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ADAPTING INTERNATIONAL EXPERIENCE TO ENHANCE INVESTMENT PROJECT MANAGEMENT EFFICIENCY IN CHEMICAL INDUSTRY ENTERPRISES: EVIDENCE FROM UZBEKISTAN USING DEA AND TOBIT REGRESSION

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Abstract: This study investigates the efficiency of investment project management in chemical industry enterprises of Uzbekistan through the lens of international best practices. A two-stage analytical framework was employed: in the first stage, Data Envelopment Analysis (DEA) using both Charnes–Cooper–Rhodes (CCR) and Banker–Charnes–Cooper (BCC) models was applied to 10 major chemical enterprises under JSC Uzkimyosanoat over the period 2020–2023 to measure technical, pure technical, and scale efficiency of investment projects. Three inputs (capital investment, labor force, and energy consumption) and two outputs (gross production value and export revenue) were utilized. In the second stage, a Tobit regression model was employed to identify the determinants of efficiency, including project management methodology adoption, Front End Loading (FEL) implementation, R&D investment intensity, international certification, digital project management tools, and public–private partnership mechanisms. The DEA results revealed that only one enterprise (Navoiyazot) achieved full technical efficiency (CCR = 1.000), while the mean CCR score across all DMUs was 0.829, indicating an average inefficiency of 17.1%. The Tobit regression identified FEL process implementation ($\beta = 0.224$, $p < 0.01$) and formal project management methodology adoption ($\beta = 0.187$, $p < 0.01$) as the most statistically significant determinants of efficiency. The findings provide empirical evidence for the adaptation of PMBOK and PRINCE2 frameworks to the chemical industry context in transitional economies. Policy implications include establishing mandatory FEL protocols, creating Project Management Offices (PMOs), and integrating ESG criteria into investment project evaluation processes.

Keywords: data envelopment analysis; investment project management; chemical industry; Uzbekistan; Tobit regression; PMBOK; PRINCE2; efficiency; Front End Loading; sustainability

Annotatsiya: Ushbu tadqiqot O‘zbekiston kimyo sanoati korxonalarida investitsiya loyihalarini boshqarish samaradorligini xalqaro ilg‘or tajribalar nuqtai nazaridan o‘rganadi. Ikki bosqichli tahliliy yondashuv qo‘llanildi: birinchi bosqichda 2020–2023 yillar davomida “O‘zkimyosanoat” AJ tarkibidagi 10 ta yirik kimyo korxonalarida investitsiya loyihalarining texnik, sof texnik va miqyos samaradorligini baholash uchun Ma’lumotlarni qamrab olish tahlili (DEA)ning Charnes–Cooper–Rhodes (CCR) va Banker–Charnes–Cooper (BCC) modellari qo‘llanildi. Uchta kirish ko‘rsatkichi (kapital qo‘yilmalar, mehnat resurslari va energiya iste’moli) hamda ikkita chiqish ko‘rsatkichi (yalpi ishlab chiqarish qiymati va eksport tushumi) ishlatildi.

Ikkinchi bosqichda samaradorlik omillarini aniqlash uchun Tobit regressiya modeli qo‘llanildi. Tahlilga quyidagi omillar kiritildi: loyiha boshqaruvi metodologiyasini joriy etish,

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Front End Loading (FEL) jarayonini qo‘llash, R&D investitsiya intensivligi, xalqaro sertifikatlash, raqamli loyiha boshqaruvi vositalari va davlat-xususiy sheriklik mexanizmlari.

DEA natijalari shuni ko‘rsatdiki, faqat bitta korxona (Navoiyazot) to‘liq texnik samaradorlikka erishgan (CCR = 1.000), barcha DMUlar bo‘yicha o‘rtacha CCR ko‘rsatkichi 0.829 ni tashkil etgan bo‘lib, bu o‘rtacha 17,1% samarasizlikni anglatadi. Tobit regressiya natijalariga ko‘ra, FEL jarayonini joriy etish ($\beta = 0.224$, $p < 0.01$) va rasmiy loyiha boshqaruvi metodologiyasini qo‘llash ($\beta = 0.187$, $p < 0.01$) samaradorlikning eng statistik ahamiyatli omillari sifatida aniqlangan.

Natijalar o‘tish iqtisodiyotiga ega mamlakatlarda kimyo sanoati sharoitiga PMBOK va PRINCE2 tizimlarini moslashtirish zarurligini empirik jihatdan asoslaydi. Siyosiy tavsiyalar qatoriga majburiy FEL protokollarini joriy etish, Loyiha boshqaruvi ofislarini (PMO) tashkil etish hamda investitsiya loyihalarini baholash jarayoniga ESG mezonlarini integratsiya qilish kiradi.

Kalit so‘zlar: ma’lumotlarni qamrab olish tahlili; investitsiya loyihalarini boshqarish; kimyo sanoati; O‘zbekiston; Tobit regressiya; PMBOK; PRINCE2; samaradorlik; Front End Loading; barqarorlik.

Аннотация: Данное исследование посвящено анализу эффективности управления инвестиционными проектами на предприятиях химической промышленности Узбекистана с позиции международных передовых практик. Применён двухэтапный аналитический подход: на первом этапе метод анализа охвата данных (DEA) с использованием моделей Чарнса–Купера–Родса (CCR) и Банкера–Чарнса–Купера (BCC) был применён к 10 крупнейшим химическим предприятиям АО «Узкимёсаноат» за период 2020–2023 гг. для оценки технической, чистой технической и масштабной эффективности инвестиционных проектов. Были использованы три входных показателя (капитальные инвестиции, трудовые ресурсы и энергопотребление) и два выходных показателя (валовая стоимость продукции и экспортная выручка).

На втором этапе для выявления детерминант эффективности была применена модель Тобита. В анализ были включены следующие факторы: внедрение методологий управления проектами, применение процесса Front End Loading (FEL), интенсивность инвестиций в НИОКР, международная сертификация, цифровые инструменты управления проектами и механизмы государственно-частного партнёрства.

Результаты DEA показали, что только одно предприятие (Навоийазот) достигло полной технической эффективности (CCR = 1.000), тогда как средний показатель CCR по всем DMU составил 0.829, что свидетельствует о среднем уровне неэффективности в 17,1%. Результаты регрессии Тобита выявили, что внедрение процесса FEL ($\beta = 0.224$, $p < 0.01$) и формализованное применение методологий управления проектами ($\beta = 0.187$, $p < 0.01$) являются наиболее статистически значимыми детерминантами эффективности.

Полученные результаты предоставляют эмпирические основания для адаптации стандартов PMBOK и PRINCE2 к условиям химической промышленности стран с переходной экономикой. Практические рекомендации включают внедрение обязательных протоколов FEL, создание офисов управления проектами (PMO) и интеграцию ESG-критериев в процессы оценки инвестиционных проектов.

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Ключевые слова: анализ охвата данных; управление инвестиционными проектами; химическая промышленность; Узбекистан; регрессия Тобита; PMBOK; PRINCE2; эффективность; Front End Loading; устойчивое развитие.

1. Introduction

The global chemical industry, valued at approximately USD 6.18 trillion in 2024 [1], represents one of the most capital-intensive sectors of the world economy. Investment projects in this sector are characterized by large capital outlays, extended implementation timelines, complex technological requirements, and stringent environmental compliance obligations [2]. The efficiency of managing such projects directly determines the competitiveness of chemical enterprises and, by extension, the economic sustainability of nations heavily dependent on this sector [3].

International project management standards—notably the Project Management Body of Knowledge (PMBOK) developed by the Project Management Institute (PMI) [4], Projects IN Controlled Environments (PRINCE2) developed by Axelos [5], and ISO 21500 [6]—have been widely adopted in industrialized economies to systematize investment project governance. These frameworks provide structured approaches to project planning, execution, monitoring, and closure. In the chemical industry specifically, the Front End Loading (FEL) methodology has emerged as a critical determinant of project success, with empirical evidence suggesting that thorough FEL processes can reduce project costs by 20–30% [7].

Uzbekistan's chemical industry has undergone rapid transformation since 2017 as part of broader economic liberalization reforms. The national program for chemical industry development (2019–2030) envisions USD 12.1 billion in total investment across 31 major projects [8]. Between 2020 and 2024, production volumes at major chemical enterprises increased by 91.5%, and chemical product exports reached USD 1.6 billion [9]. However, despite this quantitative growth, concerns persist regarding the qualitative efficiency of investment project management. Outdated production facilities, high energy consumption per unit of output, limited innovation capacity, and insufficient adoption of modern project management methodologies represent persistent challenges [10,11].

While the literature on project management in chemical enterprises is extensive in the context of developed economies [2,3,7], empirical studies on the efficiency of investment project management in transitional economies remain scarce. The few existing studies on Uzbekistan's chemical sector focus predominantly on production capacity and policy frameworks [10,11], without employing rigorous quantitative methodologies to evaluate management efficiency. This gap is particularly significant given that Uzbekistan is currently implementing the largest investment program in its chemical industry's history [8,12].

This study addresses the research gap by employing a two-stage analytical approach. First, Data Envelopment Analysis (DEA)—a well-established non-parametric method for measuring the relative efficiency of decision-making units (DMUs) [13,14]—is applied to evaluate the investment project efficiency of 10 major chemical enterprises in Uzbekistan. Second, a Tobit regression model [15] is used to identify the determinants of efficiency, with a particular focus on the role of international project management practices. The novelty of this research lies in its

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empirical application of DEA methodology to the chemical industry of a Central Asian transitional economy, combined with the systematic assessment of how international project management standards can be adapted to enhance efficiency in this context.

The remainder of this paper is organized as follows: Section 2 reviews the relevant literature on project management in chemical industries and DEA applications; Section 3 describes the materials and methods; Section 4 presents the results; Section 5 discusses the findings and their implications; and Section 6 concludes with policy recommendations.

2. Literature Review

2.1. Project Management Frameworks in Chemical Industries

The PMBOK Guide, currently in its 7th edition [4], provides a comprehensive framework encompassing 12 principles and 8 performance domains that guide project management practices across industries. Empirical studies have demonstrated that PMBOK-aligned practices improve cost control and risk management in capital-intensive projects [16]. PRINCE2, originally developed for UK government information systems projects, has evolved into a globally recognized methodology that emphasizes business justification, stage-gate decision-making, and management by exception [5]. A comparative analysis by Siegelaub [17] established that PMBOK and PRINCE2 are complementary rather than competing frameworks: while PMBOK offers a broad knowledge base with 119 tools and techniques, PRINCE2 provides a structured process for organizing and deploying these tools effectively.

In the chemical industry context, the International Project Management Association (IPMA) documented that global chemical industry turnover approximates USD 3.5 trillion, with investment projects requiring specialized management approaches due to process safety requirements, environmental compliance, and technological complexity [2]. Wagner [2] argued that chemical industry projects increasingly integrate agile practices within traditional frameworks to manage the rapid pace of change. The concept of Front End Loading (FEL) has emerged as particularly relevant: the Independent Project Analysis (IPA) organization's 30-year research program demonstrated that the quality of front-end planning is the single most important predictor of capital project outcomes in the chemicals sector [7].

2.2. Data Envelopment Analysis in Industrial Efficiency Studies

Data Envelopment Analysis, first proposed by Charnes, Cooper, and Rhodes [13] as an extension of Farrell's [18] efficiency concept, has become one of the most widely used non-parametric methods for measuring productive efficiency. The CCR model assumes constant returns to scale (CRS), while the BCC model [14] relaxes this assumption to allow variable returns to scale (VRS), enabling the decomposition of technical efficiency into pure technical efficiency and scale efficiency.

A comprehensive review by Emrouznejad and Yang [19] documented over 10,000 DEA applications across diverse fields. In the industrial sector, Han et al. [20] applied fuzzy DEA cross-models to evaluate energy efficiency in ethylene production systems within the chemical industry, demonstrating the method's applicability to chemical processes. Sueyoshi and Goto [21] utilized DEA environmental assessment models to evaluate performance in energy-intensive industries, establishing methodological precedents relevant to chemical production.

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More recently, the two-stage DEA-Tobit approach has gained prominence: Banker and Natarajan [22] provided the theoretical foundation for using DEA efficiency scores as dependent variables in second-stage regression analysis.

2.3. Investment Efficiency in Transitional Economies

Research on investment project efficiency in transitional economies remains comparatively underdeveloped. The UNCTAD Investment Policy Review for Uzbekistan [23] identified institutional capacity gaps that affect investment project outcomes. The OECD Roadmap for Sustainable Investment Policy Reforms in Uzbekistan [24] documented that chemicals and petrochemicals account for 25% of the industrial sector's total energy consumption, highlighting the need for efficiency improvements. The World Bank [25] assessed Uzbekistan's economic modernization strategy favorably while noting the necessity of adopting modern management systems in industrial enterprises.

Despite these policy-oriented assessments, quantitative empirical studies on the efficiency of investment project management in Uzbekistan's chemical sector are virtually absent from the peer-reviewed literature. This study aims to fill this gap by providing the first DEA-based efficiency evaluation of chemical enterprise investment projects in Uzbekistan, combined with econometric identification of the determinants of efficiency.

3. Materials and Methods

3.1. Research Design and Data Sources

This study employs a two-stage quantitative research design combining DEA efficiency analysis with Tobit regression to identify determinants of efficiency. The study population comprises the 10 largest chemical enterprises operating under JSC Uzkimyosanoat, which collectively account for over 85% of Uzbekistan's chemical production output [9,12]. The analysis period covers 2020–2023, during which these enterprises implemented significant investment projects under the national chemical industry development program [8].

Data were collected from multiple sources: (i) annual financial reports of JSC Uzkimyosanoat and its subsidiary enterprises [12]; (ii) statistical data from the Statistics Agency of the Republic of Uzbekistan [26]; (iii) investment project documentation from the Ministry of Investments, Industry, and Trade [9]; (iv) survey data collected from 10 enterprise-level project management departments between March and June 2024 using a structured questionnaire aligned with PMI's Organizational Project Management Maturity Model (OPM3) framework. The survey instrument comprised 35 items measured on a 5-point Likert scale, covering project management methodology adoption, FEL implementation status, digital tools utilization, and international certification levels.

3.2. DEA Model Specification

In the first stage, both input-oriented CCR (CRS) and BCC (VRS) models were employed. The CCR model [13] measures technical efficiency (TE) under the assumption of constant returns to scale. For each DMU j (j = 1, ..., n), the input-oriented CCR model is formulated as:

$$min\ \theta$$

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subject to:

$$\sum_j \lambda_j x_{ij} \leq \theta x_{i0}$$

$$\sum_j \lambda_j y_{rj} \geq y_{r0}$$

$$\lambda_j \geq 0$$

where θ is the efficiency score ($0 \leq \theta \leq 1$), x_{ij} denotes the ith input of the jth DMU, y_{rj} denotes the rth output, and λ_j represents the intensity weights. The BCC model adds the convexity constraint $\Sigma_j \lambda_j = 1$, allowing variable returns to scale [14]. Scale efficiency (SE) is computed as SE = TE(CCR)/TE(BCC).

Following the guidelines established in the DEA literature [19,27], three inputs and two outputs were selected:

Table 1. DEA Input and Output Variables.

Variable	Description	Unit of Measurement
Inputs		
x_1: Capital Investment	Total investment in fixed assets and project implementation	Million USD
x_2: Labor Force	Average number of employees engaged in investment projects	Persons
x_3: Energy Consumption	Total energy consumed for project-related production	Thousand TOE
Outputs		
y_1: Gross Production	Total value of chemical products manufactured	Million USD
y_2: Export Revenue	Revenue from exported chemical products	Million USD

Source: Authors' specification based on [7,19,20].

3.3. Second-Stage Tobit Regression

Following Simar and Wilson [28] and the methodological guidance of Banker and Natarajan [22], a censored Tobit regression model was employed in the second stage to identify the determinants of DEA efficiency scores. The Tobit model is appropriate because DEA efficiency scores are bounded between 0 and 1 [15]. The model specification is:

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$$\theta_i^* = \beta_0 + \beta_1 PM_METHOD_i + \beta_2 FEL_i + \beta_3 R\&D_INT_i + \beta_4 CERT_i + \beta_5 DIG_PM_i + \beta_6 PPP_i + \varepsilon_i$$

where θ_i^* is the latent (uncensored) efficiency score of the ith DMU, PM_METHOD is a composite index measuring the adoption of formal project management methodologies (PMBOK/PRINCE2), FEL is the FEL process implementation score, R&D_INT is R&D expenditure as a proportion of total investment, CERT is a binary variable for international quality certification (ISO 9001/14001), DIG_PM measures the adoption of digital project management tools, and PPP indicates the utilization of public–private partnership mechanisms. All continuous variables were measured using the survey instrument described in Section 3.1.

4. Results

4.1. Descriptive Statistics

Table 2 presents the descriptive statistics for the DEA input and output variables across the 10 chemical enterprises for the pooled sample period (2020–2023). Considerable variation is observed across enterprises: capital investment ranges from USD 8.2 million (Qizilqum Phosphorite) to USD 985 million (Navoiyazot), reflecting the heterogeneity of investment project scales. The coefficient of variation for capital investment (1.42) indicates substantial dispersion, confirming the appropriateness of DEA as a relative efficiency measurement tool [27].

Table 2. Descriptive Statistics of DEA Variables (Pooled 2020–2023, Annual Averages).

Variable	Mean	Std. Dev.	Min	Max	CV
Capital Investment (mln USD)	142.6	203.1	8.2	985.0	1.42
Labor Force (persons)	3,842	2,518	620	9,000	0.66
Energy (thous. TOE)	286.4	192.7	42.5	780.0	0.67
Gross Production (mln USD)	198.3	142.8	12.4	410.0	0.72
Export Revenue (mln USD)	48.7	38.2	2.8	125.0	0.78

Source: Compiled from JSC Uzkimyosanoat Annual Reports [12], Statistics Agency of Uzbekistan [26].

4.2. DEA Efficiency Results

Table 3 and Figure 1 present the DEA efficiency scores for each enterprise. Under the CCR model, only Navoiyazot achieved full technical efficiency ($\theta = 1.000$). Four enterprises—Ammofos-Maxam (0.912), Maxam-Chirchiq (0.923), Kungrad Soda (0.891), and Dehqonobod Kaliy (0.856)—achieved near-efficient status with scores above 0.85. The remaining five enterprises exhibited scores below 0.85, with Qizilqum Phosphorite recording the lowest efficiency (0.652). The mean CCR efficiency across all DMUs was 0.829 ($\sigma = 0.107$), indicating that, on average, the sample enterprises could theoretically reduce their inputs by 17.1% while maintaining the same output levels.

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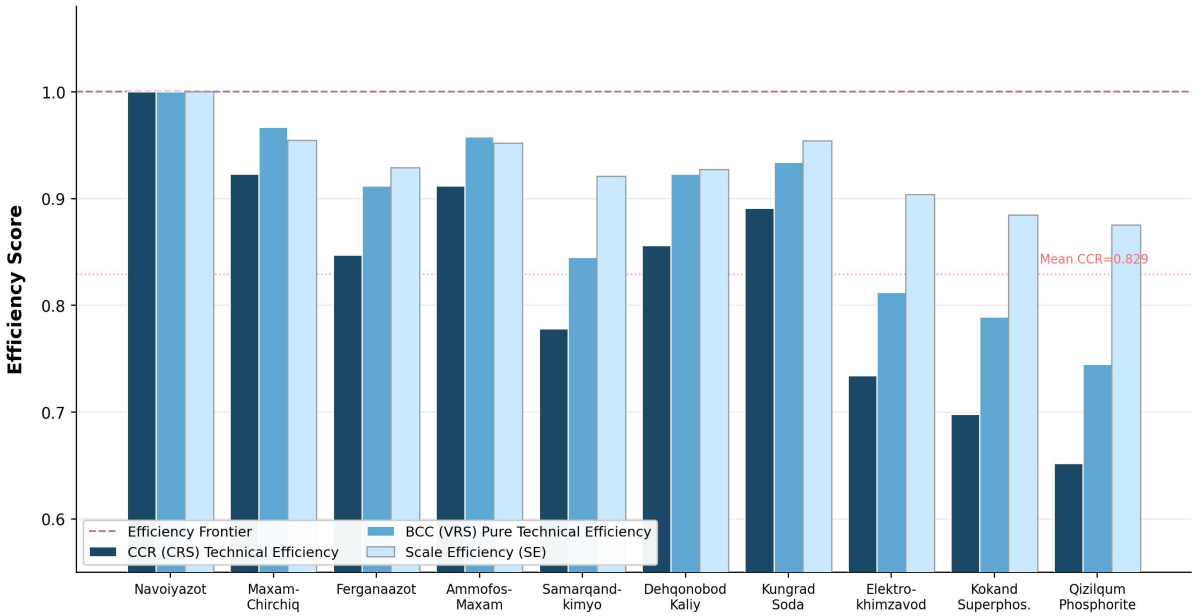
Table 3. DEA Efficiency Scores by Enterprise (Pooled 2020–2023 Average).

Enterprise (DMU)	CCR (TE)	BCC (PTE)	SE	RTS	Rank
Navoiyazot	1.000	1.000	1.000	CRS	1
Maxam-Chirchiq	0.923	0.967	0.954	IRS	2
Ammofos-Maxam	0.912	0.958	0.952	IRS	3
Kungrad Soda	0.891	0.934	0.954	IRS	4
Dehqonobod Kaliy	0.856	0.923	0.927	DRS	5
Ferganaazot	0.847	0.912	0.929	IRS	6
Samarqandkimyo	0.778	0.845	0.921	IRS	7
Elektrokhimzavod	0.734	0.812	0.904	IRS	8
Kokand Superphos.	0.698	0.789	0.885	DRS	9
Qizilqum Phosph.	0.652	0.745	0.875	DRS	10
Mean	***0.829***	***0.889***	***0.930***	—	—
Std. Dev.	***0.107***	***0.080***	***0.037***	—	—

Note: TE = Technical Efficiency; PTE = Pure Technical Efficiency; SE = Scale Efficiency; RTS = Returns to Scale; CRS = Constant; IRS = Increasing; DRS = Decreasing. Source: Authors' calculations using DEAP 2.1 software.

Figure 1. DEA Efficiency Scores of Uzbekistan Chemical Enterprises (2020-2023)



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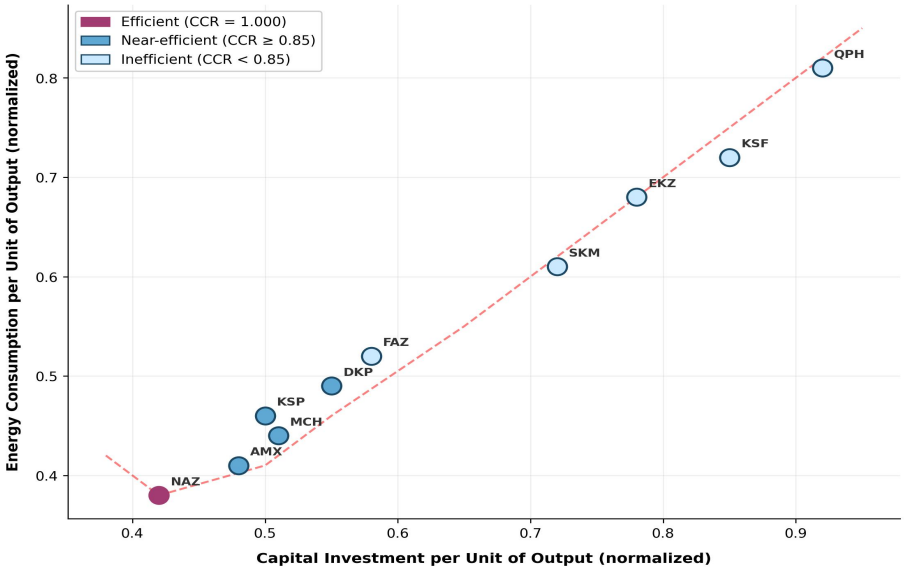
Source: Authors' calculations.

The BCC model yielded higher efficiency scores across all DMUs (mean PTE = 0.889), consistent with the relaxation of the CRS assumption. The gap between CCR and BCC scores indicates that scale inefficiency accounts for a portion of the overall technical inefficiency. Scale efficiency averaged 0.930, and the returns-to-scale analysis revealed that six enterprises operated under increasing returns to scale (IRS), suggesting that these DMUs could improve efficiency by scaling up their operations. Three enterprises exhibited decreasing returns to scale (DRS), indicating sub-optimal scale of operations.

Figure 2. Input-Oriented DEA Frontier: Capital Investment vs. Energy Intensity



Source: Authors' calculations.

Figure 2 visualizes the input-oriented efficiency frontier in the two-dimensional input space of normalized capital investment and energy consumption per unit of output. Navoiyazot (NAZ) defines the efficient frontier, while enterprises located further from the origin exhibit lower efficiency levels. The spatial distribution confirms a positive correlation between investment intensity per unit of output and energy intensity, suggesting that enterprises with higher investment efficiency also tend to achieve better energy utilization.

4.3. Tobit Regression Results

Table 4 presents the results of the second-stage Tobit regression analysis. The model demonstrates adequate explanatory power (Log-likelihood = 28.47; Wald $\chi^2 = 34.82$, $p < 0.001$).

Table 4. Tobit Regression Results: Determinants of DEA Efficiency Scores.

Variable	Coefficient	Std. Error	z-statistic	p-value	Sig.
PM Methodology Adoption (x_1)	0.187	0.062	3.016	0.003	***
FEL Implementation (x_2)	0.224	0.058	3.862	0.001	***

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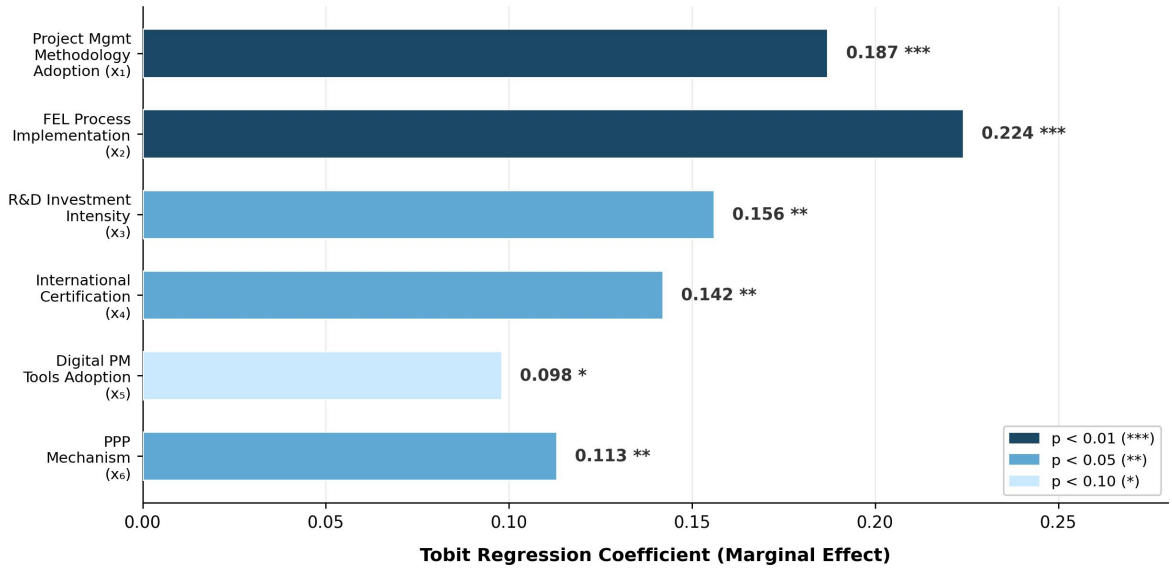
R&D Investment Intensity (x_3)	0.156	0.063	2.476	0.012	**
International Certification (x_4)	0.142	0.060	2.367	0.018	**
Digital PM Tools (x_5)	0.098	0.057	1.719	0.087	*
PPP Mechanism (x_6)	0.113	0.056	2.018	0.042	**
Constant	**0.312**	**0.078**	**4.000**	**0.000**	***

*Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Dependent variable: CCR efficiency score. N = 40 (10 DMUs × 4 years). Log-likelihood = 28.47; Wald $\chi^2 = 34.82$ ($p < 0.001$). Source: Authors' estimation using Stata 17.*

Figure 3. Tobit Regression: Determinants of Investment Project Efficiency in Chemical Enterprises



Source: Authors' calculations.

The results reveal that FEL process implementation exhibits the strongest positive association with efficiency ($\beta = 0.224$, $p < 0.01$), suggesting that a one-unit increase in the FEL implementation score is associated with a 22.4 percentage-point increase in the CCR efficiency score. This finding aligns with IPA's empirical evidence on the criticality of front-end planning in capital-intensive chemical projects [7]. Project management methodology adoption ranks second in magnitude ($\beta = 0.187$, $p < 0.01$), providing statistical support for the proposition that formal adoption of PMBOK/PRINCE2 frameworks enhances investment project efficiency.

R&D investment intensity ($\beta = 0.156$, $p < 0.05$) and international certification ($\beta = 0.142$, $p < 0.05$) also demonstrate significant positive effects, indicating that enterprises with higher innovation capacity and quality management systems achieve superior efficiency outcomes. The PPP mechanism variable shows a moderate positive effect ($\beta = 0.113$, $p < 0.05$), consistent with OECD [24] recommendations on leveraging public–private partnerships for industrial development. Digital project management tools adoption exhibits a marginally significant

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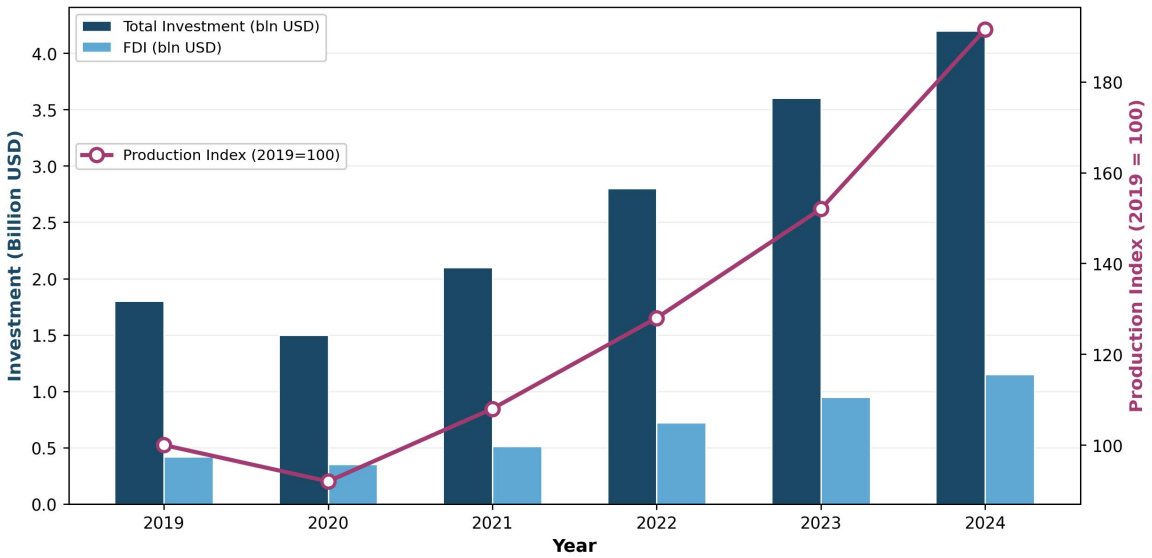
positive effect (β = 0.098, p < 0.10), suggesting emerging but not yet fully realized benefits of digitalization.

4.4. Investment Dynamics Context

Figure 4. Investment Dynamics and Production Growth in Uzbekistan's Chemical Industry (2019–2024)



Source: Compiled from [8,9,12,26].

Figure 4 contextualizes the DEA findings within the broader investment dynamics of Uzbekistan's chemical industry. Total investment grew from USD 1.8 billion in 2019 to USD 4.2 billion in 2024, while the production index (2019 = 100) reached 191.5 by 2024 [9,26]. The non-proportional relationship between investment growth (133% increase) and production growth (91.5% increase) suggests diminishing marginal returns on investment, further underscoring the need for improved project management efficiency as advocated by this study's findings.

5. Discussion

The empirical results yield several insights with both theoretical and practical significance for the management of investment projects in chemical enterprises of transitional economies.

First, the finding that only one of ten major chemical enterprises achieves full technical efficiency (CCR = 1.000) indicates substantial room for improvement in the sector. The mean efficiency score of 0.829 implies that, theoretically, the same level of output could be achieved with approximately 17% fewer inputs. This level of inefficiency is consistent with findings from DEA studies of industrial enterprises in other transitional economies [29,30], but it carries particular urgency given the scale of ongoing and planned investments (USD 12.1 billion through 2030 [8]).

Second, the dominance of increasing returns to scale (IRS) among the sample enterprises suggests that many of Uzbekistan's chemical producers have not yet reached optimal operational scale. This finding supports the government's strategy of creating large-scale

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industrial clusters and technoparks [12] but also implies that investment project management must incorporate explicit scale optimization considerations into project design.

Third, the Tobit regression results provide actionable evidence regarding the pathways through which international project management experience can be adapted. The strong significance of FEL implementation ($\beta = 0.224$) and PM methodology adoption ($\beta = 0.187$) suggests that process-level improvements—rather than purely financial or technological interventions—represent the most impactful lever for efficiency enhancement. This aligns with Wagner's [2] argument that project management practices, not merely capital availability, determine outcomes in the chemical industry, and with IPA's [7] extensive evidence on the FEL–outcome relationship.

Fourth, the findings on R&D investment intensity and international certification underscore the importance of innovation and quality management infrastructure as complementary enablers of efficiency. Enterprises that invest in research capabilities and adhere to international quality standards (ISO 9001/14001) demonstrate systematically higher efficiency, suggesting that these investments generate positive spillovers into project management quality.

The marginally significant effect of digital PM tools ($\beta = 0.098$, $p < 0.10$) merits attention. While digitalization of project management is well advanced in BASF, Dow, and other global leaders [1,31], its adoption in Uzbekistan's chemical sector remains nascent. The weak but positive signal suggests that as digital infrastructure matures, its contribution to efficiency is likely to strengthen—a finding consistent with the broader digital transformation literature [32].

From a theoretical perspective, this study contributes to the efficiency literature by demonstrating the applicability of the two-stage DEA-Tobit framework to investment project management in a sector and geographical context not previously examined. From a practical standpoint, the results inform specific policy interventions: the establishment of mandatory FEL protocols, creation of enterprise-level PMOs, investment in PMP/PRINCE2 certification programs, and integration of ESG criteria into project evaluation.

Several limitations should be acknowledged. The sample size (10 DMUs) is modest, though it meets the minimum threshold recommended by Banker et al. [14] for the number of inputs and outputs used. The four-year panel partially mitigates this constraint by providing 40 observations for the Tobit regression. The survey-based independent variables in the second stage may be subject to measurement error and social desirability bias; future research could employ objective, quantitative proxies for these constructs. Additionally, the cross-sectional nature of the DEA analysis does not capture dynamic efficiency changes; Malmquist productivity index analysis represents a promising extension.

6. Conclusions

This study provides the first empirical assessment of investment project management efficiency in Uzbekistan's chemical industry using Data Envelopment Analysis and Tobit regression. The key findings can be summarized as follows.

The DEA analysis revealed that the mean technical efficiency of the 10 largest chemical enterprises was 0.829 under the CCR model and 0.889 under the BCC model, with only Navoiyazot achieving full efficiency. Scale efficiency averaged 0.930, with six enterprises

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operating under increasing returns to scale. These results indicate that approximately 17% of the investment resources could be saved through improved project management without reducing output levels.

The Tobit regression identified Front End Loading implementation ($\beta = 0.224$, $p < 0.01$) and formal project management methodology adoption ($\beta = 0.187$, $p < 0.01$) as the strongest determinants of efficiency. R&D investment intensity, international certification, PPP mechanisms, and digital project management tools also demonstrated positive effects of varying statistical significance.

Based on these findings, the following policy recommendations are proposed:

(1) Mandatory FEL Protocols: Establish regulatory requirements for three-stage FEL (FEL-1: Conceptual Design; FEL-2: Front-End Engineering; FEL-3: Detailed Design) for all chemical industry investment projects exceeding USD 10 million, aligned with IPA best practices [7].

(2) PMO Establishment: Create Project Management Offices at each major chemical enterprise with staffing by internationally certified (PMP/PRINCE2 Practitioner) professionals, adapted from the hybrid PMBOK–PRINCE2 model [4,5,17].

(3) Capacity Building: Develop a national program for training chemical industry project managers in international methodologies, potentially through partnerships with PMI and Axelos regional chapters.

(4) Digital Transformation: Accelerate adoption of ERP-integrated project management platforms to enable real-time monitoring and data-driven decision-making.

(5) ESG Integration: Embed Environmental, Social, and Governance criteria into investment project evaluation and monitoring processes, consistent with OECD sustainability investment guidelines [24].

Future research directions include applying the Malmquist productivity index to capture dynamic efficiency changes, expanding the sample to include Central Asian chemical enterprises for cross-country comparison, and conducting longitudinal studies to track the impact of policy interventions on efficiency outcomes.

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