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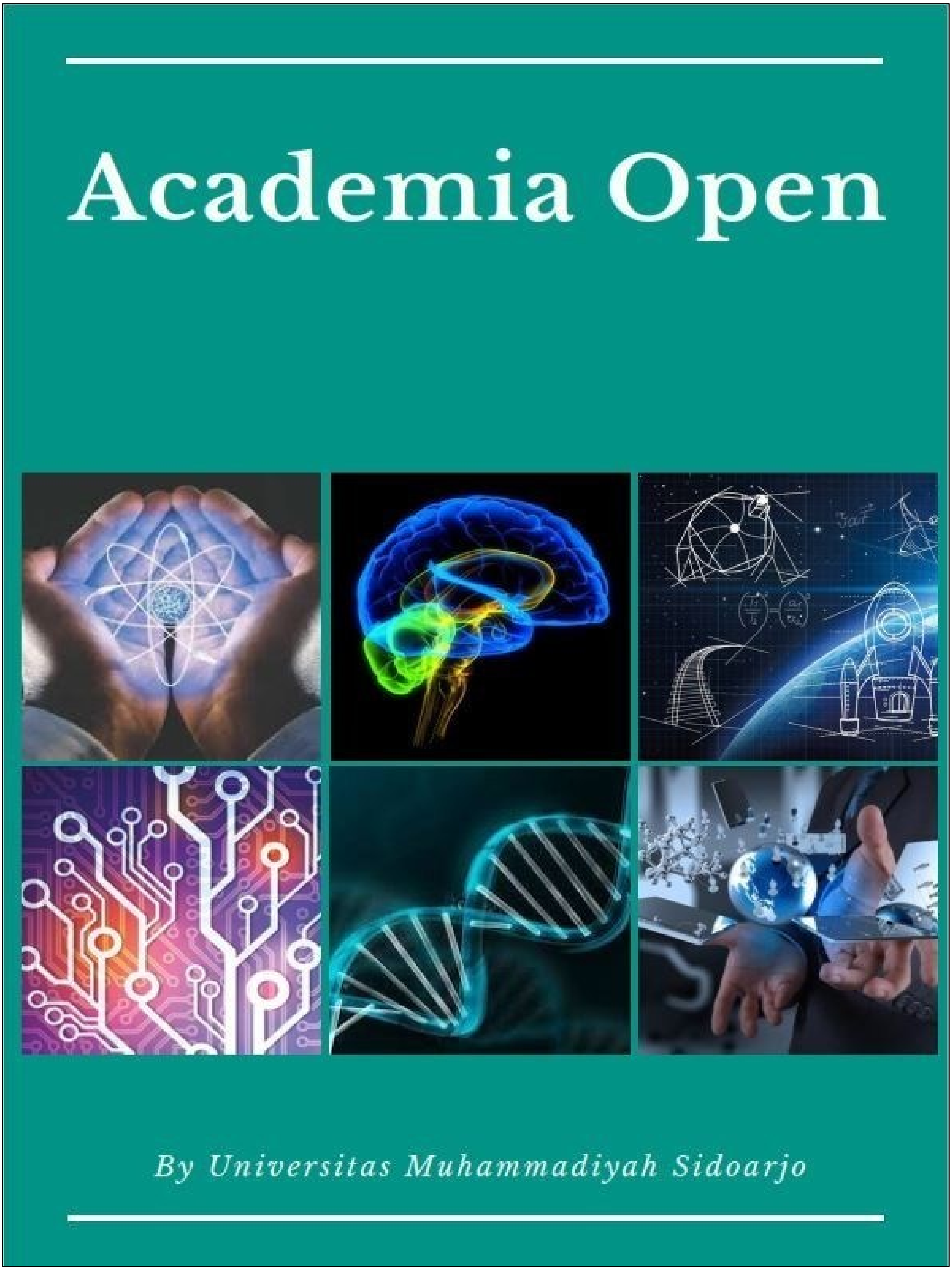

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Innovative Model for Developing the Service System in the Agro-Industrial Complex Based on Clustering Principles

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Abstract

General Background: The agro-industrial complex serves as a cornerstone of national economic stability, integrating agricultural production, processing, and distribution systems that ensure food security and rural development. **Specific Background:** Rapid globalization, technological change, and increasing competitiveness have revealed the inefficiency of conventional service infrastructures in agro-industrial systems, particularly in resource utilization, innovation adoption, and coordination among stakeholders. **Knowledge Gap:** Despite the global emphasis on clustering as a driver of competitiveness, there remains limited empirical and methodological understanding of how cluster-based service models can optimize performance through digital and economic integration in emerging economies such as Uzbekistan. **Aims:** This study aims to develop an innovative cluster-based model for agro-industrial service systems that enhances efficiency, technological independence, and competitiveness through mathematical modeling and digital monitoring tools. **Results:** The proposed model integrates key indicators—including technical independence, infrastructure competitiveness, socio-economic stability, and export potential—into a unified efficiency index supported by regression-based analysis. The findings demonstrate that implementing a Public-Private Partnership (PPP)-driven cluster framework enables balanced investment distribution, improved financial flow management, and enhanced innovation performance across the agro-industrial value chain. **Novelty:** The study introduces a digitally enabled cluster model governed by Key Performance Indicators (KPIs) and data analytics, providing a new paradigm for evaluating and optimizing service systems in agro-industrial networks. **Implications:** The model offers a replicable framework for policymakers and practitioners to foster sustainable agro-industrial development, enhance investment attractiveness, and strengthen economic resilience in developing regions.

Highlights:

- Introduces a cluster-based digital model to enhance agro-industrial efficiency.
- Develops a unified efficiency index integrating key economic and technical indicators.
- Promotes PPP-driven collaboration for sustainable and competitive agro-industrial growth.

Keywords: Agro-industrial Cluster, Innovation, Competitiveness, Digital Model, Sustainability

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Introduction

Agro-industrial complex is one of the most important branches of the national economy that covers the production of agricultural products, their processing, and the delivery of finished products to the consumers. The degree of development of the infrastructure of its services is a major factor in the stable operation of this complex. Over the last few years, the evolution of the market economy, the growing competitive environment, and swift technological transformations have become sure indicators of the necessity to modernize the service system in the agro-industrial sectors. The service system of the agro-industrial complex comprises production enterprises, logistic centers, technical maintenance facilities, consulting organizations as well as information technology services. Such a system helps producers to utilize resources effectively, minimize the cost of production, and enhance the quality of the product. Thus, the enhancement of the service infrastructure and the creation of it on the innovative basis are important conditions of the increase of the agro-industrial complex competitiveness.

The process of the digitalization of agro-industrial service systems, their structuring according to the principles of clustering, and the application of scientific and technical potential in the practice have become topical issues in the present context. The cluster approach increases the collaboration of service providers and producers, enhances the rational utilization of resources, and speeds up the process of innovative solution implementation.

As a result, the efficient organization of the service system within the agro-industrial complex, the formation of this system within the framework of the cluster model, and the analysis of its performance using mathematical modeling have become two of the main issues of scientific interest. Research on this line of work helps to provide economic stability of the agro-industrial complex, broadens the exportability, and job opportunities in rural districts.

Porter's cluster theory is fundamental — he defines clusters as geographically proximate and interrelated groups of firms, suppliers, service providers, and research institutions. Porter's main conclusion is that clusters: (1) increase the productivity of enterprises; (2) enhance the intensity of innovations; and (3) strengthen competitiveness. In the agro-industrial context, this means that organizing service infrastructure — including technical maintenance, logistics, marketing, and consulting — in the form of clusters significantly improves production efficiency and innovation activity. Furthermore, Porter emphasizes the importance of policy and strategy, noting that the development of clusters requires government involvement and consideration of regional policies[1].

Ketels and his colleagues analyzed cluster policies and practical cluster initiatives, demonstrating that successful cluster development requires government–private partnerships, the involvement of cluster facilitators, and clear monitoring and evaluation mechanisms. They also emphasized that the effectiveness of cluster initiatives in developing and transition economies is highly dependent on the local context, including institutional capacity, financing, and human resources. For agro-industrial clusters, this implies that

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implementing service systems requires a strong central organizational role, financial support, and effective training and know-how transfer mechanisms[2].

Yunusov and his colleagues analyzed Uzbekistan's practical experience and demonstrated that the development of agro-clusters requires creating a favorable business environment, identifying leading operators, and centralizing service providers within the network (including logistics, technical services, packaging, and consulting). They provided evidence that practical challenges—such as inadequate infrastructure, limited financial support, and issues related to standards and certification—reduce the overall efficiency of clusters. In terms of mathematical or modeling recommendations, the authors emphasized that establishing facilitators and monitoring systems as third-party mechanisms can gradually enhance the effectiveness of the service network[3].

In Toshboyev's work, the stages and practical recommendations for implementing the cluster system in Uzbekistan are outlined as follows: (1) economic diversification, (2) integration with the processing chain, and (3) modernization of personnel and technologies. Toshboyev particularly demonstrates, through concrete examples, that coordinating service functions within the cluster—such as technical maintenance, transportation/logistics, and quality control—can significantly increase the overall value of the value chain. The study provides context-specific and practical recommendations applicable to local policy implementation[4].

In Ismoilova's research, methodological recommendations are provided for developing agro-clusters within the agricultural product processing chain — from farm to processing. The author particularly emphasizes the role of the service system, including quality control, logistics, packaging, and marketing services, noting that standardizing these services within clusters can significantly enhance export potential. Ismoilova also recommends strengthening the reliability of the service network through financial instruments such as microloans, collateral mechanisms, and quality certification systems[5].

Method

Entrepreneurial entities integrated into cluster structures generate knowledge in three ways:

1. Through various forms of collaboration among enterprises, universities, and other organizations.
2. As a result of competition and the intensification of rivalry among entities within the cluster.
3. Due to the spillover of knowledge arising from population mobility and social interactions among people.

The agro-industrial sector is considered to be a key strategically significant sphere in the guarantee of economic stability and competitiveness in the modern stage of development. The enhancement and creation of the regulatory and legal framework that will promote the growth of the industry and its fortification is one of the priorities in this sphere. Mechanisms of managing financial flows are also very vital in ensuring economic stability and are the core components of the success of agro-industrial clusters.

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The economic nature of the cluster system is that out of the relationship between producers, service providers and research institutions is integrated into a common economic space. With such a combined structure, it can be optimized to make the best of the resources used, minimize the cost of production and maximize profitability. In the process, cash flow is a significant pointer to evaluate the financial stability and sustainability of the cluster.

The financial flow system reflects the circulation of goods and services, investment processes, and external economic relations within the cluster[10]. These relationships can be expressed by the following mathematical formula:

$$CF = CG - CE \quad (1)$$

where:

CF – cash flow balance,

CG – cash inflow,

CE – cash outflow.

This formula helps determine the internal economic equilibrium of the cluster. If the cash inflow exceeds the outflow, it indicates financial stability and sustainability. Conversely, if outflows dominate, the efficiency of resource utilization should be reassessed.

The synergistic effect of the cash flows in the cluster theory denotes the case when the result of the joint activity of the separate participants is greater than the sum of their independent results. That is, the performance of the entire cluster will be more efficient than the mere aggregate of the performance of the individuals in the cluster. This is brought about by collaboration, sharing of innovation and infrastructure sharing in the cluster.

Thus, the enhancement of the financial flow analysis and management mechanisms in agro-industrial clusters would help to provide sustainable economic development, improve the potential of investments, and increase the socio-economic growth of the regions. The economic system of the cluster, in its turn, provides the coordinated financial cooperation between the agricultural producers, processing enterprises, and service providers.

At present, the agro-industrial complex of the Republic performs a critical role in the economic stability and food security, but almost two-thirds of its operation is based on outside environmental conditions. This implies that most sectors in the complex are very dependent on imported resources, foreign technologies and external technical support. Although this kind of dependence makes it possible to use modern technologies, it also decreases the degree of economic and technological self-sufficiency of the national agro-industrial system.

For sustainable development of the agro-industrial sector, it is essential to assess the extent to which production relies on domestic resources. Therefore, a production and technological independence index is

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used as a key indicator. This index reflects the degree of dependence of industries on external material and technical resources and is calculated using the following formula:

$$£ = Q_1 \div Q_2 \qquad (2)$$

where:

$£$ – index of production and technological independence,

Q_1 – value of domestically produced resources,

Q_2 – value of imported production resources.

The closer the index value is to 1, the higher the sector’s reliance on domestic production resources. Conversely, an index value less than 1 indicates dependence on imported resources. Thus, this index can serve as a reliable indicator of economic and technological security within the agro-industrial system.

Enhancing the technological independence of the agro-industrial complex requires increasing the share of local resources, strengthening scientific and technical capacity, and implementing import-substituting technologies. In particular, developing domestic production of agricultural machinery, fertilizers, seeds, and fuel will significantly reduce dependence on foreign suppliers and strengthen the country's overall economic resilience.

The following table presents the conditional values of the technological independence index for selected branches of the agro-industrial complex. These values help determine the degree of reliance on imported resources across different sectors[10].

Table 1. Conditional Values of the Technological Independence Index for Agro-Industrial Sectors

No.	**Sector**	**Domestic Resources Value (Q1), mln UZS**	**Imported Resources Value (Q2), mln UZS**	**Production & Technological Independence Index** ($£ = Q_1 \div Q_2$)
1	Agricultural machinery manufacturing	1200	1800	0.67
2	Fertilizers and chemical products	950	1300	0.73
3	Packaging and processing industry	700	900	0.78
4	Livestock processing industry	850	750	1.13
5	Food production	1100	900	1.22

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As shown in the table, certain branches — particularly food production and livestock processing — exhibit a high level of independence due to greater utilization of domestic resources, resulting in self-sufficiency index values exceeding 1. In contrast, sectors such as agricultural machinery manufacturing and fertilizer production continue to rely heavily on imported inputs.Overall, achieving production and technological independence within the agro-industrial complex is a strategic priority for ensuring food security, stable economic growth, and improved competitiveness. Therefore, government policies should focus on expanding the domestic resource base, introducing innovative technologies, and modernizing production infrastructure to strengthen the self-sufficiency and sustainability of the national agro-industrial system.

At the present stage of agricultural development, one of the most urgent tasks is the creation of a modern production infrastructure adapted to the conditions of rural areas. The effectiveness of this process largely determines the pace of agricultural modernization, the integration of production units, and the improvement of living standards in rural regions. In this context, ensuring the competitiveness of industrial infrastructure plays a decisive role in achieving sustainable growth in the agro-industrial sector.

The competitiveness index of industrial infrastructure efficiency (β) in the agricultural sector reflects the relationship between the volume of private sector investment directed toward the creation of new production infrastructure and the value of the existing infrastructure. This indicator helps assess how effectively financial and material resources are utilized in developing rural industrial systems[10].

Formally, this relationship is represented as:

$$\beta = b_1 \div b_2 \qquad (3)$$

where:

β — index of industrial infrastructure competitiveness or efficiency;

b_1 — volume of private sector investments directed toward creating production infrastructure;

b_2 — value of the existing production infrastructure under rural development conditions.

An increase in the β coefficient indicates an improvement in the efficiency of private sector involvement and the strengthening of industrial potential in rural areas. Conversely, a low β value shows that the sector still heavily depends on outdated infrastructure and insufficient private investment. Thus, the β index serves as an important diagnostic tool for identifying the strengths and weaknesses of agricultural development policies.

The development of an effective industrial infrastructure in agriculture contributes to optimizing production chains, reducing logistical costs, and improving the quality and quantity of agricultural products. Moreover, this approach creates favorable conditions for attracting investment, introducing innovations, and increasing employment in rural areas.

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The interaction between state support and private initiatives is also crucial for ensuring sustainable infrastructural development. Government programs aimed at subsidizing private investment or public-private partnerships (PPP) can stimulate the creation of technologically advanced and competitive infrastructures.

The following table shows an example of the competitiveness index (β) of industrial infrastructure in the agricultural sector:

Table 2. Competitiveness Index (β) of Industrial Infrastructure in the Agricultural Sector

Indicator	Description	Symbol	Example Value
Private sector investments in production infrastructure	Funds allocated for creating new rural infrastructure	b_1	150 million UZS
Existing industrial infrastructure value	Total value of current infrastructure facilities	b_2	300 million UZS
Competitiveness index of industrial infrastructure	The ratio of b_1 to b_2	$\beta = b_1 \div b_2$	0.5

This example demonstrates that the competitiveness index of 0.5 indicates a moderate level of efficiency in the involvement of private investments in the development of industrial infrastructure. Strengthening this index would signify progress toward more dynamic, independent, and sustainable agricultural production in the national economy.

Result and Discussion

Public-Private Partnership (PPP) plays a crucial role as a key institutional mechanism in the establishment and sustainable management of agro-industrial clusters. Through this mechanism, the public sector acts as a regulatory and infrastructural developer, creating the legal and institutional framework, while the private sector contributes capital, innovative technologies, and management expertise. The combination of these two sectors ensures the efficient functioning of agro-industrial clusters, enhancing their competitiveness, stimulating innovation, and expanding export potential.

Within the PPP framework, functional integration among cluster participants is significantly strengthened. Vertical integration unites production, processing, and distribution stages into a single value chain. Horizontal integration promotes the exchange of resources, experience, and technologies among enterprises operating in the same field, while conglomerate integration harmonizes various sectors, increasing the cluster's level of diversification. As a result, the internal economic stability of the cluster is reinforced, and its competitiveness grows both regionally and internationally.

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In the PPP-based cluster model, the service infrastructure — including marketing, logistics, technical maintenance, and financial services — is consolidated under an integrated management platform. This approach aligns with the concept of a “digital agro-ecosystem”, where every participant’s performance is monitored and evaluated through digital technologies. Real-time analysis of service efficiency, production costs, and logistics flows ensures transparency and improves decision-making at every level of the cluster.

The scientific novelty of this model lies in the fact that management processes within the cluster are driven by digital indicators (KPI) and data analytics algorithms. These indicators measure production efficiency, service quality, logistics costs, export dynamics, and investment flows. Based on these indicators, profit distribution, resource utilization, and levels of technological modernization are optimized among PPP participants.

In the A-stage, key performance indicators (indices) are calculated — including the economic efficiency index, technical provision coefficient, innovation activity index, export dynamics index, and service infrastructure competitiveness coefficient. These indices, derived through digital analytical tools, serve as core metrics for assessing the internal stability and productivity of each cluster.

The B-stage is based on regression and productivity models that quantitatively evaluate the efficiency of service systems within the cluster. At this stage, the relationships between indices are analyzed to determine their impact on cluster performance. For example, regression analysis between the innovation activity index and the technical provision coefficient helps reveal how innovation contributes to the growth of production output.

This PPP-based mathematical model provides a comprehensive framework for analyzing cluster management by considering not only economic efficiency but also social and innovative factors. Through such an approach, a sustainable development strategy for agro-industrial clusters is formed, accelerating their integration into global value chains[19].

Ultimately, this model — built upon PPP mechanisms — does more than optimize production processes. It enables the digital transformation of service systems, enhances investment attractiveness, and fosters a culture of innovation-driven management in the agro-industrial sector. Therefore, it can be recognized as a scientifically grounded and practically significant methodology for modern agro-cluster governance.

A comprehensive approach that integrates economic, technical, and social indicators is essential for evaluating and managing the efficiency of agro-industrial clusters. Each indicator serves as an important parameter reflecting the stability and competitiveness of the system. In analyzing the performance of clusters, economic-mathematical models, indices, and regression approaches play a crucial role, as they not only determine the current state but also enable forecasting of future developments. For this purpose, the developed integrated model allows for the assessment of the overall efficiency level of an agro-industrial cluster based on its technical, infrastructural, and social indicators.

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1. Technical Independence Index (Ł)

The technical independence of a cluster can be assessed using the ratio:

$$Ł = Q_1 / Q_2, \tag{4}$$

where Q_1 represents the value of domestically produced resources, and Q_2 denotes the value of imported resources. If $Ł > 1$, it indicates the dominance of internal resources, reflecting a higher level of technological self-sufficiency and reduced dependence on external inputs.

2. Infrastructure Competitiveness Index (β)

The infrastructure competitiveness of a cluster can be measured as follows:

$$\beta = b_1 / b_2, \tag{5}$$

where b_1 is the investment made by the private sector in infrastructure development, and b_2 represents the total value of existing infrastructure. A higher β suggests stronger investment activity, modernization, and active participation of private investors in the regional or industrial development process.

3. Socio-Economic Stability Index (Ḡ)

To assess the social and employment stability of a cluster, the following indicator is used:

$$\bar{G} = C_1 / C_2, \tag{6}$$

where C_1 is the number of newly created jobs, and C_2 is the number of previously existing jobs. If $\bar{G} > 1$, it implies an improvement in social stability and employment conditions within the cluster, which is crucial for long-term sustainable development.

4. Export Potential Coefficient (Ŷ)

The export potential of the production system can be defined as:

$$\hat{Y} = d_1 / d_2, \tag{7}$$

where d_1 indicates the volume of exported products, and d_2 represents the total production volume. The value of Ŷ reflects the export-oriented capacity and competitiveness of the cluster in international markets.

5. Production–Regressive Model

To evaluate cluster efficiency (S), a linear regression model is proposed:

$$S = \alpha + \beta_1 \cdot Ł + \beta_2 \cdot \beta + \beta_3 \cdot \hat{G} + \beta_4 \cdot \hat{Y} + \beta_5 \cdot X_1 + \ldots + \beta_n \cdot X_n + \varepsilon, \tag{8}$$

where S is the cluster efficiency indicator (for example, based on production value, profitability, or service quality); $Ł$, β, $\hat{G}, \hat{Y}$ are the indices described above; X_1 are additional factorial indicators (such as investment volume, technology level, logistics costs, and labor qualification). Here, α denotes the intercept, β_i are regression coefficients, and ε is the stochastic error term. Model parameters can be estimated using

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Ordinary Least Squares (OLS) or robust estimation methods. If the data have a panel structure, fixed or random effects regression provides more accurate results.

6. Integrated Efficiency Indicator *(E)*

To bring the overall efficiency of the agro-industrial cluster to a single measurable dimension, the following composite indicator is proposed:

$$E = w_1 \cdot norm(Ł) + w_2 \cdot norm(\beta) + w_3 \cdot norm\left(\hat{G}\right) + w_4 \cdot norm\left(\hat{Y}\right) \quad (9)$$

where E is the aggregate efficiency index of the cluster; w_1, w_2, w_3, w_4 are the weighting coefficients of each factor, with their total sum equal to 1 $(w_1 + w_2 + w_3 + w_4 = 1)$. The weights can be determined through expert evaluation, Analytic Hierarchy Process (AHP), or analytical assessment methods.

7. Optimization of Investment Distribution

The process of allocating investments for cluster infrastructure development can be modeled as a simplified optimization problem:

$$\sum p_i = P\_total, \quad p_i \geq 0, \quad (10)$$

where p_i represents the allocated share of resources among cluster elements, and P_total is the total available investment. The objective function $E(P)$ for example, profit, efficiency, or energy level) should be maximized under the constraint that no p_i is negative. This ensures rational distribution of investments among production, logistics, and technological infrastructure components.

Efficiency indicators of the agro-industrial cluster:

Table 3. Efficiency Indicators of the Agro-Industrial Cluster

Indicator Name	Formula	Description
Technical Independence Index (Ł)	$Ł = Q_1 / Q_2$	Dominance of internal resources
Infrastructure Competitiveness (β)	$\beta = b_1 / b_2$	Level of investment activity
Socio-Economic Stability Index (Ḡ)	$\bar{G} = C_1 / C_2$	Growth of employment opportunities
Export Potential Coefficient (Ŷ)	$\hat{Y} = d_1 / d_2$	Integration into foreign markets
Overall Efficiency Index (E)	$E = w_1 Ł + w_2 b + w_3 \hat{G} + w_4 \hat{Y}$	Comprehensive integrated indicator

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The proposed indices and regression-based model create a comprehensive analytical framework for evaluating cluster performance. By integrating indicators of independence, competitiveness, stability, and export potential, decision-makers can form a quantitative understanding of a cluster's efficiency. This approach not only enables accurate monitoring but also supports strategic investment planning and sustainable economic growth.

Conclusion

This study concludes that the development of an innovative service system in the agro-industrial complex based on clustering principles represents a scientifically grounded and practically significant approach to enhancing the competitiveness and sustainability of the agricultural sector. The research confirms that the integration of cluster mechanisms strengthens cooperation among enterprises, research institutions, and government bodies, while improving the rational use of resources and stimulating technological modernization. The proposed mathematical and production-regression models provide a reliable basis for evaluating the efficiency of clusters through key indicators such as technical independence, infrastructure competitiveness, socio-economic stability, and export potential. The consolidation of these metrics into a unified efficiency index allows for a comprehensive assessment of the sector's performance and its capacity to adapt to changing economic conditions. The inclusion of digital monitoring tools ensures transparency and informed decision-making, creating opportunities for data-driven governance and innovation-oriented management. The findings suggest that balancing investment distribution, strengthening digital infrastructure, and fostering innovation networks are essential for building a resilient and adaptive agro-industrial ecosystem. In the long term, further research should focus on refining the quantitative models of inter-cluster interaction and developing predictive algorithms for resource optimization, ensuring that the cluster-based approach continues to evolve in response to technological and environmental challenges.

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