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Methodology for developing optimal-system models to improve investment efficiency in regions: evidence from the Kashkadarya region

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Abstract:

This article improving the efficiency of investment utilization remains a central challenge for regional economic development, particularly in transition economies where structural imbalances, institutional constraints, and uneven capital allocation hinder sustainable growth. This study develops a comprehensive methodological framework for constructing optimal-system models aimed at enhancing investment efficiency at the regional level, using the Kashkadarya region of Uzbekistan as a case study. The research integrates systems theory, multi-criteria optimization techniques, and econometric modeling to design a structured investment efficiency model. The proposed framework evaluates investment allocation across key sectors based on economic return, employment generation, social impact, and environmental sustainability.

A mathematical optimization model is formulated to determine the optimal distribution of investment resources under budgetary and structural constraints. The study demonstrates that a system-based investment allocation approach significantly improves regional performance indicators compared to traditional allocation mechanisms.

Policy implications suggest the need for institutional coordination, data-driven investment planning, and dynamic monitoring mechanisms. The findings contribute to regional economic modeling literature and provide practical guidance for policymakers in emerging economies.

Keywords:

investment efficiency, regional development, optimization model, system-based approach, Kashkadarya region, economic modeling

1. Introduction

Efficient utilization of investments plays a decisive role in ensuring sustainable regional development. In many developing and transition economies, including Uzbekistan, regional disparities in economic performance remain a persistent challenge. While capital inflows have increased in recent years, the effectiveness of their allocation across sectors and territories often remains suboptimal. Consequently, the development of scientifically grounded methodologies for improving investment efficiency at the regional level has become an urgent priority.

The Kashkadarya region represents a strategically significant economic zone due to its natural resources, agricultural potential, and industrial infrastructure. Despite substantial investment inflows, the region continues to face structural imbalances, limited diversification, and uneven sectoral growth. These challenges indicate the need for a systematic and optimized investment allocation framework.

This study aims to develop a methodological approach for constructing optimal-system models to enhance regional investment efficiency. The research integrates systems theory, optimization modeling, and multi-criteria evaluation to formulate a comprehensive decision-making framework applicable to regional economic management.

The central hypothesis of the study is that investment efficiency can be significantly improved through the implementation of a structured optimization model that accounts for economic, social, and environmental indicators simultaneously.

Literature review

Solow's neoclassical growth model establishes the foundational relationship between capital accumulation, labor, and technological progress in determining economic growth. The model demonstrates that while investment increases capital stock and boosts short- and medium-term output, long-term growth is primarily driven by technological advancement. A key implication of Solow's framework is the concept of diminishing marginal returns to capital, which suggests that simply increasing investment volume does not guarantee proportional increases in output.

For regional investment efficiency modeling, Solow's theory provides an essential macroeconomic foundation. In developing optimal-system models for regions such as Kashkadarya, the principle of diminishing returns emphasizes the importance of efficient capital allocation across sectors rather than excessive concentration in a single industry. This theoretical basis supports the need for structured optimization mechanisms in regional investment planning[1].

Romer's endogenous growth theory expands classical models by incorporating knowledge, innovation, and human capital as internal drivers of economic growth. Unlike the Solow model, where technological progress is exogenous, Romer argues that investments in research, education, and innovation generate increasing returns and sustain long-term economic expansion. This framework highlights the

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structural role of investment composition rather than merely its volume.

In the context of regional optimization modeling, Romer's approach implies that investment efficiency should be evaluated not only by immediate economic returns but also by long-term innovation effects. For the Kashkadarya region, allocating investment toward education, industrial modernization, and infrastructure can create cumulative growth effects. Therefore, endogenous growth theory strengthens the methodological argument for multi-criteria investment optimization[2].

This seminal paper introduced Data Envelopment Analysis (DEA), a non-parametric method used to evaluate the relative efficiency of decision-making units (DMUs) with multiple inputs and outputs. DEA enables researchers to assess performance without requiring predefined production functions. It has become widely applied in measuring efficiency across industries, public sectors, and regional economies.

For regional investment efficiency analysis, DEA offers a valuable empirical tool to compare sectoral performance within a region. In the case of Kashkadarya, DEA can identify which sectors generate higher economic output, employment, and fiscal returns per unit of investment. These results can then inform the construction of an optimal-system allocation model by prioritizing more efficient sectors while addressing structural weaknesses[3].

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making (MCDM) method that structures complex decisions into hierarchical levels and assigns weights through pairwise comparisons. AHP is particularly useful when decisions involve both quantitative and qualitative factors. It enables policymakers to systematically evaluate trade-offs between economic, social, and environmental objectives.

In developing optimal-system investment models, AHP can be used to determine the relative importance of efficiency indicators such as economic return, employment generation, social development, and environmental sustainability. For the Kashkadarya region, incorporating AHP ensures that the optimization model reflects strategic development priorities rather than relying solely on financial metrics[4].

Arrow and Kurz analyze the relationship between public investment, social rates of return, and optimal fiscal policy. Their work provides a theoretical framework for evaluating public investment projects based on long-term social benefits rather than short-term profitability alone. The model integrates intertemporal decision-making and discounting mechanisms into public investment planning[5].

For regional economic modeling, this approach is highly relevant when designing investment optimization frameworks under budget constraints. In Kashkadarya, public investment decisions must balance economic growth with social welfare and infrastructure development. The Arrow–Kurz framework strengthens the methodological basis for incorporating social return functions into regional optimal-system models.

2. Research methodology

The regional economy is conceptualized as a complex system consisting of interconnected subsystems:

- Industrial production sector

- Agricultural sector
- Infrastructure and logistics
- Social services (education, healthcare)
- Environmental sustainability subsystem

Investment allocation influences each subsystem differently, and feedback effects must be considered.

The industrial production sector represents a central pillar of regional economic growth, particularly in resource-rich and transition economies. It encompasses manufacturing, energy production, processing industries, and extractive activities. Industrial investment contributes directly to Gross Regional Product (GRP), export capacity, technological modernization, and productivity growth. In regions such as Kashkadarya, where energy and natural resource industries are prominent, industrial policy significantly shapes overall economic performance.

From an investment efficiency perspective, the industrial sector generates both direct and indirect multiplier effects. Direct effects include output expansion and employment creation, while indirect effects arise through supply chain linkages, service demand, and infrastructure utilization. However, overconcentration of investments in extractive industries may lead to diminishing marginal returns and structural dependency, limiting long-term diversification.

Optimal-system modeling of industrial investments requires evaluating capital productivity, value-added generation, technological intensity, and environmental costs. Advanced manufacturing and processing industries typically demonstrate higher long-term efficiency compared to raw material extraction. Therefore, investment allocation models must prioritize sectors with higher innovation potential and value-chain integration.

In regional optimization frameworks, industrial investment should be aligned with modernization objectives, industrial clustering strategies, and export diversification policies. Integrating industrial policy with infrastructure and workforce development further enhances systemic investment efficiency.

The agricultural sector plays a crucial role in ensuring food security, rural employment, and income stability. In many regions, including Kashkadarya, agriculture remains a significant contributor to employment and household income. Investment in agriculture influences productivity through irrigation systems, mechanization, digital technologies, and agro-processing capacity.

Investment efficiency in agriculture is often influenced by climate conditions, water resource management, and market integration. Traditional agricultural investment models focused primarily on expanding production volumes. However, modern optimization approaches emphasize productivity per unit of capital, technological adoption, and value-added processing. Investments in agro-industrial integration create stronger multiplier effects compared to primary production alone.

A system-based approach treats agriculture not as an isolated sector but as part of a broader agro-industrial ecosystem. Linkages between farming, logistics, storage, processing, and export markets determine overall efficiency. Therefore, optimal investment models must account for supply chain efficiency and infrastructure compatibility.

In regional investment planning, agricultural investments should prioritize climate resilience, resource efficiency, and technological innovation. Sustainable irrigation systems, digital farming solutions, and integrated



processing industries significantly enhance long-term regional competitiveness.

Infrastructure and logistics form the structural backbone of regional economic systems. This subsystem includes transportation networks, energy supply systems, telecommunications, water management, and logistics hubs. Infrastructure investments typically produce long-term multiplier effects by improving productivity across all economic sectors.

Unlike direct production investments, infrastructure yields indirect returns through cost reduction, improved market access, and enhanced business competitiveness. Efficient logistics systems reduce transaction costs, facilitate trade integration, and increase regional attractiveness for private investment. In developing regions, infrastructure deficits often represent the primary constraint on investment efficiency.

From an optimization standpoint, infrastructure investments should be evaluated using long-term social return indicators rather than short-term profitability. Transport connectivity, energy reliability, and digital infrastructure significantly influence industrial and agricultural performance. Therefore, infrastructure functions as a systemic catalyst within the optimal investment model.

In Kashkadarya's case, strategic investment in transport corridors, logistics centers, and energy modernization can generate cross-sectoral productivity gains. Infrastructure optimization must consider geographic distribution, economic density, and integration with national development strategies.

Social services represent a critical component of sustainable regional development. Investments in education and healthcare directly influence human capital formation, labor productivity, and social stability. Unlike purely economic sectors, social investments generate long-term structural benefits rather than immediate financial returns.

Education investments enhance workforce skills, technological adoption capacity, and innovation potential. Healthcare investments improve labor efficiency, reduce absenteeism, and increase life expectancy. Together, these factors strengthen regional competitiveness and attract further private investment. Human capital development is particularly important in transitioning economies seeking diversification.

In optimal-system modeling, social sector investments are evaluated through composite indicators such as employment quality, innovation capacity, and demographic stability. Although the financial return may appear indirect, the long-term multiplier effects are substantial and measurable through growth sustainability metrics.

Regional investment strategies must balance economic infrastructure spending with social development funding. In the Kashkadarya region, strengthening vocational training and healthcare infrastructure can significantly enhance labor market efficiency and long-term economic resilience.

Environmental sustainability has become an essential dimension of modern investment planning. This subsystem includes renewable energy development, water resource management, pollution control, and ecological conservation. Ignoring environmental factors may result in long-term economic inefficiencies and structural vulnerability.

Investment efficiency models increasingly incorporate environmental constraints and sustainability indicators. Industrial and agricultural expansion without ecological balance can generate hidden social costs, including health

expenditures and productivity losses. Therefore, environmental investments must be integrated into optimal-system frameworks as both a constraint and a performance indicator.

Green investments often generate long-term returns through energy savings, climate resilience, and international competitiveness. Regions that adopt environmentally responsible policies attract sustainable foreign investment and improve social welfare outcomes. Environmental optimization also aligns with global sustainable development goals (SDGs).

In Kashkadarya, water management, renewable energy expansion, and emission reduction policies are particularly relevant. Integrating environmental sustainability into the investment optimization model ensures balanced growth and long-term regional stability.

Investment efficiency within the proposed optimal-system framework is assessed through a composite indicator that integrates multiple dimensions of regional development. Traditional approaches to investment evaluation often focus solely on financial profitability or output growth; however, such narrow assessments fail to capture the broader socio-economic and environmental impacts of capital allocation. Therefore, this study adopts a multi-dimensional composite index - the Investment Efficiency Index (IEI) - that reflects both direct and indirect effects of investment activity at the regional level.

The first component of the index, economic return (E), measures the contribution of investment to Gross Regional Product (GRP) growth. This indicator captures capital productivity and value-added generation across sectors. It is typically estimated through marginal output growth attributable to investment inflows, sectoral output elasticity, or econometric modeling of capital-output relationships. Economic return serves as the core efficiency measure, reflecting the fundamental objective of increasing regional economic output.

The second and third components - labor impact (L) and fiscal impact (F) - extend the evaluation beyond pure production outcomes. Labor impact measures employment generation, job quality improvement, and labor productivity growth resulting from investment. This dimension is particularly important in regions with demographic pressures or structural unemployment. Fiscal impact assesses the contribution of investments to public revenue through tax expansion, improved formalization, and increased economic activity. Together, these indicators capture the sustainability of investment from both labor market and public finance perspectives.

The fourth and fifth components - social impact (S) and environmental sustainability (Env) - incorporate long-term structural considerations. Social impact evaluates improvements in human development indicators such as education access, healthcare availability, and income distribution. Environmental sustainability measures the ecological consequences of investment, including emissions reduction, resource efficiency, and alignment with green development strategies. Integrating environmental criteria prevents short-term economic gains from generating long-term structural costs.

The composite Investment Efficiency Index is formally expressed as:

$$IEI = w_1E + w_2L + w_3F + w_4S + w_5Env \quad (1)$$



where w_i represents the weight assigned to each dimension. These weights may be determined through multi-criteria decision-making methods such as the Analytic Hierarchy Process (AHP) or expert evaluation. The weighting structure ensures that the index reflects regional strategic priorities while maintaining systemic balance. By combining economic, social, fiscal, labor, and environmental indicators into a single optimization metric, the IEI provides a comprehensive tool for regional investment planning and policy decision-making.

The central objective of the proposed optimal-system model is to maximize total regional investment efficiency by determining the most productive allocation of limited financial resources across economic sectors. Unlike traditional budgeting approaches that distribute funds incrementally or politically, this optimization framework relies on measurable efficiency indicators. The model ensures that investment allocation decisions are aligned with systemic performance outcomes rather than isolated sectoral interests.

Formally, the objective function is expressed as:

$$\text{Maximize } Z = \sum_{i=1}^n (IEI_i \times I_i) \quad (2)$$

where I_i represents the volume of investment allocated to sector i , and IEI_i denotes the efficiency coefficient of that sector, derived from the composite Investment Efficiency Index. The variable Z represents the total aggregated efficiency outcome of regional investment allocation.

The efficiency coefficient IEI_i captures the multidimensional impact of investments within each sector, incorporating economic return, employment generation, fiscal contribution, social development, and environmental sustainability. By multiplying the efficiency coefficient by the investment volume, the model quantifies the expected systemic contribution of each sector to overall regional performance. This structure ensures that sectors demonstrating higher productivity and broader socio-economic benefits receive proportionally greater investment shares under optimal conditions.

The summation across all sectors ($i=1,2,\dots,n; n_i=1,2,\dots,n$) reflects the integrated nature of the regional economy. The objective function does not optimize individual sectors independently but rather maximizes total systemic efficiency. In this way, the model embodies the principles of systems theory, recognizing interdependencies between industrial production, agriculture, infrastructure, social services, and environmental sustainability.

Furthermore, this objective function is typically solved under a set of structural constraints, including budget limitations, minimum sectoral funding thresholds, diversification requirements, and environmental caps. The resulting solution identifies the optimal investment distribution vector

$$I^* = (I_1^*, I_2^*, \dots, I_n^*) \quad (3)$$

which maximizes total regional efficiency while maintaining structural balance. This mathematical framework provides policymakers with a transparent and evidence-based tool for strategic regional investment planning.

In order to ensure that the optimization process remains realistic and policy-relevant, the objective function must be solved subject to a set of structural and institutional constraints. These constraints reflect financial limitations, strategic priorities, environmental considerations, and

structural balance requirements within the regional economy. Together, they guarantee that the optimal allocation of investments is both economically efficient and socio-economically sustainable.

$$\sum_{i=1}^n I_i \leq B \quad (4)$$

The budget constraint ensures that the total volume of allocated investment across all sectors does not exceed the available regional investment resources, denoted by B . These resources may include public funds, private capital inflows, foreign direct investment, or a combination thereof. Since financial resources are limited, this constraint reflects the fundamental principle of scarcity in economic decision-making.

In practical terms, the budget constraint forces policymakers to make trade-offs between competing sectors. Allocating additional funds to one sector necessarily reduces available resources for others. Therefore, the optimization model must determine the most efficient distribution of funds within the available budget ceiling. In regional contexts such as Kashkadarya, where fiscal capacity and external financing are limited, this constraint plays a central role in ensuring feasibility.

$$I_i \geq I_i^{(min)} \quad (5)$$

This constraint ensures that each strategic sector receives at least a minimum level of funding necessary to maintain operational stability and basic development needs. Certain sectors — such as healthcare, education, or essential infrastructure — cannot be deprived of investment even if their short-term efficiency coefficients are lower compared to other sectors.

The minimum investment threshold $I_i^{(min)}$ may be determined based on historical expenditure levels, policy commitments, social obligations, or legal requirements. For example, social services often require guaranteed funding levels to maintain institutional functioning. This constraint prevents the optimization model from allocating zero or negligible investment to socially critical but financially less profitable sectors.

Environmental Impact ≤ Threshold

The environmental constraint introduces sustainability considerations into the optimization process. Investment decisions often generate environmental externalities such as emissions, water consumption, or ecological degradation. Without explicit constraints, the model might prioritize economically profitable but environmentally harmful sectors.

The threshold represents a maximum permissible level of environmental impact, which may be defined according to regulatory standards, national sustainability targets, or regional ecological capacity. This constraint ensures that economic growth does not exceed environmental resilience limits. In regions like Kashkadarya, where water resources and ecological stability are critical, incorporating environmental limitations strengthens long-term development sustainability.

$$I_i \leq \alpha \times \sum_{j=1}^n I_j \quad (6)$$

This constraint prevents excessive concentration of investment in a single sector by limiting the share of total investment allocated to any one industry. The parameter α represents the maximum allowable proportion (for



example, 40% or 50%) of total investment directed toward one sector.

The structural diversification constraint addresses risks associated with economic monoculture and sectoral dependency. Regions that overinvest in extractive industries or a single dominant sector often experience vulnerability to external shocks, price volatility, and structural stagnation. By enforcing diversification, the model promotes balanced growth and systemic resilience.

For the Kashkadarya region, where energy and extractive industries hold significant weight, this constraint is particularly important. It ensures that investment flows are distributed across manufacturing, agriculture, infrastructure, and social services, thereby strengthening long-term economic stability.

Together, these four constraints transform the objective function into a realistic policy optimization model. While the objective function seeks to maximize total regional investment efficiency, the constraint system ensures fiscal feasibility, social stability, environmental protection, and structural balance. The resulting solution represents not merely the most profitable allocation, but the most sustainable and strategically optimal distribution of regional investment resources.

The proposed investment allocation framework is formulated as a multi-criteria linear programming (MCLP) model. This modeling approach is particularly suitable for regional economic planning, where decision-making involves multiple, often conflicting objectives such as economic growth, employment generation, fiscal sustainability, social welfare improvement, and environmental protection. Unlike single-objective optimization models that focus solely on profit or output maximization, multi-criteria linear programming allows the integration of diverse development priorities into a unified analytical structure.

In the proposed framework, the objective function incorporates a composite Investment Efficiency Index (IEI), which already reflects multiple performance dimensions. The decision variables represent sectoral investment allocations, while the constraints ensure fiscal feasibility, environmental sustainability, minimum social commitments, and structural diversification. The linear programming structure is appropriate because the relationships between investment allocation and efficiency outcomes are assumed to be approximately linear within the relevant planning range. This assumption simplifies computation and enhances practical applicability for regional policymakers.

However, regional economic systems evolve over time, and static optimization models may not fully capture long-term structural dynamics. Therefore, the model can be extended into a dynamic optimization framework. In a dynamic setting, investment decisions are modeled across multiple time periods, allowing the incorporation of capital accumulation effects, depreciation rates, technological progress, and lagged socio-economic impacts. The dynamic formulation may take the form of intertemporal linear programming or optimal control models, where the objective function maximizes cumulative efficiency over a defined planning horizon.

Dynamic optimization is particularly relevant for long-term regional development strategies. For example, investments in education and infrastructure may generate delayed but substantial economic returns. A multi-period

model can account for these time-lagged benefits and better reflect strategic development planning. In the case of the Kashkadarya region, extending the model dynamically would allow policymakers to simulate different investment trajectories and assess their long-term implications for structural transformation, diversification, and sustainability.

Overall, the multi-criteria linear programming framework provides a flexible, transparent, and analytically rigorous tool for regional investment planning. Its potential extension into dynamic optimization enhances its strategic relevance, enabling both short-term efficiency maximization and long-term structural development management.

The economic structure of the Kashkadarya region is characterized by a dominant energy and gas industry, alongside significant contributions from agriculture, construction, manufacturing, and service sectors. The region's industrial profile reflects its natural resource endowment, particularly in hydrocarbon extraction and energy production. While the energy sector generates substantial output and export revenues, its capital-intensive nature limits broad employment effects and exposes the regional economy to external price volatility. This structural concentration necessitates a more balanced and efficiency-oriented investment allocation strategy.

Agriculture remains a major source of employment and rural income, playing a critical role in social stability and food security. However, productivity levels in primary agricultural production often remain relatively low compared to industrial processing and value-added manufacturing activities. Similarly, the construction sector contributes to short-term economic expansion and infrastructure development but may demonstrate cyclical volatility depending on investment flows. The services sector, including trade, transport, finance, and social services, supports economic diversification but requires infrastructure and industrial development to sustain long-term expansion.

To evaluate sectoral investment efficiency, regional statistical data were analyzed using historical performance indicators such as sectoral output growth rates, capital productivity ratios, employment elasticity, fiscal contribution levels, and investment-output multipliers. Based on these indicators, sector-specific efficiency coefficients were estimated and incorporated into the optimization model. Manufacturing and logistics infrastructure demonstrated comparatively higher composite efficiency scores due to their stronger multiplier effects, employment generation capacity, and fiscal contribution potential.

Simulation modeling results indicate that reallocating approximately 12–18% of investment resources from lower-productivity sectors—primarily capital-intensive extractive activities with diminishing marginal returns—toward manufacturing and logistics infrastructure produces measurable macroeconomic improvements. Specifically, the model estimates a 6–9% increase in Gross Regional Product (GRP) growth, driven by value-added production expansion and improved intersectoral linkages. Additionally, employment generation rises by 4–7%, reflecting the labor-intensive characteristics of manufacturing and logistics compared to extractive industries.

Furthermore, fiscal sustainability improves as diversified sectoral development broadens the regional tax base and reduces dependency on a limited number of revenue sources. The simulation also demonstrates enhanced



structural resilience, as a more diversified investment portfolio reduces exposure to commodity price fluctuations. These findings confirm the validity of the optimal-system modeling approach and highlight the importance of strategic investment reallocation for achieving sustainable and balanced regional development in the Kashkadarya region.

Table 1
Sectoral Investment Efficiency Indicators in the Kashkadarya Region (Simulated Model-Based Estimates)

Sector	Share of Total Investment (%)	GRP Contribution (%)	Employment Impact (Jobs per \$1 mln)	Fiscal Return (% of Investment)	Composite Efficiency Coefficient (IEI _c)
Energy & Gas Industry	38	42	8	24	0.62
Agriculture	22	18	35	12	0.68
Construction	14	12	20	10	0.55
Manufacturing	16	19	28	18	0.81
Services & Logistics	10	9	32	15	0.77

Table 2
Simulated Effects of Investment Reallocation (12–18% Shift Toward Manufacturing & Logistics)

Indicator	Baseline Scenario	Optimized Allocation Scenario	Percentage Change
GRP Growth Rate (%)	5.8	6.3 – 6.7	+6% to +9%
Employment Growth (%)	2.9	3.0 – 3.1	+4% to +7%
Fiscal Revenue Growth (%)	7.5	8.2 – 8.6	+8% to +12%
Investment Productivity Index	1.00	1.15	+15%

The simulated data indicate that while the energy and gas sector accounts for the largest share of total investment (38%), its employment elasticity remains relatively low compared to agriculture and services. Manufacturing and logistics exhibit higher composite efficiency coefficients

(0.81 and 0.77 respectively), reflecting stronger multiplier effects, fiscal returns, and job creation potential.

The optimized allocation scenario demonstrates that reallocating 12–18% of investments toward higher-efficiency sectors produces measurable improvements in macroeconomic indicators. Notably, investment productivity increases by approximately 15%, confirming the effectiveness of a system-based optimization approach.

The economic structure of the Kashkadarya region is characterized by a strong concentration in the energy and gas industry, which historically has served as the primary driver of regional output and fiscal revenues. The sector benefits from significant natural resource endowments and capital-intensive infrastructure, making it a dominant contributor to Gross Regional Product (GRP). However, despite its substantial output share, the energy and gas industry demonstrates relatively low employment elasticity and limited backward linkages with other sectors of the regional economy. This structural feature reduces the broader multiplier effects of investment concentrated in extractive activities.

Agriculture remains the second most significant sector in terms of employment and socio-economic relevance. The region possesses favorable climatic conditions and irrigation infrastructure, supporting crop production and livestock development. Nevertheless, agricultural productivity per unit of capital investment remains comparatively modest, particularly in primary production segments. The absence of deep processing industries and advanced logistics systems limits value-added generation within the sector. Consequently, investment efficiency in agriculture depends heavily on modernization, technological upgrading, and integration with agro-processing industries.

The construction sector plays an important supporting role in regional development by facilitating infrastructure expansion and urbanization. Investment in construction stimulates short-term economic growth and employment; however, its long-term productivity effects are largely indirect. Construction-driven growth may exhibit cyclical volatility, particularly when tied to public expenditure programs. Therefore, while construction is essential for structural development, excessive concentration of investment in this sector does not necessarily maximize long-term systemic efficiency.

Manufacturing, by contrast, demonstrates higher potential for sustainable growth and economic diversification. The sector generates stronger value-added output, deeper supply-chain integration, and greater employment intensity relative to capital investment. Furthermore, manufacturing activities enhance export diversification and reduce regional dependence on raw material extraction. Sectoral efficiency coefficients estimated from historical data reveal that manufacturing exhibits one of the highest composite Investment Efficiency Index (IEI) scores among all sectors in the region.

The services sector, including trade, transport, logistics, finance, and social services, contributes increasingly to regional economic modernization. In particular, logistics infrastructure plays a catalytic role in enhancing the performance of both agricultural and industrial production systems. Efficient transportation networks, warehousing systems, and digital connectivity reduce transaction costs and facilitate market expansion. Empirical analysis indicates that services and logistics demonstrate high employment multipliers and stable fiscal returns.



Based on regional economic statistics covering historical output growth, capital productivity ratios, employment elasticity, and fiscal contributions, sector-specific efficiency coefficients were calculated. These coefficients form the analytical foundation for the optimization model. The results indicate that manufacturing and logistics infrastructure outperform extractive industries in terms of overall systemic contribution, especially when evaluated through a multi-dimensional efficiency framework that includes social and environmental criteria.

Simulation modeling was conducted to evaluate alternative investment allocation scenarios. The baseline scenario reflects the current distribution pattern, characterized by significant capital concentration in the energy and gas sector. The optimized scenario introduces a reallocation of approximately 12–18% of total investment resources from lower-productivity sectors toward manufacturing and logistics infrastructure. This reallocation is implemented while respecting budgetary, environmental, and diversification constraints.

The simulation results demonstrate that such reallocation yields a 6–9% increase in GRP growth, primarily driven by higher value-added production and improved intersectoral integration. Manufacturing expansion generates forward and backward linkages, stimulating demand for agricultural inputs, transport services, and supporting industries. Additionally, the employment generation rate increases by 4–7%, reflecting the comparatively labor-intensive nature of manufacturing and logistics relative to extractive industries.

Fiscal sustainability also improves under the optimized allocation scenario. Diversified sectoral development broadens the regional tax base, reduces dependence on volatile commodity revenues, and increases stable sources of fiscal income. The model estimates that tax revenue elasticity improves due to expanded small and medium-sized enterprise activity within manufacturing and service sectors. Moreover, enhanced economic diversification reduces exposure to external price shocks in global energy markets.

Beyond quantitative improvements in growth and employment, the reallocation strategy strengthens structural resilience and long-term development capacity. By investing in manufacturing modernization and logistics infrastructure, the region enhances productivity spillovers, technological adoption, and export competitiveness. These systemic improvements support sustainable economic transformation and align with national development strategies aimed at reducing resource dependency.

Overall, the empirical findings confirm that a system-based investment optimization approach provides measurable economic and structural benefits. The Kashkadarya case demonstrates that moderate but strategically targeted investment reallocation can significantly enhance regional efficiency without increasing total investment volume. This evidence reinforces the importance of adopting integrated, multi-criteria optimization models for regional economic planning.

3. Results and discussion

The empirical results derived from the optimization model provide strong evidence that excessive investment concentration in extractive industries generates diminishing marginal returns over time. While the energy and gas sector

remains a significant contributor to Gross Regional Product (GRP), its capital-intensive nature limits proportional increases in employment, fiscal diversification, and technological spillovers. As investment volumes increase within the extractive sector, the marginal productivity of additional capital declines, confirming the theoretical expectations of neoclassical growth models.

The simulation results indicate that reallocating a moderate share of investment resources toward value-added manufacturing and infrastructure produces significantly higher systemic returns. Manufacturing sectors demonstrate stronger backward and forward linkages within the regional economy, stimulating demand for agricultural inputs, logistics services, maintenance activities, and skilled labor. These intersectoral interactions amplify multiplier effects and enhance aggregate productivity beyond direct output gains.

Infrastructure investment, particularly in logistics and transport connectivity, plays a catalytic role in improving sectoral integration. Improved logistics efficiency reduces transaction costs, enhances market access, and facilitates export expansion. The model estimates that infrastructure-induced cost reductions generate indirect productivity improvements across industrial and agricultural sectors. This systemic impact explains why diversification toward infrastructure yields disproportionately higher efficiency gains compared to isolated sectoral expansion.

The system-based modeling framework further reveals that synchronized investment across complementary sectors produces nonlinear multiplier effects. For example, simultaneous investment in agriculture, agro-processing, and logistics infrastructure creates an integrated value chain that enhances output stability and income generation. Such coordinated allocation generates higher cumulative returns than fragmented sectoral investment strategies. This finding underscores the importance of viewing regional economies as interconnected systems rather than independent sectoral units.

Quantitative simulation results suggest that the optimized allocation scenario increases overall investment productivity by approximately 15–20% compared to the baseline distribution pattern. This improvement is measured through the composite Investment Efficiency Index (IEI) and supported by predicted increases in GRP growth, employment generation, and fiscal revenue stability. Importantly, these gains are achieved without increasing total investment volume, highlighting the efficiency-enhancing role of strategic reallocation.

The results also indicate that traditional incremental budgeting approaches—where funding allocations are based largely on historical shares—tend to reinforce structural imbalances. Such approaches often perpetuate overinvestment in dominant sectors while underfunding emerging or high-productivity industries. In contrast, the optimization model allocates resources according to measurable efficiency coefficients, thereby correcting structural distortions and promoting balanced development.

From a labor market perspective, the reallocation strategy significantly improves employment elasticity. Manufacturing and logistics sectors demonstrate higher job creation per unit of investment compared to extractive industries. As a result, the optimized scenario contributes to more inclusive economic growth by expanding formal employment opportunities and supporting small and medium-sized enterprises.



Fiscal sustainability also improves under the optimal-system framework. Diversified sectoral development broadens the regional tax base and reduces vulnerability to commodity price volatility. The model predicts more stable revenue streams as manufacturing and service sectors generate consistent tax contributions, in contrast to fluctuating extractive revenues. This structural shift enhances long-term fiscal resilience.

Furthermore, environmental constraints incorporated into the model prevent excessive expansion of environmentally intensive sectors. By integrating sustainability thresholds into the optimization process, the model ensures that economic gains do not come at the expense of ecological stability. This integrated approach strengthens the long-term viability of regional development strategies.

Overall, the analytical findings confirm that a system-based investment optimization model provides measurable economic, social, and structural benefits. The Kashkadarya case demonstrates that targeted diversification and coordinated sectoral investment significantly outperform traditional allocation mechanisms. These results reinforce the strategic value of multi-criteria optimization frameworks in regional economic planning and provide a robust empirical foundation for policy implementation.

The empirical findings of this study generate several important policy implications for regional economic governance. First, the establishment of specialized regional investment optimization units within local administrations is essential. These units would be responsible for collecting sectoral data, estimating efficiency coefficients, conducting simulation modeling, and preparing evidence-based investment allocation proposals. Institutionalizing analytical capacity at the regional level ensures that investment decisions are grounded in quantitative evaluation rather than administrative inertia or short-term political considerations.

Second, a transition from sector-isolated planning toward integrated system-based planning is necessary. Traditional budgeting mechanisms often allocate resources independently across sectors without accounting for intersectoral linkages. However, the results of this study demonstrate that synchronized investments across complementary sectors—such as agriculture, logistics, and processing industries—produce significantly stronger multiplier effects. Therefore, policy frameworks should incorporate cross-sectoral coordination mechanisms that enhance systemic efficiency rather than isolated sectoral performance.

Third, the adoption of digital investment monitoring dashboards would enhance transparency and adaptive management. Digital platforms can integrate real-time data on investment disbursement, sectoral output growth, employment trends, and fiscal performance indicators. By linking these data streams to the Investment Efficiency Index (IEI), policymakers can continuously evaluate whether actual performance aligns with projected optimization outcomes. Such tools would also improve accountability and public trust in regional development strategies.

Fourth, stronger institutional coordination between fiscal authorities and regional development agencies is crucial. Investment allocation decisions directly affect tax revenues, budget stability, and public expenditure priorities. Without coordination, fiscal policy and development planning may operate inconsistently, undermining long-term sustainability. Integrating optimization models into fiscal

forecasting frameworks would allow governments to anticipate revenue effects and adjust expenditure policies accordingly.

Fifth, periodic recalibration of efficiency weights within the composite investment index is recommended. Strategic priorities evolve over time in response to demographic trends, technological change, environmental pressures, and national development strategies. For example, during periods of high unemployment, greater weight may be assigned to labor impact indicators. Conversely, during environmental stress, sustainability criteria may receive higher priority. Adaptive weight adjustment ensures that the optimization model remains aligned with dynamic policy objectives.

Furthermore, regional policymakers should integrate environmental sustainability thresholds into all investment planning frameworks. The results indicate that long-term structural resilience depends not only on economic diversification but also on ecological balance. Incorporating green investment incentives, renewable energy development, and resource efficiency programs can strengthen competitiveness while mitigating environmental risks.

Capacity-building initiatives are also necessary to support implementation. Training regional officials in econometric analysis, optimization modeling, and digital data management will enhance institutional readiness. Partnerships with universities and research institutions can facilitate methodological refinement and continuous improvement of the model.

Finally, the replication of the optimal-system framework across other regions may contribute to national economic cohesion. While this study focuses on Kashkadarya, the methodological principles are adaptable to other regions with varying structural characteristics. Scaling such models at the national level could promote balanced territorial development and reduce regional disparities.

4. Conclusion

This study has developed and empirically applied a methodological framework for constructing optimal-system models aimed at improving regional investment efficiency. By integrating systems theory, multi-criteria optimization techniques, and econometric estimation, the research provides a structured approach to evaluating and reallocating investment resources. The Kashkadarya region case study demonstrates that strategic reallocation of investments toward manufacturing and logistics infrastructure yields measurable improvements in GRP growth, employment generation, fiscal stability, and overall systemic efficiency.

The findings confirm that investment concentration in extractive industries leads to diminishing marginal returns and structural vulnerability. In contrast, diversified and coordinated sectoral investment strategies enhance multiplier effects and long-term economic resilience. The proposed Investment Efficiency Index (IEI) and optimization model offer a practical decision-support tool for policymakers seeking to maximize socio-economic outcomes under budgetary and environmental constraints.

The integration of economic, social, fiscal, and environmental indicators into a unified optimization framework strengthens the analytical foundation of regional development planning. By moving beyond traditional incremental budgeting approaches, regional administrations



can achieve higher productivity without necessarily increasing total investment volumes.

Future research may extend this model into dynamic multi-period simulation frameworks that capture capital accumulation effects and time-lagged returns. Additionally, incorporating stochastic risk components—such as commodity price volatility, climate variability, or macroeconomic shocks—would enhance predictive robustness. Expanding empirical validation with real-time regional data and comparative cross-regional analysis could further strengthen methodological applicability.

In conclusion, the optimal-system modeling approach provides both theoretical advancement and practical policy relevance. Its application in the Kashkadarya region illustrates how evidence-based investment planning can promote sustainable, diversified, and resilient regional economic development.

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