP Growth</i>	-0.2719***	0.0349	-7.78	0.000
<i>Trade (% GDP)</i>	-0.0906***	0.0176	-5.16	0.000
<i>FDI Inflow</i>	-0.2332	0.4114	-0.57	0.571
<i>Constant</i>	17.4107***	0.7122	24.44	0.000
Model Statistics				
<i>Observations: 64</i>	<i>Between R²: 0.9116</i>			
<i>Countries: 4</i>	<i>Overall R²: 0.1776</i>			
<i>Within R²: 0.0544</i>				

Table 9 presents the main empirical findings of the study. The coefficient of the Digital Infrastructure Index is negative and statistically significant at the 1% level ($\beta = -1.1339$, $p = 0.003$). This result suggests that, within the sample of Central Asian economies, improvements in digital infrastructure are associated with lower levels of adjusted net savings. One possible explanation is that the expansion of digital infrastructure may initially require substantial investments and resource consumption, thereby reducing short-term sustainability indicators. GDP growth also exhibits a significant negative effect on adjusted net savings ($\beta = -0.2719$, $p < 0.001$), indicating that economic expansion may still be closely linked to the intensive use of natural capital. Similarly, trade openness negatively affects adjusted net savings ($\beta = -0.0906$, $p < 0.001$), implying that increased integration into international markets may require stronger sustainability-oriented resource management mechanisms. In contrast, FDI inflows do not exert a statistically significant effect, suggesting that foreign investment has neither a clearly positive nor a clearly negative impact on sustainability outcomes during the study period. Overall, the results indicate that digitalization and economic expansion in Central Asia have not yet fully contributed to measurable improvements in green economic growth, highlighting the need for policies that better align digital transformation with sustainability objectives.

CONCLUSION AND SUGGESTIONS

This study investigated the relationship between digital infrastructure and green economic growth in four Central Asian economies during the period 2006–2021. To capture the multidimensional nature of digitalization, a Digital Infrastructure Index (DII) was constructed using Principal Component Analysis based on Internet usage, mobile subscriptions, and broadband penetration indicators. Green economic growth was proxied by adjusted net savings, which reflects the sustainability of economic development through the inclusion of natural resource depletion and environmental damages. Panel econometric techniques were employed to estimate the relationship between digital infrastructure and sustainable economic performance.



The empirical findings provide several important insights. First, the results of the Hausman specification test indicate that the random-effects model is the most appropriate estimator for the analysis. Second, digital infrastructure was found to have a statistically significant negative impact on adjusted net savings. This finding suggests that the expansion of digital infrastructure in Central Asia may currently be associated with increased resource utilization, infrastructure investment costs, and environmental and resource-related pressures that may limit the realization of potential sustainability benefits in the short term. Third, GDP growth and trade openness also exert significant negative effects on adjusted net savings, indicating that economic expansion and international integration may still be influenced by resource-intensive development patterns within the region. In contrast, foreign direct investment does not appear to have a significant influence on sustainable economic growth.

These findings carry important policy implications. Policymakers should recognize that digital infrastructure development can generate stronger sustainability outcomes when supported by complementary environmental and innovation policies. To maximize the benefits of digital transformation, investments in digital infrastructure should be complemented by green innovation policies, renewable energy deployment, environmental regulations, and sustainable resource management practices. Integrating digital technologies into environmental monitoring systems, energy-efficient production processes, and smart infrastructure projects may help transform digitalization into a driver of sustainable development.

Despite its contributions, this study is subject to several limitations. The analysis focuses on four Central Asian economies and employs adjusted net savings as the primary measure of green economic growth. Future research may expand the geographical scope, incorporate alternative sustainability indicators, and explore nonlinear or dynamic relationships between digitalization and environmental performance. Further investigation into the channels through which digital infrastructure influences sustainability outcomes would also contribute to a deeper understanding of the digitalization–green growth nexus.

Overall, the study demonstrates that while digital infrastructure plays an increasingly important role in economic development, its contribution to green economic growth in Central Asia requires further policy support and empirical investigation.

Achieving sustainable development objectives will require a more integrated policy framework that aligns digital transformation with environmental sustainability goals.

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