

REGIONAL ELECTRICITY INTENSITY AND INDUSTRIAL DEVELOPMENT IN UZBEKISTAN: PANEL EVIDENCE FROM 12 REGIONS

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Abstract: This study examines how regional electricity intensity is related to industrial development across 12 regions of Uzbekistan during 2016–2025. Using 120 region-year observations from official open data, electricity intensity is measured as electricity consumption relative to gross regional product. The analysis shows a clear decline in the average intensity indicator, from 0.1966 in 2016 to 0.0452 in 2025. Panel regression results suggest that industrial output is negatively associated with electricity intensity, while regional characteristics and common time trends also play an important role. The findings indicate that improving electricity efficiency requires region-specific policies, better-quality investment, industrial modernization, and regular monitoring. Since regional data on industrial electricity consumption are not fully available, the indicator is interpreted as a regional electricity-intensity proxy rather than a direct measure of industrial energy intensity.

Keywords: *electricity intensity, energy efficiency, industrial development, regional panel data, fixed effects, investment intensity, industrial output, Uzbekistan*

РЕГИОНАЛЬНАЯ ЭЛЕКТРОЭНЕРГЕТИЧЕСКАЯ ИНТЕНСИВНОСТЬ И ПРОМЫШЛЕННОЕ РАЗВИТИЕ В УЗБЕКИСТАНЕ: ПАНЕЛЬНЫЕ ДАННЫЕ ПО 12 ОБЛАСТЯМ

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Аннотация: Данное исследование посвящено анализу взаимосвязи между региональной электроэнергетической интенсивностью и промышленным развитием в 12 областях Узбекистана в 2016–2025 годах. Эмпирическая база включает 120 наблюдений «регион–год», сформированных на основе официальных открытых данных. Электроэнергетическая интенсивность рассчитывается как отношение потребления электроэнергии к валовому региональному продукту. Результаты показывают устойчивое снижение среднего значения данного показателя с 0,1966 в 2016 году до

0,0452 в 2025 году. Панельный регрессионный анализ выявил отрицательную связь между объёмом промышленного производства и электроэнергетической интенсивностью, при этом существенную роль также играют региональные особенности и общие временные тенденции. Полученные результаты подтверждают необходимость дифференцированного регионального подхода, модернизации промышленности, повышения качества инвестиций и систематического мониторинга энерго-эффективности. В связи с отсутствием полной информации о потреблении электроэнергии непосредственно промышленностью показатель рассматривается как региональный индикатор электроэнергетической интенсивности, а не как прямой показатель энергоёмкости промышленности.

Ключевые слова: *электроэнергетическая интенсивность, энерго-эффективность, промышленное развитие, панельные данные, фиксированные эффекты, инвестиционная интенсивность, промышленное производство, Узбекистан*

INTRODUCTION

Improving energy efficiency has become a central component of sustainable industrial development because the amount of energy required to generate a unit of economic output affects production costs, competitiveness, energy security, and the environmental footprint of growth. For economies undergoing rapid industrial expansion, the policy challenge is not simply to increase electricity supply, but to ensure that industrial and regional output grows faster than the resources required to support it. Energy intensity is therefore widely used as a summary indicator of the relationship between economic activity and energy use, although its interpretation depends critically on the definition of both energy input and economic output.

Uzbekistan provides a particularly relevant setting for such analysis. The International Energy Agency notes that the country achieved a substantial reduction in economy-wide energy intensity during the previous decade, while remaining relatively energy intensive by international standards. The IEA also identifies industry and residential consumption among the major areas with significant energy-efficiency potential and points to data-quality limitations as an important constraint on detailed sectoral analysis [7]. These conditions create a strong need for reproducible regional indicators built from official open data and for empirical approaches capable of distinguishing common national trends from persistent territorial differences.

During 2016-2025, the regions of Uzbekistan experienced rapid changes in gross regional product, industrial output, fixed-capital investment, population, and electricity demand [1-6]. However, these variables evolved unevenly across

territories. Navoi and Tashkent regions combine high industrial concentration with large electricity demand, whereas other regions display lower absolute energy consumption but different trajectories of output growth and investment. Such heterogeneity means that national averages alone can conceal important regional patterns relevant to industrial modernisation and energy-efficiency management.

The central research problem is that region-level industrial electricity consumption is not available as a complete open annual series for the 12 regions over 2016-2025. Consequently, directly estimating industrial energy intensity as industrial electricity consumption divided by real industrial output is not currently feasible from a single consistent public source. To preserve empirical transparency, this study constructs a regional electricity-intensity proxy using total subscriber electricity consumption divided by GRP. Industrial output, investment intensity, and population are then used to assess how the intensity indicator co-moves with industrial and regional development. This distinction is methodologically important: the indicator measures the electricity intensity of regional economic activity, not the technical energy efficiency of industrial enterprises in isolation.

The article has four objectives. First, it constructs a balanced open-data panel for 12 regions of Uzbekistan covering 2016-2025. Second, it measures the dynamics and territorial differences of regional electricity intensity. Third, it estimates pooled and fixed-effects panel specifications linking electricity intensity with industrial output, investment intensity, and population. Fourth, it derives policy implications for regionally differentiated industrial modernisation and electricity-efficiency management. The study contributes to the national literature by demonstrating how official open statistics can be organised into a reproducible panel framework while explicitly separating descriptive association from causal inference.

LITERATURE REVIEW

The empirical literature generally treats energy intensity as the outcome of several interacting forces: income growth, industrial structure, technological progress, investment, urbanization, energy prices, and institutional conditions. A recurring finding is that industrialization can increase energy intensity when the expansion of manufacturing and heavy industry raises energy demand faster than output, while technological upgrading and structural change can reduce intensity by improving productivity and shifting activity towards less energy-intensive production.

Sadorsky [8], using heterogeneous panel methods for 76 developing countries, found that higher income is associated with lower long-run energy intensity, whereas industrialization tends to raise it. This result is important for Uzbekistan because regional industrial expansion can have two opposing effects, a

scale effect that raises electricity demand and a productivity or modernization effect that lowers electricity use per unit of output. The net effect is therefore an empirical question rather than an assumption.

Regional evidence from China reinforces the importance of spatial and structural heterogeneity. Guang et al. [9] show that the determinants of energy intensity differ across the conditional distribution of regional intensity: economic growth and foreign investment reduce intensity, while industrialization and urbanization increase it in their provincial sample. Jiang, Folmer and Ji [10] likewise report that the secondary-sector share raises energy intensity, whereas capital deepening can reduce it. These findings justify the use of regional fixed effects because unobserved industrial composition and resource endowment can be persistent over time.

Investment is another important channel. Herrerias, Cuadros and Orts [11] find that foreign and non-state investment contributes to declining energy intensity across Chinese provinces, although the effect depends on investment ownership and regional conditions. The implication is that the volume of investment alone is not sufficient; investment quality and its technological content matter. This motivates the use of fixed-capital investment intensity in the present study, while recognizing that the variable cannot directly distinguish energy-saving investment from capacity-expansion investment.

Technological progress and industrial organization also shape energy outcomes. Huang, Du and Hao [12] identify technological progress as a factor that can reduce energy intensity and show that industrialization explains part of high-intensity outcomes. Ma and Yu [13], using city-level panel data, demonstrate that internal industrial structure and energy-saving regulation are important for explaining differences in aggregate energy intensity. Lin and Zhu [14] find dynamic relationships between industrial structure, urbanization, energy intensity and carbon intensity, highlighting that the effect of structural upgrading can evolve over time.

More recent work emphasizes nonlinear structural effects. Luan et al. [15] find that industrial structure optimization can reduce energy intensity, while expansion of highly energy-intensive industries can work in the opposite direction. Dai and Liu [16] further demonstrate that energy productivity and structural transformation have heterogeneous effects across provincial regions. Together, these studies support a panel framework in which regional heterogeneity and time-specific common shocks are explicitly controlled.

The literature also suggests an important interpretive caution. Energy intensity is not identical to engineering energy efficiency. It can decline because of technological improvements, structural change, price effects, output composition, or nominal valuation of the denominator. In the Uzbekistan dataset used here, GRP and industrial output are reported in current prices. The empirical strategy therefore

includes year effects and a separate time-trend specification to absorb common nominal and macroeconomic movements. The resulting coefficients are interpreted as conditional statistical associations rather than causal estimates.

RESEARCH METHODOLOGY

The empirical analysis uses a balanced regional panel covering 12 regions of Uzbekistan - Andijan, Bukhara, Jizzakh, Kashkadarya, Navoi, Namangan, Samarkand, Surkhandarya, Syrdarya, Tashkent region, Fergana and Khorezm - over 2016-2025. The Republic of Karakalpakstan and Tashkent City are excluded because the research scope is restricted to the 12 regions. This produces 120 region-year observations.

The database is compiled from the SIAT open-data system of the National Statistics Committee of the Republic of Uzbekistan. GRP is taken from the annual regional product series [1], industrial output from the annual industrial production series for 2016-2024 [2], electricity consumption from the subscriber electricity-consumption series [3], permanent population from regional demographic statistics [4], and fixed-capital investment from the investment series [5]. For 2025, annual industrial output is reconstructed from the official December per-capita industrial-output indicator and the average of the beginning- and end-period permanent population [4,6]. This reconstructed value is treated transparently as an author calculation. A robustness model is therefore also estimated for 2016-2024, excluding the reconstructed 2025 industrial-output observation.

The dependent variable is regional electricity intensity (EI), calculated as total subscriber electricity consumption divided by GRP. Because electricity consumption is reported in million kWh and GRP in billion soums, the numerical ratio can be interpreted as kWh per 1,000 soums of GRP. The variable is used in logarithmic form in the regression analysis to reduce skewness and facilitate proportional interpretation.

$$Elit = Electricity \frac{consumptionit}{GRPit}$$

The first explanatory variable is industrial output (IND), measured in billion soums and transformed into natural logarithms. The second is investment intensity (INVINT), calculated as fixed-capital investment divided by GRP and multiplied by 100. The third is permanent population (POP), measured in thousand persons and entered in logarithmic form. Investment intensity captures the relative scale of capital formation, while the population variable controls for regional demand and scale. The primary panel specification is:

$$\ln(Elit) = \beta_0 + \beta_1 \ln(INDit) + \beta_2 INVINTit + \beta_3 \ln(POPit) + mui + \lambda dat + \epsilon it$$

where i denotes region, t denotes year, μ_i captures time-invariant regional characteristics, λ_{at} captures common year effects, and ϵ_{it} is the idiosyncratic disturbance. Four specifications are reported: pooled OLS with heteroskedasticity-robust standard errors, a region fixed-effects model, a two-way fixed-effects model with both regional and year effects, and a region fixed-effects model with a linear time trend. For fixed-effects estimates, standard errors are clustered at the regional level. This approach follows the broader panel-data logic used in the literature on regional energy intensity [9-16].

Pairwise correlations among the regressors are modest, and variance-inflation factors for $\ln(\text{industrial output})$, investment intensity and $\ln(\text{population})$ are approximately 1.08-1.10, indicating no material multicollinearity problem in the baseline specification. The analysis focuses on association rather than causality. Potential endogeneity may remain because investment, industrial activity and electricity intensity can be jointly determined, and the available open data do not provide suitable instruments for a causal identification strategy.

Table 1

Variables, measurement and data sources

Variable	Definition	Measurement transformation	Role	Source
$\ln(EI)$	Regional electricity intensity	$\ln \left(\text{Electricity} \frac{\text{consumption}}{GRP} \right)$	Dependent	SIAT [1,3]
$\ln(IND)$	Industrial output	Natural log of industrial production, bln UZS	Explanatory	SIAT [2,6]
$INVINT$	Investment intensity	$\text{Fixedcapital} \frac{\text{investment}}{GRP} * 100$	Explanatory	SIAT [1,5]
$\ln(POP)$	Permanent population	Natural log of permanent population, thousand persons	Control	SIAT [4]
$TREND$	Linear time trend	0 for 2016, ..., 9 for 2025	Robustness/trend	Author work

ANALYSIS AND RESULTS

The descriptive evidence indicates a pronounced decline in the regional electricity-intensity proxy over the observation period. The unweighted average across the 12 regions fell from 0.1966 in 2016 to 0.1614 in 2017. After a temporary increase to 0.1657 in 2018, the indicator declined to 0.1099 in 2019, 0.0947 in 2020 and 0.0830 in 2021. By 2023 it had fallen to 0.0628, and by 2025 it reached 0.0452. Relative to 2016, the 2025 average is approximately 77.0% lower. This is a strong descriptive trend, but it should not be interpreted mechanically as a 77% engineering

efficiency gain because the GRP denominator is measured in current prices and the indicator also reflects structural and valuation changes.

At the same time, the 12-region aggregate of nominal industrial output increased markedly, from about UZS 80.2 trillion in 2016 to more than UZS 666.4 trillion in 2024; the 2025 value derived from official per-capita industrial output and population information is approximately UZS 846.6 trillion. Electricity consumption increased much more moderately over most of the period, from 39.0 billion kWh across the 12 regions in 2016 to 57.1 billion kWh in 2024 before declining to 53.8 billion kWh in 2025. This divergence between the growth of nominal economic output and electricity demand is the immediate arithmetic source of the downward electricity-intensity trend.

Table 2

Descriptive statistics of the main variables, 2016-2025

Variable	N	Mean	Std. dev.	Minimum	Maximum
Electricity intensity (EI)	120	0.1051	0.0693	0.0350	0.5412
ln(industrial output)	120	9.7989	1.0327	7.6015	12.1819
Investment intensity, %	120	31.8639	13.5342	11.7484	75.4586
ln(permanent population)	120	7.7103	0.4935	6.6728	8.3658

The variation in EI is substantial, the maximum observation (0.5412) is recorded for Navoi region in 2016, whereas the minimum (0.0350) is recorded for Khorezm in 2025. The simple pairwise correlation between EI and ln(industrial output) is -0.369; the correlations with investment intensity and ln(population) are -0.218 and -0.212, respectively. These correlations provide an initial indication of negative co-movement, but they do not control for persistent regional characteristics or common time shocks.

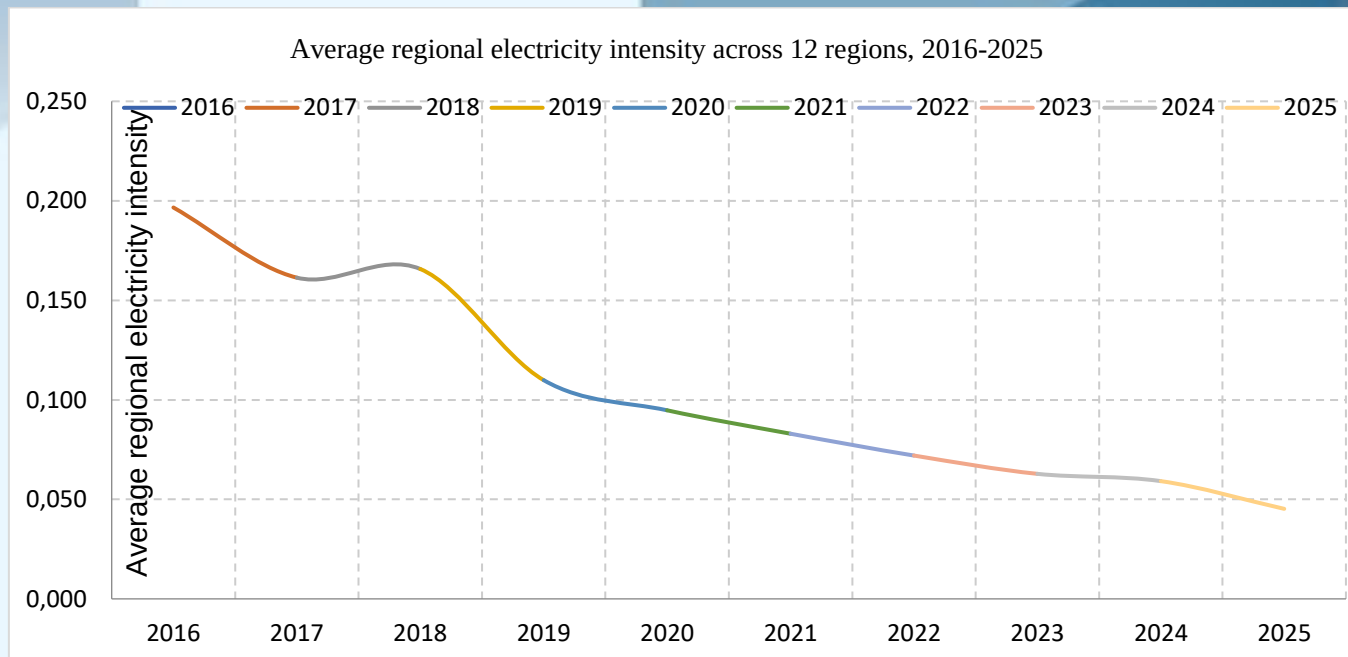


Figure 1. Average regional electricity intensity across 12 regions, 2016-2025

Figure 1 confirms that the decline is broad and persistent rather than confined to a single year. The sharpest breaks occur after 2018, although the exact year-to-year path is influenced by volatility in electricity consumption and nominal GRP. The persistence of the downward trajectory motivates the inclusion of explicit year effects and a time-trend specification in the econometric analysis.

Table 3

Panel regression results: determinants of $\ln(\text{regional electricity intensity})$

Variable	(1) Pooled OLS	(2) Region FE	(3) Two-way FE	(4) Region FE + trend
$\ln(\text{Industrial output})$	-0.2259*** (0.0352)	-0.5315*** (0.1974)	-0.3941* (0.2327)	-0.3603 (0.2313)
Investment intensity	-0.0077** (0.0031)	0.0042 (0.0034)	0.0045 (0.0031)	0.0046 (0.0033)
$\ln(\text{Population})$	-0.0931 (0.1066)	-1.3292 (2.0337)	3.2485 (2.3935)	3.0549 (2.2222)
Linear trend				-0.1269** (0.0566)
Region fixed effects	No	Yes	Yes	Yes
Year effects	No	No	Yes	Trend
Observations	120	120	120	120
R-squared	0.295	0.884	0.915	0.893
Adjusted R-squared	0.277	0.868	0.894	0.878

Source: Author estimates. Standard errors are shown in parentheses. Pooled OLS uses HC3 robust standard errors; FE models use region-clustered standard errors. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

The pooled OLS results show a negative and statistically significant association between industrial output and electricity intensity. The coefficient on

$\ln(\text{industrial output})$ is -0.2259 ($p < 0.01$), implying that, in the pooled cross-sectional and time-series variation, a 1% increase in nominal industrial output is associated with approximately a 0.23% lower electricity-intensity proxy, holding the other included variables constant. Investment intensity is also negative and statistically significant in the pooled model a one-percentage-point increase in the investment-to-GRP ratio is associated with about a 0.77% lower EI in log terms. Population is not statistically significant.

The region fixed-effects model substantially increases explanatory power ($R\text{-squared} = 0.884$) and retains a negative coefficient on industrial output (-0.5315 , $p < 0.01$). This result indicates that, within a region over time, higher industrial output is associated with lower regional electricity intensity after controlling for time-invariant regional characteristics. However, the investment coefficient changes sign and becomes statistically insignificant, suggesting that the simple negative pooled relationship partly reflects cross-regional differences in investment structure and development level rather than a stable within-region effect.

The two-way fixed-effects model adds year effects to control for common macroeconomic, price, policy and system-wide factors. Its $R\text{-squared}$ reaches 0.915. The coefficient on industrial output remains negative (-0.3941) but is significant only at the 10% level, while investment intensity and population are not statistically significant. This weakening is substantively informative: much of the observed decline in electricity intensity is common across regions and therefore absorbed by year effects. The results imply that national time dynamics and persistent regional characteristics together account for a large share of the variation.

The region fixed-effects model with a linear time trend provides a complementary interpretation. The time-trend coefficient is -0.1269 ($p = 0.0249$), corresponding to an average conditional decline of roughly 11.9% per year in the logged electricity-intensity proxy. Once this common trend is included, the individual structural coefficients are no longer statistically significant at conventional levels. Thus, the evidence is consistent with a broad economy-wide decline in regional electricity intensity combined with substantial territorial heterogeneity, rather than a single dominant explanatory factor operating uniformly across all regions.

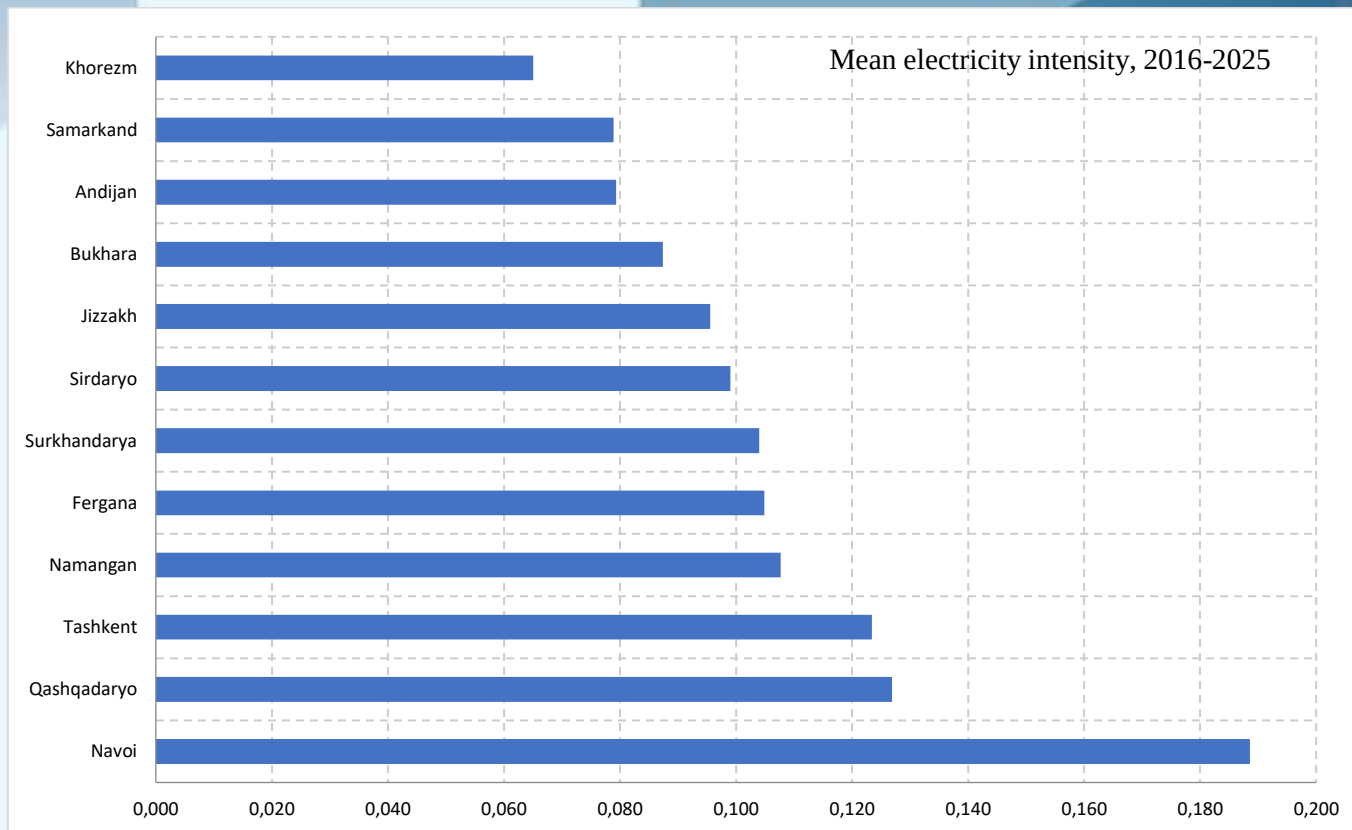


Figure 2. Regional differences in mean electricity intensity, 2016-2025

Regional averages reveal marked heterogeneity. Navoi records the highest mean intensity over the period (0.1886), followed by Kashkadarya (0.1269) and Tashkent region (0.1234). The lowest averages are observed in Khorezm (0.0650), Samarkand (0.0789) and Andijan (0.0793). These rankings should be interpreted as a regional economic-electricity intensity comparison rather than a direct ranking of industrial technical efficiency. Navoi, for example, has a resource- and industry-intensive production structure, while regional GRP composition and the coverage of subscriber electricity consumption differ across territories.

Table 4

Robustness check excluding reconstructed 2025 industrial output (2016-2024)

Variable	Coefficient	Clustered std. error	p-value
ln(Industrial output)	-0.3683	0.2249	0.1014
Investment intensity	0.0040	0.0027	0.1433
ln(Population)	3.6585	2.6073	0.1606
Region fixed effects	Yes	-	-
Year fixed effects	Yes	-	-
Observations	108	-	-
R-squared	0.904	-	-
Adjusted R-	0.879	-	-

squared			
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The 2016-2024 robustness specification produces the same qualitative pattern as the full sample. The industrial-output coefficient remains negative (-0.3683), investment intensity remains positive but statistically insignificant, and population remains statistically insignificant. The R-squared is 0.904. The close similarity between the full-sample and 2016-2024 estimates indicates that the main conclusions are not driven by the reconstruction of the 2025 industrial-output value. Overall, the empirical evidence suggests three broad conclusions. First, regional electricity intensity has declined substantially across Uzbekistan's 12 regions during 2016-2025. Second, industrial-output expansion is negatively associated with intensity in simpler and region fixed-effects specifications, but its independent statistical significance weakens once common year effects are controlled. Third, investment intensity by itself does not display a stable within-region coefficient, which supports the view that the composition and technological direction of investment may matter more than the aggregate investment ratio. These conclusions are consistent with international findings that energy intensity reflects a combination of structural, technological, investment and regional effects rather than a single determinant [8-16].

CONCLUSION AND RECOMMENDATIONS

This study developed an open-data panel framework for assessing regional electricity intensity and industrial development across 12 regions of Uzbekistan over 2016-2025. The principal descriptive result is a substantial reduction in the average electricity-intensity proxy, from 0.1966 in 2016 to 0.0452 in 2025. At the same time, regional industrial output and fixed-capital investment expanded considerably, while electricity consumption grew more moderately and remained volatile across individual years and territories.

The econometric results confirm that regional heterogeneity is central to the analysis. Pooled OLS identifies significant negative associations of industrial output and investment intensity with electricity intensity. The region fixed-effects specification retains a significant negative industrial-output coefficient, whereas the two-way fixed-effects specification indicates that common time shocks and national trends absorb much of the explanatory power of individual covariates. A separate fixed-effects specification with a linear trend identifies a statistically significant downward trend, while the 2016-2024 robustness model produces qualitatively similar coefficients to the full sample.

The results have several practical implications. First, regional energy-efficiency policy should be differentiated rather than based solely on national averages.

Regions with persistently high electricity intensity, particularly those with resource- and heavy-industry concentration, require deeper energy audits, technology modernization, digital metering and enterprise-level energy-management systems. Second, investment policy should place greater emphasis on the technological and energy-saving content of capital expenditure. The absence of a stable coefficient for aggregate investment intensity suggests that increasing investment volumes alone is not sufficient to guarantee lower electricity intensity. Third, regional monitoring systems should integrate electricity consumption, industrial production, investment and output indicators in a single analytical framework so that changes in energy productivity can be identified earlier and linked to management decisions.

Fourth, the statistical infrastructure should be strengthened by publishing region-by-industry electricity consumption and, where possible, physical or constant-price industrial output measures. Such data would make it possible to estimate true industrial electricity intensity and separate technical efficiency from changes in prices and economic structure. Fifth, future research should combine enterprise-level energy data with financial, technological and management indicators. This would support causal and micro econometric analyses of how energy-management systems, financing mechanisms, digital monitoring, and investment in energy-saving technologies affect industrial energy performance.

The main methodological limitation is that the dependent variable is a regional electricity-intensity proxy rather than a sector-specific industrial energy-intensity measure. Moreover, GRP and industrial output are reported in current prices, so common inflation and valuation effects may contribute to the downward ratio. Year effects and robustness checks reduce but do not fully eliminate this limitation. Therefore, the findings should be interpreted as evidence of regional statistical association and structural dynamics, not as a causal estimate of technical energy-efficiency improvements.

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