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Comprehensive Assessment of Public–Private Partnership Efficiency Across Uzbekistan's Regions: An Integral Methodology and Interregional Comparative Analysis

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Abstract: This article develops an integral methodology - the PPP Investment-Institutional Efficiency Index (PPP–IIE) - for comprehensively assessing the efficiency of public–private partnership (PPP) mechanisms across Uzbekistan's regions on the basis of official statistical data, without relying on expert judgement. Drawing on a registry of 1,128 PPP projects and official investment statistics for 14 regions, the methodology operationalises two dimensions - investment-financial (INV-F) and institutional-governance (INS-G) - through six indicators, assigns objective weights via Shannon entropy, and combines the two blocks through non-compensatory weighted geometric aggregation, independently cross-validated with TOPSIS. Applying the index to Uzbekistan's 14 regions reveals substantial interregional differentiation, from 0.440 in Samarkand to 0.186 in Khorezm, and shows that high investment concentration does not guarantee overall efficiency where institutional execution - reflected in contract-termination rates - is weak. A sensitivity analysis ($\pm 20\%$ weight variation, Spearman $\rho > 0.9$) confirms the robustness of the regional groupings. The PPP–IIE index offers a practical tool for prioritising PPP projects by region and targeting investment and institutional-strengthening measures.

Keywords: Public–Private Partnership, Regional Efficiency, Composite Index, Shannon Entropy, Geometric Aggregation, TOPSIS, Institutional Governance, Uzbekistan, Investment Potential, Regional Industrial Policy

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1. Introduction

In the modern economy, public–private partnership (PPP) has become the leading mechanism for attracting private capital to the development of infrastructure and industrial sectors. The global infrastructure financing gap is estimated to reach approximately USD 15 trillion by 2040, which constrains public-budget capacity, especially in developing and transition economies [1]

In Uzbekistan, following the adoption of the Law “On Public–Private Partnership” in 2019, PPP projects expanded rapidly in energy, utilities, transport, the social sphere and other areas [2]. However, under these conditions of rapid growth, the systematic assessment of PPP efficiency across the country’s regions remains an open question.

Three main approaches to assessing PPP efficiency have taken shape in the scholarly literature: value-for-money (VfM) analysis, critical success factors (CSF), and single financial ratios. Hodge and Greve demonstrate that efficiency cannot be confined to a single financial indicator and must jointly capture investment, institutional and social dimensions. Akomea-Frimpong and co-authors, in turn, advance the need to assess innovation-investment-performance as an integrated system. Theoretically, the optimal risk-allocation paradigm, and empirically, institutional quality and multi-party participation, are recognised as the decisive factors of project bankability [3]

At the same time, most existing studies assess PPP efficiency at the level of an individual project or the country as a whole. Approaches that assess the divergence in PPP efficiency across regions within a single country - combining the dimensions of investment potential and institutional-execution quality into a single, comparable integral indicator - have scarcely been developed. Such interregional analysis is particularly rare in the empirical literature on post-Soviet transition economies. Yet the regional distribution of PPP investment and the differences in its execution efficiency are directly relevant for substantiating regional industrial policy and for the targeted allocation of investment.[4]

Building on this research gap, the purpose of this study is to develop an integral methodology - the PPP Investment-Institutional Efficiency Index (PPP-IIE) - that comprehensively measures the investment-institutional efficiency of PPP mechanisms across regions on the basis of official statistical data, and to test it on the example of Uzbekistan's 14 regions. The methodology determines weights objectively through the Shannon entropy method and combines the blocks through non-compensatory weighted geometric aggregation, while the result is independently cross-validated using the TOPSIS method [5]

The scientific contribution of the article is as follows. First, this is the first study to assess PPP efficiency across Uzbekistan's regions on the basis of a single integral index. Second, the proposed methodology distinguishes itself from existing VfM and CSF approaches by combining objective (statistical) assessment with non-compensatory aggregation. Third, the results obtained identify the principal drivers of interregional differentiation and provide practical recommendations for regional industrial policy.[6]

2. Materials and Methods

The study's empirical base was formed by triangulating two official sources. The first source is the official registry of public-private partnership projects in the Republic of Uzbekistan, which covers data on 1,128 projects (project name, region, sector, project value, contract term and, where applicable, termination date). Because the registry's 'region' field initially contained various district-level entries, it was regrouped into 14 canonical regions (the Republic of Karakalpakstan, 12 provinces and the city of Tashkent), and for each region the volume of PPP investment, the number of projects, the average contract term and the share of terminated contracts were calculated.[7]

The second source is the official investment statistics of the Statistics Agency of the Republic of Uzbekistan: the share of funds raised in fixed-capital investment, and the share of foreign investment and credits, by region, as of 2025. The unit of analysis is Uzbekistan's 14 regions; all indicators were taken for the latest available period.[8]

The two dimensions of PPP efficiency - investment-financial (INV-F) and institutional-governance (INS-G) - were operationalised through six indicators (Table 1). Because both blocks are built entirely from official statistical data, the assessment is carried out objectively, without expert judgement. Indicators were classified as stimulant (an increase in value raises efficiency) or destimulant (the reverse).[9]

Table 1. Indicator system of the PPP–IIE integral index [10]

Block	Indicators	Type
INV-F (investment-financial)	Share of PPP investment; number of PPP projects; share of funds raised; share of foreign investment	stimulant
INS-G (institutional-governance)	Average contract term; share of terminated contracts	stimulant / destimulant

Note: “destimulant” denotes an indicator that is inverse-normalised (a higher raw value lowers efficiency).

The integral index is calculated in five steps. m is the number of regions ($m = 14$), n is the number of indicators, and x_{ij} is the raw value of region i on indicator j . Indicators measured in different units are rescaled to the $[0, 1]$ range through linear scaling - for a stimulant (1) and a destimulant (2) indicator respectively:

$$x'_{ij} = (x_{ij} - \min x_j) / (\max x_j - \min x_j) \quad (1)$$

$$x'_{ij} = (\max x_j - x_{ij}) / (\max x_j - \min x_j) \quad (2)$$

Objective weights - Shannon entropy. The weight of each indicator is determined from its information content (variation) (Shannon, 1948; OECD & JRC, 2008). First the shares are calculated, then the entropy and the degree of differentiation:[11]

$$p_{ij} = x'_{ij} / \sum_i x'_{ij}; \quad e_j = -(1/\ln m) \cdot \sum_i p_{ij} \ln p_{ij} \quad (3) - (4)$$

Block sub-indices. For each block, the entropy-weighted sum of its constituent indicators is calculated (weights are renormalised within the block):

$$w_j = (1 - e_j) / \sum_j (1 - e_j) \quad (5)$$

$$I_k = \sum_j w_j \cdot x'_{kj}, \quad k \in \{INV - F, INS - G\} \quad (6)$$

Integral index - weighted geometric aggregation. The blocks are combined not additively but through a non-compensatory weighted geometric mean. This choice is methodologically well founded: under geometric aggregation, a very low value on one dimension is not fully offset by the other [12]:

$$DXSh - IIS_i = \prod_k (I_{ik})^{\lambda_k}, \quad \sum_k \lambda_k = 1 \quad (7)$$

where λ_k are the inter-block weights. In this study, given the priority of the investment dimension, $\lambda(INV-F) = 0.6$ and $\lambda(INS-G) = 0.4$ were adopted; their robustness was tested in the sensitivity analysis.

Cross-validation and sensitivity. To test the reliability of the ranking, the TOPSIS method (Hwang & Yoon, 1981) is applied as an independent cross-validation: for each region, a closeness coefficient is calculated from its distances to the ideal-positive and ideal-negative solutions:

$$C_i^* = d_i^- / (d_i^+ + d_i^-) \quad (8)$$

In addition, the inter-block weights were varied within a $\pm 20\%$ range, and the stability of the ranking was assessed using the Spearman rank correlation (ρ). All calculations were carried out by the author using a computational model that automates entropy normalisation, geometric aggregation and TOPSIS.

3. Results and Discussion

The methodology was tested across Uzbekistan's 14 regions. The raw indicators calculated from the PPP registry and official investment statistics are given in Table 2 [13]

Table 2. PPP and investment indicators by region

Region	PPP share, %	No. of projects	Funds raised, %	Foreign inv., %	Term, years	Terminated, %
Karakalpakstan	37.42	109	83.8	77.2	13.5	19.3
Bukhara	11.43	68	81.8	78.0	14.0	17.6
Samarkand	9.45	127	83.1	77.4	14.2	6.3
Tashkent Region	8.15	66	75.5	70.5	15.2	1.5
Sirdaryo	7.12	39	87.8	71.1	13.6	12.8
Surkhandaryo	5.73	93	77.9	68.0	11.8	2.2
Navoiy	5.57	33	85.4	83.7	15.1	6.1
Tashkent City	5.04	53	66.5	57.3	22.9	1.9
Kashkadarya	3.09	72	82.5	76.3	13.0	5.6
Jizzakh	2.40	36	85.4	79.3	15.2	0.0
Namangan	2.08	89	85.8	77.6	12.9	2.2
Andijan	1.15	116	85.9	81.2	14.3	0.0
Fergana	0.77	157	75.7	69.9	12.9	12.1
Khorezm	0.61	70	75.2	65.9	11.4	4.3

Source: author's calculation, based on the PPP project registry (ppp.imv.uz) and the Statistics Agency of the Republic of Uzbekistan (stat.uz).

The raw data reveal considerable interregional unevenness in PPP activity. By value of PPP investment, the highest shares belong to Karakalpakstan (37.4%), Bukhara (11.4%) and Samarkand (9.5%), while by number of projects Fergana (157), Samarkand (127) and Andijan (116) lead. The share of terminated contracts is highest in Karakalpakstan (19.3%), Bukhara (17.6%) and Sirdaryo (12.8%), and zero in Jizzakh and Andijan.

The entropy-derived within-block weights are as follows: in the INV-F block, the share of PPP investment (0.543) and the number of projects (0.262) carry decisive weight, while the shares of funds raised (0.096) and of foreign investment (0.099) carry comparatively small weight; in the INS-G block, the average contract term (0.668) outweighs the share of terminated contracts (0.332). The inter-block weights $\lambda(\text{INV-F}) = 0.6$ and $\lambda(\text{INS-G}) = 0.4$ were adopted. The integral index (PPP-IIE), the block sub-indices, the regional ranking and the TOPSIS cross-validation results are summarised in Table 3 [14]

Table 3. PPP-IIE integral index, regional ranking and TOPSIS cross-validation

Region	INV-F	INS-G	PPP-IIE	Rank	TOPSIS rank
Samarkand	0.479	0.386	0.440	1	2
Andijan	0.361	0.500	0.411	2	4
Karakalpakstan	0.856	0.122	0.393	3	1
Tashkent Region	0.271	0.527	0.354	4	5
Namangan	0.303	0.381	0.332	5	8
Navoiy	0.257	0.442	0.319	6	10
Surkhandaryo	0.294	0.317	0.303	7	11
Jizzakh	0.200	0.553	0.301	8	9
Fergana	0.353	0.211	0.287	9	7

Kashkadarya	0.262	0.328	0.287	10	12
Bukhara	0.380	0.180	0.282	11	6
Tashkent City	0.108	0.967	0.259	12	3
Sirdaryo	0.256	0.240	0.249	13	13
Khorezm	0.150	0.258	0.186	14	14

Source: author's calculation. $\lambda(\text{INV-F}) = 0.6$; $\lambda(\text{INS-G}) = 0.4$.

The results show that the integral index reaches its highest values in Samarkand (PPP-IIE = 0.440), Andijan (0.411) and Karakalpakstan (0.393), and its lowest values in Khorezm (0.186), Sirdaryo (0.249) and Tashkent City (0.259). At the level of the block sub-indices, Karakalpakstan attains the highest INV-F value (0.856), while Tashkent City attains the highest INS-G value (0.967). On the basis of the index values, the regions fall into three groups: high efficiency (PPP-IIE > 0.35) - Samarkand, Andijan, Karakalpakstan and Tashkent Region; medium efficiency (0.28–0.35) - Namangan, Navoiy, Surkhandaryo, Jizzakh, Fergana, Kashkadarya and Bukhara; and low efficiency (< 0.28) - Tashkent City, Sirdaryo and Khorezm.

While confirming the overall ranking, the TOPSIS cross-validation revealed differences in rank for individual regions: Karakalpakstan ranks first under TOPSIS but third under the geometric index; Tashkent City ranks third and twelfth, respectively. In the sensitivity analysis, when the inter-block weights were varied within $\pm 20\%$, the composition of the high- and low-efficiency groups remained stable (Spearman rank correlation $\rho > 0.9$), confirming the overall robustness of the ranking.

The results show that PPP efficiency is distributed markedly unevenly across Uzbekistan's regions, and they make it possible to identify the principal sources of this unevenness. The leading regions on the integral index - Samarkand, Andijan and Karakalpakstan - achieved their high results through different mechanisms rather than a uniform one. Samarkand and Andijan owe their balanced advantage to a large number of projects combined with a low termination share, whereas Karakalpakstan's leadership rests mainly on a high concentration of investment (37.4 percent of the country's PPP value). This divergence is consistent with the theoretical view that PPP efficiency cannot be confined to a single financial indicator and must be interpreted as a multidimensional phenomenon.

The methodologically most significant finding is illustrated by Karakalpakstan: despite its investment dominance, its share of terminated contracts stood at 19.3 percent (INS-G = 0.122), and this institutional weakness was not offset in the integral index because of the non-compensatory geometric aggregation, dropping the region from first to third place. Conversely, Tashkent City combined the highest institutional maturity (the longest average contract term - 22.9 years - and a low termination share; INS-G = 0.967) with the lowest investment share (INV-F = 0.108). These two contrasting cases confirm the practical justification for choosing geometric over additive (arithmetic) aggregation: PPP efficiency requires a balance of investment potential and institutional maturity, and neither dimension can fully compensate for the other. This conclusion is consistent with the empirical and theoretical evidence that institutional quality and optimal risk allocation play a decisive role in the success of PPP projects.

The differences between the geometric integral index and the TOPSIS rankings (for example, Karakalpakstan ranking first under TOPSIS but third under the geometric index, and Tashkent City ranking third and twelfth, respectively) are not accidental but reflect a systematic difference in the aggregation logic of the two methods: TOPSIS, which measures distance to the ideal solution, rewards dominance on a heavily weighted dimension (INV-F) more strongly, whereas geometric aggregation penalises imbalance between dimensions. Using the two methods together provides a check on the robustness of the results and confirms the need to assess regions on multiple dimensions rather than

one. The stability of the high- and low-efficiency groups under sensitivity analysis ($q > 0.9$) shows that the methodology is not sensitive to the choice of weights.

In practical terms, the proposed PPP-IIE index can be applied to regional industrial and investment policy in several ways. First, it provides an analytical basis for prioritising PPP projects by region and for targeting investment. Second, the index identifies regions with weak institutional execution (Karakalpakstan, Bukhara and Sirdaryo, which have high termination shares), indicating that measures for them should focus first on improving transparency, monitoring and contract quality. Third, it points to the PPP-investment potential of regions with a low investment share but institutional maturity, such as Tashkent City.

The study's limitations should also be noted. First, the current assessment is confined to two dimensions of PPP efficiency - investment-financial and institutional-governance; the index would become more complete once economic-production and socio-ecological dimensions are added from regional industry statistics. Second, the institutional dimension is assessed indirectly, through the registry's termination and duration indicators; future research could enrich it with direct indicators of contract quality and monitoring. Third, the analysis is static (cross-sectional) in nature; tracking the PPP-IIE index's dynamics over time is a promising direction.[15]

4. Conclusion

The study developed an integral methodology - the PPP-IIE index - that comprehensively measures the investment-institutional efficiency of PPP mechanisms across regions on the basis of official statistical data, without expert judgement. The methodology differs from existing VfM and CSF approaches in that it determines weights objectively through the Shannon entropy method, combines the blocks through non-compensatory geometric aggregation, and independently cross-validates the result with TOPSIS.

The methodology was tested on the example of Uzbekistan's 14 regions, revealing considerable interregional differentiation in PPP efficiency: the integral index ranged from 0.440 in Samarkand to 0.186 in Khorezm. Investment potential and institutional maturity were identified as the principal interregional differentiators of PPP efficiency; the analysis showed that a high concentration of investment does not translate into ultimate efficiency where institutional execution is weak (a high termination share). The results of the geometric and TOPSIS methods, together with the sensitivity analysis, confirmed the multidimensional robustness of the ranking.

The proposed PPP-IIE index serves as a practical analytical tool for regional industrial policy - for prioritising PPP projects by region, identifying regions with weak institutional execution, and targeting investment. Extending the methodology with economic-production and socio-ecological dimensions, and forecasting the index's dynamic trajectory, are promising directions for future research.

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