Research article

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Agro-Industrial Complex Sustainability in the Eurasian Economic Union Countries: The Aspect of Food Security

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Abstract

This article analyses the sustainability of the agro-industrial complex (AIC) in the Eurasian Economic Union (EAEU) countries with an emphasis on food security. The study covers challenges and threats to food security in Russia, Belarus, Armenia, Kazakhstan, and Kyrgyzstan, given the difficult geopolitical situation. The article examines data from the national statistical services of the EAEU countries, as well as international sources such as the FAO and the World Bank. Correlation and cluster analysis approaches are applied to assess the impact of socioeconomic indicators on the sustainability of the AIC. Significant correlations between indicators of food security and such factors as the volume of agricultural production, investments in the agricultural sector, the level of technological development, and government support are revealed. On average, for the period from 2015 to 2022, the added value of agriculture amounted to 8.2% of GDP, and the food production index was 104.1. The results of the cluster analysis showed that the EAEU countries can be grouped by levels of agricultural development and food security. Thus, K-means and GMM identified three clusters in which Russia found itself both in a separate cluster and in combination with other countries. Agglomerative and spectral clustering also showed similar results, distinguishing three main groups of countries. The average silhouette coefficient for agglomerative and spectral clustering was 0.41, which indicates a better clustering quality compared to K-means and GMM (0.38). It is confirmed that integration and coordination of efforts within the EAEU, as well as diversification of agricultural production and increased investment in innovation, determine the state of sustainability of the agro-industrial complex.

Keywords: agro-industrial complex sustainability, food security, EAEU, agriculture, cluster analysis, correlation analysis, agricultural sector investments, production diversification

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Научная статья

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Устойчивость Агропромышленного Комплекса в Странах Евразийского Экономического Союза: Аспект Продовольственной Безопасности

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Аннотация

Настоящая статья анализирует устойчивость АПК в странах ЕАЭС с акцентом на продовольственную безопасность. Исследование охватывает вызовы и угрозы продовольственной безопасности в России, Беларуси, Армении, Казахстане и Кыргызстане, учитывая непростую геополитическую ситуацию. В статье рассматриваются данные национальных статистических служб стран ЕАЭС, а также международные источники, такие как ФАО и Всемирный банк. Применены методы корреляционного и кластерного анализа для оценки влияния социально-экономических показателей на устойчивость АПК. Выявлены значимые корреляции между показателями продовольственной безопасности и такими факторами, как объем сельскохозяйственного производства, инвестиции в аграрный сектор, уровень технологического развития и государственной поддержки. В среднем за период с 2015 по 2022 годы добавленная стоимость сельского хозяйства составила 8.2% от ВВП, а индекс производства продуктов питания составил 104.1. Результаты кластерного анализа показали, что страны ЕАЭС могут быть сгруппированы по уровням развития АПК и продовольственной безопасности. Так, KMeans и GMM выделили три кластера, в которых Россия оказалась как в отдельном кластере, так и в комбинации с другими странами. Агломеративная и спектральная кластеризация также показали схожие результаты, выделяя три основные группы стран. Средний силуэтный коэффициент для агломеративной и спектральной кластеризации составил 0.41, что указывает на лучшее качество кластеризации по сравнению с KMeans и GMM (0.38). Подтверждено, что интеграция и координация усилий в рамках ЕАЭС, а также диверсификация аграрного производства и увеличение инвестиций в инновации определяют состояние устойчивости АПК.

Ключевые слова: устойчивость агропромышленного комплекса, продовольственная безопасность, ЕАЭС, сельское хозяйство, кластерный анализ, корреляционный анализ, инвестиции в аграрный сектор, диверсификация производства

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1. Introduction

The sustainability of the agro-industrial complex (AIC) in the context of global transformations and geopolitical challenges plays a key role in ensuring food security in the countries of the Eurasian Economic Union (EAEU). Food security directly affects the social and economic well-being of the population. In the current situation, the issues of agribusiness sustainability and food security are becoming increasingly relevant for the EAEU countries. Thus, ensuring the sustainability of the AIC in Russia, Belarus, Armenia, Kazakhstan, and Kyrgyzstan is becoming critical.

The EAEU's growth points lie in the area of integration and joint projects. An analysis of the integration of agricultural and food markets in the context of food security of the EAEU shows that increasing production volumes and strengthening trade ties contribute to increasing the level of self-sufficiency in key food products at the macro level for the EAEU states and at the micro level for the population (Iashina et al., 2023). Developments in breeding, genetics, and agricultural machinery to strengthen food security will help unlock the potential of the Union, orienting countries to achieve full food independence (Gusev, 2023a; Shoba et al., 2023).

The aim of this study is to analyse the sustainability of the AIC in the EAEU countries and assess the factors affecting food security in the region. To achieve this goal, the following steps were taken: 1) challenges and threats to food security in the EAEU countries were analysed, 2) the impact of socioeconomic indicators on the sustainability of the AIC was determined, and 3) methods of correlation and cluster analysis were applied to identify the main trends and patterns.

The object of the study is the AIC of the EAEU countries. The subject of the study is the socioeconomic indicators related to the sustainability of the AIC and food security.

The analysis is based on data from the national statistical services of the EAEU countries, and also includes information from international organizations such as the FAO and the World Bank. To achieve these goals, the following methods were used: 1) correlation analysis to determine the relationships between different socioeconomic indicators and 2) cluster analysis to group countries by similar indicators of food security and agricultural sustainability.

The study contributes to the expansion of theoretical knowledge about the impact of various economic and social factors on the sustainability of the AIC, as well as on the mechanisms of ensuring food security in multinational associations. The results of this work can be used to formulate strategies aimed at strengthening food security and agribusiness sustainability in the EAEU countries, which is especially important for developing measures to respond to challenges associated with geopolitical transformations.

2. Materials and Methods

2.1. Review of Agribusiness Sustainability and Food Security Issues in the EAEU Countries

The study of agricultural sustainability and food security in the EAEU countries relies on a wide range of scientific and analytical sources, including international publications, reports of national statistical services, and data from organizations.

Food security concepts include an analysis of the economic and physical availability of food, as well as the dependence of the domestic market on imports. The current food security criteria are formally met for most food products, but there is still a problem of insufficient economic availability of food in the required volumes and assortment for a significant part of the population. The main part of agricultural raw materials and food imports is supplied from the EAEU partner countries, which reduces the risks of external shocks in the supply of agri-food products and creates prerequisites for softening the targets of the food security concept in the EAEU countries with respect to minimum levels of food self-sufficiency (Polzikov, 2020). At the same time, the development of integration processes and joint projects within the EAEU contributes to strengthening food security and reducing dependence on exter-

nal supplies. Thus, increasing production volumes and strengthening trade ties within the EAEU contribute to increasing the level of self-sufficiency in key food products. A number of areas can be identified for maintaining the sustainability of the agro-industrial complex in the EAEU countries (Table 1).

Table 1. Directions of agribusiness sustainability in the EAEU countries

Country	Agribusiness sustainability direction
Armenia	• Development of agricultural technologies • Improvement of water supply and irrigation systems • Support to rural farms and territories
Belarus	• Increase in agricultural productivity (return-on effect) • Reduction of waste in production • State support for agricultural producers
Kazakhstan	• Innovations in agriculture • Development of agricultural infrastructure • Reducing dependence on imports (agro-import substitution)
Kyrgyzstan	• Support for small agricultural producers • Improvement systems of the agricultural education system • Development of organic agriculture
Russia	• Technological modernization of the AIC • Development of agro-industrial clusters • Sustainable use of land resources

The desire for economic integration was a central aspect of politics in the post-Soviet space. As a result of several initiatives, a real achievement was the establishment of the Customs Union between Belarus, Kazakhstan, and Russia in 2010, which served as a prerequisite for the launch of the Single Economic Space in 2012. This led to the formation of the EAEU in 2015, which also included Armenia and Kyrgyzstan. The main goal of the EAEU is economic integration, which provides for the liberalization of mutual trade in goods and the development of a common market through the harmonization of internal regulatory requirements and the elimination of other non-tariff barriers. This ambitious project has a significant and fundamental impact on the economy of the participating countries, affecting the production and trade of food products (Götz et al., 2022; Iashina et al., 2023).

The formation of a sustainable food security system is a priority task for the EAEU member states. However, researchers note the need to form mechanisms for ensuring food security at the supranational level with the provision of certain guarantees to the EAEU countries (Kamalyan, 2022; Kusainova et al., 2020). In the context of economic sanctions imposed by the United States and the EU on Russia, the issue of ensuring food security is also relevant for other EAEU countries. The EAEU countries mainly export crop products, while they import livestock products. In this regard, it is necessary to find an effective solution to the problem of ensuring the food security of the EAEU and reducing import dependence, which will require improving the adopted coordinated agricultural policy in a number of areas. In this context, it is proposed to analyse retrospective trends and scenario forecasts of consumption and production of agricultural raw materials and food in the EAEU countries, which will help identify factors that contribute to and prevent the aggravation of contradictions in mutual trade in agricultural products in the future (Glotova, 2014; Ksenofontov et al., 2020).

Maintaining sustainability is closely linked to the use of the resource potential of territories, which can create certain problems in conditions of economic instability. Therefore, it is necessary to analyse available resources and develop strategies aimed at their effective use and adaptation to changes in the external environment (Sorokozherdyev et al., 2023). The development of agriculture in the context of

global economic instability requires a flexible approach, including the introduction of innovative technologies and adaptive management methods. In practice, the stability and productivity of the agricultural sector depends on the environment and government policy. To do this, state structures in the EAEU countries should focus investment projects on increasing the return on available resources in order to maximize the return on investment in the AIC, contributing to improving food security (Trofimova et al., 2020; Zhiltsov et al., 2022). Table 2 shows the main guidelines for ensuring food security in the EAEU countries.

Table 2. Directions of food security in the EAEU countries

Country	Food security in the destination country
Armenia	• Ensuring the availability of food for the population • Improving the quality of food
Belarus	• Diversification of agricultural production • Increased exports of food and agricultural products
Kazakhstan	• Provision of strategic food supplies • Support for local production
Kyrgyzstan	• Increasing self-sufficiency in key food products • Fight against food losses in agricultural production
Russia	• Import substitution in agricultural sectors • Improve product safety standards and improve quality control

Conceptual and practical challenges related to the development of sustainable food systems include the development of an ontology of the food system, which implies the systematization and categorization of the main relationships. In this context, there is a need to integrate sustainable and adaptive strategies to improve food security, and the importance of a holistic approach to food security increases (Zhiltsov et al., 2022). Under conditions of uncertainty, many areas are characterized by significant changes. For example, due to the transformation of economic and political factors, the tourism sector is being transformed, which activates the development of specific areas of agribusiness as well as the development of renewable energy sources, contributing to improving energy security in the context of ensuring the stability of the economic systems of territories (Ergunova and Simagina, 2023; Van Wassenaer et al., 2021). It is worth noting that the EAEU countries are activating the innovative development of various economic spheres, which directly affects the state of economic security. A comprehensive assessment of the region's economic security and innovation component involves analysing the region's potential to introduce innovative technologies (Zaytsev et al., 2022).

In order to increase the sustainability of food systems in the EAEU countries, it is necessary to develop and ensure the implementation of multiphase regional programmes aimed at the structural transformation of economic policies to achieve food self-sufficiency and the adoption of 'good' agricultural practices (Adelaja and George, 2021; Haji and Himpel, 2024). The adoption of food security as a component of the EAEU agricultural policy and its political priority affect domestic food production and the interaction of the EAEU with the global agri-food market. The current food policy of the EAEU is focused on reducing dependence on food imports. The EAEU food policy includes three sub-policies, each of which is at the protectionist end of the trade strategy spectrum (Dragneva, 2022):

1. A multi-pronged approach to food security, including reducing dependence on imported food, sustainability of the food system in the traditional sense regarding consumption and nutrition standards, food safety, product tracking, and label reliability.

2. Food self-sufficiency, which refers to efforts to increase agricultural production to meet domestic needs for basic commodities.

3. A policy of import substitution, which involves replacing imported goods with domestic ones (where possible), which can lead to an increase in food prices as imported goods are replaced by domestic ones.

Methodological aspects of developing the concept of collective food security in the EAEU countries are of paramount importance, since the development of such concepts requires taking into account the diversity of socioeconomic conditions and the level of development of the AIC. For these purposes, there is a need to apply advanced analytical and predictive methods (Ksenofontov and Polzikov, 2020). It should be borne in mind that the rent approach to the geo-economic integration of the national economy allows taking into account the specific advantages and resources of each member state of the union, optimizing their use within the common economic space. This approach contributes to a more efficient allocation of resources and increases the competitiveness of the AIC of the EAEU countries (Dmitriev and Zaytsev, 2019, 2020).

Problems of hunger and malnutrition remain acute all over the world, leading to diseases and mental retardation in children. About 1 billion people are malnourished and 1.5 billion are obese. It takes 10 to 30 years of dedicated work to address these challenges, but climate change and population growth may affect these forecasts.1,2 It is important for the EAEU countries to develop international cooperation and trade in safe products, especially to address the problems caused by drought and other climate changes.

Agriculture and agribusiness remain significant sectors of the economy of the EAEU member states and have significant potential for providing food to the domestic market and for the sustainable development of territories. The EAEU AIC demonstrates positive dynamics, and domestic production largely meets the needs of the population. However, it remains dependent on imported fruits and berries, which requires further development of its own production. The main problems include a dependence on imported genetic resources, the development of feed, and the manufacture of plant protection products, and these areas require improvements in the coordinated agricultural policy of the EAEU. Table 3 presents the main challenges for the sustainability of the agro-industrial complex and food security in the EAEU countries.

Table 3. Main challenges for agribusiness sustainability and food security in the EAEU countries

Country	Main challenges
Armenia	• Limited water resources • Small size of agricultural land
Belarus	• Dependence on imported agricultural machinery • Lack of population to expand agricultural production
Kazakhstan	• Low soil fertility • Shortage of skilled labour
Kyrgyzstan	• High level of food addiction • Insufficient agro-infrastructure
Russia	• Destruction of agricultural land • Difficult climatic conditions in a large part of the country

For example, agriculture occupies a significant place in the Armenian economy, accounting for an average of 19% of the country's GDP in the period from 2010 to 2015. The main problems include unfavourable natural and climatic conditions and a dependence on imported genetic resources and agricultural machinery. To solve these problems, state support programmes have been developed aimed at intensifying and industrializing agriculture, including subsidizing loans and introducing anti-hail nets (Kazaryan, 2017). The solution to these problems is associated with the activation of the processes of intensification of innovations and the introduction of innovative technological developments, which is

[1]World Food Programme (WFP) (2022) 'A global food crisis'. Available at: https://www.wforg/global-hunger-crisis Accessed 15 January 2024.
[2]USDA (2022) 'USDA Agricultural Projections to 2031', USDA Long-Term Projections, February. Available at: https://www.usda.gov/ Accessed 15 January 2024.

largely facilitated by interaction between the EAEU countries. Thus, it can be noted that the use of intellectual capital in agribusiness, the active development of scientific research, and the training of highly qualified specialists open up broad prospects for the introduction of innovative technologies and improving production efficiency in the EAEU countries. For this purpose, the EAEU countries are intensifying the improvement of the quality of education and professional training of specialists by introducing modern educational technologies and programmes (Alekseeva and Trofimova, 2017; Ilchenko et al., 2020).

The experience of agricultural industrialization in different countries consists of applying methods and measures that reduce the share of manual labour and increase the level of mechanization and automation. In developed countries, the growth of agricultural production is ensured by the implementation of scientific and technological advances, such as precision farming, genomic selection, and innovative methods of resource management. One of the areas of improving food security in the EAEU countries is the digitalization of the AIC. The introduction of information technologies and automated production process management systems helps optimize resources, reduce costs, and improve product quality (Amirova et al., 2021; Sigarev and Narynbaeva, 2015). Researchers note that in order to increase the sustainability of the AIC and food security in the EAEU countries, it is necessary to actively introduce modern technologies and state support for the industrialization of agriculture (Oganisyan and Kazaryan, 2020).

The use of innovative technologies contributes not only to the development of the AIC but also to improving the efficiency of production in food enterprises. In particular, the EAEU countries' investments in these programmes have led to the introduction of automated quality control and raw material processing systems. The use of innovative technologies in agriculture (precision farming, biotechnologies, and agricultural drones) increases productivity and resistance to adverse climatic conditions, which is especially important for countries such as Armenia. Harmonization of standards and the implementation of joint research and development initiatives within the EAEU contribute to the production of high-quality, competitive agricultural products (Dmitriev, 2020; Dmitriev and Rogozina, 2020; Maslova et al., 2019).

The problems of developing a unified food policy in the field of logistics integration of the EAEU countries are related to taking into account the different levels of consumption and trade opportunities of the population in the participating countries. There is a need to create a balanced food market, given the imbalances in consumption and the development of logistics supply chains, as well as the high volume of unjustified food imports from third countries. For this purpose, the formation of national import substitution programmes is being activated, taking into account the supplies of partners in the EAEU. These areas determine the transformation of sustainability mechanisms and their impact on food security (Stone and Rahimifard, 2018; Zueva et al., 2016). It should be borne in mind that food markets have changed significantly, which complicates the relationship between participants in food chains. Such changes, of course, also affect the markets of the EAEU countries. It is necessary to ensure the identification, assessment, and prevention of factors that negatively affect the competitive environment of food and agricultural product markets in the EAEU countries (Pilipuk et al., 2022).

The UN forecasts unprecedented food shortages along with rising prices and warns that the global food market may face serious pressure due to the growing problem of food insecurity. Establishing sufficient food supply for the EAEU countries, while simultaneously reducing dependence on food imports and reducing the vulnerability of supply, is the basis for improving the level of food security (Arskiy and Khudzhatov, 2021). For these purposes, it is necessary to develop models for making managerial decisions in agriculture that can rationalize economic processes based on multidimensional data analysis. For example, it is necessary to step up the penetration of progressive supply chain management into agribusiness (Lukina et al., 2023; Vakhrusheva et al., 2021). The problem with the logistics system is that transport services take a disproportionately large share in the total volume of logistics services; the logistics sphere of some EAEU countries is limited to transportation, warehousing, and distribution. A comprehensive solution to problems, including training highly qualified specialists and state support for

infrastructure projects, can improve the situation (Kazaryan et al., 2022).

2.2. Statistical Analysis of Agribusiness in the EAEU Countries

The EAEU was created with the aim of forming a single market that ensures the freedom of movement of goods, services, capital, and labour within the Union. Initially, the stages of the integration process were planned until 2025, but in December 2023, the EAEU countries approved a declaration on the further development of economic processes with planning until 2030 and for the period up to 2045. Currently, the level of self-sufficiency of the EAEU in food has exceeded 93% (in 2020, this figure was 88%), and over the 10 years of the Union's existence, agricultural production has increased by more than a quarter. For statistical analysis, we used the report of the Eurasian Development Bank (Vinokurov et al., 2023) as well as open access data, in particular data from the national statistical services of the EAEU countries, as well as international sources such as the FAO and the World Bank.

It should be borne in mind that global agri-food chains and the food trade system have become key elements for ensuring global food supply and security. The annual increase in the volume and value of agricultural trade raises questions about the potential threat to food security associated with import dependence and the trade deficit.3 However, in 2023, the production of agricultural products in the EAEU showed a decline. According to the Eurasian Economic Commission (EEC), total agricultural production in the EAEU countries decreased by 1.1%. At the same time, Belarus and Kyrgyzstan experienced growth of 1.1% and 0.6%, respectively, while Kazakhstan and Russia experienced a decrease of 7.7% and 0.3%, respectively.

Food problems primarily affect the population of developing and underdeveloped countries. However, residents of economically developed countries also face increased costs for food and utilities, which leads to a decrease in their standard of living. According to the EAEU data, the total production of agricultural products of all categories increased in 2022 (Borodenko, 2023). According to the EEC, in 2023, in farms of all categories of the EAEU countries, the gross grain harvest after refinement amounted to 169.4 million tons, which is 11.1% less than in the previous year. Potato production increased by 5.4% to 30 million tons, while vegetable production decreased by 0.4% to 22.9 million tons. At the same time, the production of basic livestock products has increased: livestock and poultry for slaughter (in live weight) by 2.2%, milk by 3%, and eggs by 0.8%.

The EAEU has significant resource advantages. The territories of the participating countries contain 10% of all arable land on the planet and 10% of the world's fresh water reserves, more than 13% of the world's wheat reserves, more than 16% of barley, and significant fertilizer reserves—about 10% of nitrogen and phosphate fertilizers and more than 40% of potash fertilizers. Russia and Kazakhstan provide about a third of the world's sunflower oil production. Trends in Russia's economic development demonstrate that the assessment of long-term economic growth rates up to 2035,4 based on alternative scenarios, shows insufficient effectiveness of regular macroeconomic policy measures to stimulate sustainable economic growth (Gusev, 2023b). At the same time, by the end of the decade, Russia plans to increase production in the agricultural sector by a quarter and increase exports by one and a half times, especially cereals, legumes, oilseeds, meat (especially poultry and lamb), fat and oil products, flour, cereals, milk, and confectionery.

The transition to a common agribusiness policy will allow the EAEU countries to jointly increase profits, avoiding unnecessary competition. Self-sufficiency in food products is an important indicator for the EAEU. The level of food self-sufficiency varies among the EAEU countries: Belarus (94%) and Russia (90%) have the highest rates, followed by Kazakhstan (87%), Kyrgyzstan (74%), and Armenia (67%). Russia fully meets domestic demand for grain, pork, poultry meat, and vegetable oils, exporting the surplus both to its EAEU partners and to other countries. However, the production of beef, milk, and certain types of vegetables does not yet cover domestic demand.

[3]Eurasian Economic Commission (2021). Agro-Industrial Complex. Available online at: https://agro.eaeunion.org/Pages/default.aspx Accessed 15 January 2024.
[4]OECD-FAO (2022) 'OECD-FAO Agricultural Outlook 2022–2031'. Available at: https://www.oecd-ilibrary.org/agriculture-and-food/oecd-fao-agricultural-outlook-2022-2031_f1b0b29c-en Accessed 15 January 2024.

A prolonged period of high food prices is projected, driven by population growth, high energy prices, a shortage of skilled labour, increased food consumption in countries, limited opportunities for agricultural land expansion, and climate change. Reduced availability of food increases its value. Food is becoming the new 'black gold': its political significance and export potential will grow. Under the influence of the pandemic, geopolitical tensions, sanctions, the disruption of supply chains, the fuel crisis, and rising production costs, including energy and fertilizers, the cost of food has increased significantly. The Food Price Index (FAO) has increased by 46.5% over the past two years (from 98.1 in 2020 to 143.7 in 2022), remaining above the level of 2021 despite a slight decline in the second half of 2022.

The Eurasian region as a whole ensures its food security. The level of self-sufficiency for most products exceeds 80–95%, which corresponds to food independence. Figure 1 shows the level of self-sufficiency of the EAEU countries in the main areas of agricultural production. The highest level of self-sufficiency is observed for cereals and oilseeds, while the lowest level is observed for fruits.

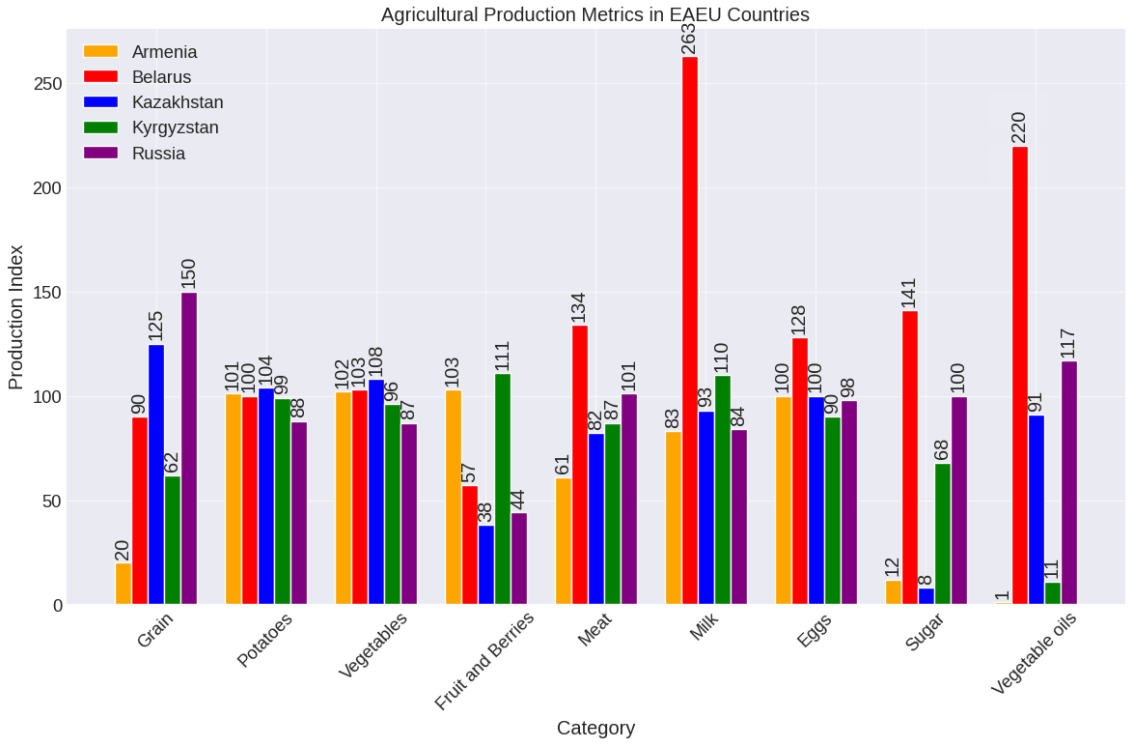

Figure 1. Level of self-sufficiency of the EAEU countries (%)

The realization of the production and resource potential of the AIC can provide the following positive effects for the Eurasian countries by 2035. It is noted that the production multipliers for the agricultural sector (USD per dollar of expenditure per sector) will be: 2.62 for Russia, 2.49 for Kyrgyzstan, 2.44 for Belarus, 1.95 for Kazakhstan, and 1.77 for Armenia. Mutual trade between the countries of the Eurasian region is steadily growing (in 2021 it reached $15.4 billion). The share of mutual exports in the total volume of exports of agricultural products was 33.6%. Over the past 20 years, the volume of mutual export supplies of agricultural products has increased 8.5 times. Since the EAEU started functioning in 2015, mutual trade in agricultural products has grown by a factor of 1.8. The largest increase in exports to the domestic market from 2015 to 2021 was observed in Armenia (3.1 times) and Russia (2.3 times).

The main part of deliveries of agricultural products to the domestic market is accounted for by Russia, Belarus, and Kazakhstan, whose combined share in mutual exports was 90%. These countries are key producers of food products and act as guarantors of food security in the region. In the structure of mutual imports, the main importers are Russia (40.2%) and Kazakhstan (21.9%), with the total share of Russia, Kazakhstan, and Belarus at 72.4% (Figure 2). Outside the EAEU, Uzbekistan is also a signif-

icant importer (13.4%).

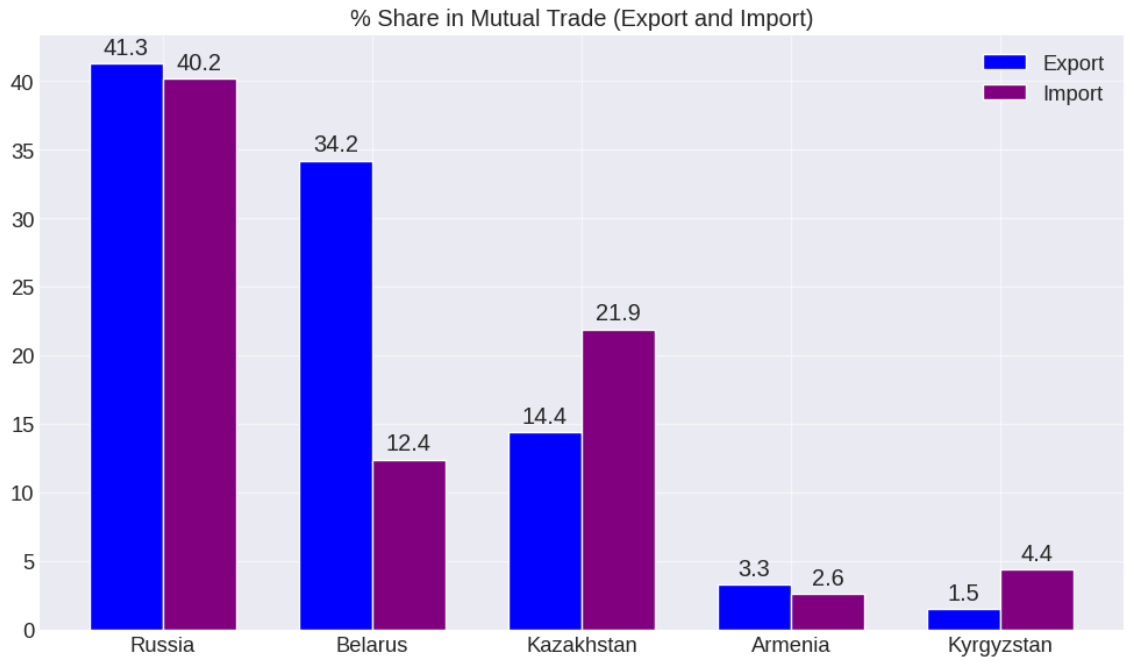

Figure 2. Share of Eurasian countries in mutual trade in agricultural products in 2021 (%)

More than one third of the volume of mutual trade in agricultural products falls into three groups: dairy products, eggs, and honey (17.9%); cereals (9.4%); and fats and oils (9.2%). The main supplier of dairy products is Belarus (85.9% in the structure of mutual exports); of cereals, Kazakhstan (67.7%); and of fats and oils, Russia (70.7%). Exports of such commodity groups as vegetables, fruits, nuts, animal products, fish, and beverages are distributed more evenly between countries.

The Eurasian market is most important for the export of the agricultural products of Belarus (78.8% in 2021) and Kyrgyzstan (69.1%). Regional imports of agricultural products are most important for Kyrgyzstan (76.1%) and Kazakhstan (66.4%). The largest growth rates of imports from Eurasian countries are observed in Belarus (a twofold increase). Kazakhstan accounted for 43.2% and Belarus for 28.4% of Russian exports of agricultural products in 2021. Russia is the main supplier of agricultural products to Belarus (97.6%), Armenia (93.6%), Kazakhstan (81.6%), and Kyrgyzstan (52.4%).

2.3. Review of the Methodological Framework of the Study

Food security diagnostic tools include methods for assessing the availability and quality of food resources, as well as monitoring their distribution and use. To build strategies and practice-oriented models, the state of the territory's resource potential should also be taken into account (Zaytsev et al., 2024). For example, the model of economic and statistical assessment of food security is used to analyse and predict the state of food security at the regional and national levels, which allows us to take into account various socioeconomic factors affecting the availability and quality of food and develop measures to improve food security (Antamoshkina, 2019a, 2019b).

Determinants of food self-sufficiency include the level of domestic production, the efficiency of agricultural technologies, and the volume of imports. Food security is determined by a country's ability to meet the population's needs for basic foodstuffs, ensuring their availability and quality in the long term (Galiev and Ahrens, 2021). Within the framework of this study analysing the sustainability of the AIC and food security in the EAEU countries, the following methodological tools are used:

1. Correlation analysis is used to determine the relationships between socioeconomic indicators. This method allows us to identify which factors (for example, the volume of agricultural production, investment in the agricultural sector, the level of technological development, and state support) affect

food security. The analysis is based on data provided by the national statistical services of the EAEU countries, as well as international organizations such as the FAO and the World Bank.

2. To group the EAEU countries by the level of agribusiness development and food security, cluster analysis methods are used, including K-means, Gaussian mixtures (GMM), and agglomerative and spectral clustering. These methods allow us to identify clusters in which countries are distributed depending on the similarity of their indicators.

3. Results and Discussion

3.1. Data Collection for the Analysis of Agro-Industrial Complex Sustainability in the EAEU Countries

The study collected and analysed data that will help assess the sustainability of the AIC and food security in the EAEU countries. The following is a description of the key indicators and their significance for the study (Table 4).

Table 4. Data for analysis of agricultural sustainability in the EAEU countries

Designation	Indicator	Description
GDP_Nominal	GDP (nominal, USD)	Assessment of the economic state of countries and opportunities to invest in the AIC.
GDP_PPP	GDP (PPP, USD)	Takes into account the purchasing power of the currency.
Agriculture_Value_Added	Agriculture, value added (% of GDP)	The contribution of agriculture to the economy and its significance for GDP.
Agricultural_Land	Agricultural land (% of total land area)	Share of land used for agriculture.
Crop_Production_Index	Crop Production Index (2004–2006 = 100)	Dynamics of agricultural production.
Food_Production_Index	Food Production Index (2004–2006 = 100)	Food production volume and its changes.
Cereal_Yield	Grain yield (kg per hectare)	Efficiency of agricultural land use.
Total_Population	Total population	Indicators per capita and scale of food security.
Mortality_Rate_Under_5	Under-5 mortality rate (per 1000 live births)	Standard of living and health of the population.
CO2_Emissions	CO2 emissions (kilotons)	Environmental impact of the AIC and its impact on the climate.
Renewable_Internal_Freshwater	Domestic renewable freshwater resources (cubic meters per capita)	Availability of water resources for agriculture.
depth_of_Food_Deficiency	Depth of food deficit (kcal per person per day)	The level of malnutrition.
Industry_Value_Added	Industry, value added (% of GDP)	The role of industry in the economy and interaction with agriculture.
Access_to_Safely_Managed_Drinking_Water	Access to safe drinking water (% of population)	Standard of living and food security.
Fertilizer_Consumption	Fertilizer consumption (kg per hectare of arable land)	The level of agricultural intensification.
Agricultural_Land_SqKm	Agricultural land (sq km)	Volume of land for agriculture.

Arable_Land_ Per_Person	Arable land (hectares per person)	Availability of arable land per capita.
Arable_Land_ Percentage	Arable land (% of land area)	Percentage of land suitable for ploughing.
Methane_Emissions	Methane emissions (cT of CO2 equivalent)	Environmental impact of the AIC.
Livestock_Production_Index	Livestock Production Index (2004–2006 = 100)	Level and dynamics of livestock production.

3.2. Descriptive Statistics for the Analysis Indicators of Agricultural Sustainability in the EAEU Countries

Indicators collected for the period from 2015 to 2022 were used to analyse the sustainability of the AIC in the EAEU countries. Table 5 shows the main results of descriptive statistics.

Table 5. Descriptive statistics of data for the analysis of agribusiness sustainability in the EAEU countries

Indicator	Mean	Standard deviation	Minimum	25th percentile	Median	75th percentile	Maximum
GDP_Nominal	380.96 billion	654.29 billion	6.68 billion	11.54 billion	60.70 billion	187.57 billion	2240.42 billion
GDP_PPP	1063.38 billion	1796.98 billion	25.09 billion	39.03 billion	199.55 billion	586.94 billion	5987.86 billion
Agriculture_ Value_Added	8.20	4.12	3.39	4.50	6.85	11.56	17.22
Agricultural_Land	49.53	22.28	13.16	41.06	54.07	58.90	80.11
Crop_Production_Index	100.94	14.91	68.53	92.49	103.71	110.10 Writing	133.67
Food_Production_Index	104.07	10.58	81.27	99.67	104.96	110.76	127.76
Cereal_Yield	2516.57	794.50	1048.80	1903.98	2718.70	3111.18	3690.20
Total_Population	36.27 million	54.94 million	2.78 million	6.17 million	9.43 million	18.82 million	144.50 million
Mortality_Rate_Under_5	10.29	5.62	2.60	5.33	10.25	13.28	22.20
CO2_Emissions	138446.90	236404.50	2319.92	4507.13	17030.29	69929.67	620983.16
Renewable_ Internal_ Freshwater	9451.83	10556.78	2382.76	3487.09	3612.91	8009.83	29929.24
Depth_of_ Food_Deficit	2.99	1.03	2.50	2.50	2.50	2.50	5.80
Industry_ Value_Added	29.49	3.44	22.26	26.50	30.76	32.19	35.27
Access_to_ Safely_Managed_Drinking_Water	82.42	7.83	66.93	75.99	82.79	89.33	93.10

Fertilizer_ Consumption	83.87	91.58	2.92	11.55	22.65	162.78	330.49
Agricultural_ Land_SqKm	902492.57	1036836.04	16748.20	83340.00	103708.00	2154940.00	2162597.00
Arable_ Land_Per_ Person	3.17	4.69	0.04	1.29	5.68	29.66	121.65
Arable_ Land_Per- centage	13.75	7.91	6.68	7.43	10.98	15.67	28.21
Methane_ Emissions	138446.90	236404.50	2319.92	4507.13	17030.29	69929.67	620983.16
Livestock_ Production_ Index	107.71	6.57	99.90	102.28	106.24	111.15	124.81

Based on the above data, we can draw the following conclusions:

- The average nominal GDP is 380.96 billion USD with a high variation (standard deviation 654.29 billion USD), which indicates significant differences in the economic state of the EAEU countries.

- The average added value of agriculture is 8.20% of GDP.

- The average yield of grain crops is 2516.57 kg per hectare.

- The average share of agricultural land in the total area is 49.53%.

- CO2 and methane emissions show a significant environmental impact of the AIC.

- The depth of nutrition deficit is on average 2.99 kcal per person per day, which indicates that there are problems with the availability of adequate nutrition.

- On average, 82.42% of the population has access to safe drinking water.

3.3. Economic and Social Determinants of Food Security

Correlation analysis based on socioeconomic indicators allows us to identify the main determinants that affect the sustainability of the AIC and, consequently, food security in the region. In the matrix shown in Figure 3, dark green cells indicate strong positive correlations, and light green cells indicate weak positive or negative correlations (correlations with values from -0.3 to 0.3 are excluded).

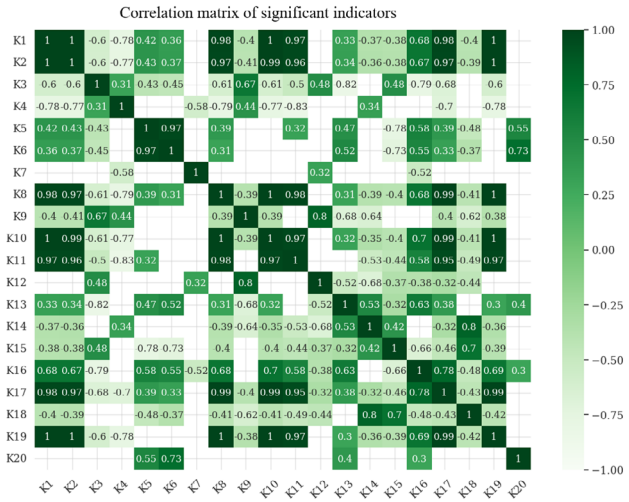

Figure 3. Correlation matrix of significant indicators for the analysis of agribusiness sustainability in the EAEU countries

The legend of indicators: K1 = GDP_Nominal; K2 = GDP_PPP; K3 = Agriculture_Value_Added; K4 = Agricultural_Land; K5 = Crop_Production_Index; K6 = Food_Production_Index; K7 = Cereal_Yield; K8 = Total_Population; K9 = Mortality_Rate_Under_5; K10 = CO2_Emissions; K11 = Renewable_Internal_Freshwater; K12 = Depth_of_Food_Deficit; K13 = Industry_Value_Added; K14 = Access_to_Safely_Managed_Drinking_Water; K15 = Fertilizer_Consumption; K16 = Agricultural_Land_SqKm; K17 = Arable_Land_Per_Person; K18 = Arable_Land_Percentage; K19 = Methane_Emissions; K20 = Livestock_Production_Index.

Economic indicators (K1 and K2):

Nominal GDP (K1) and GDP at purchasing power parity (K2) strongly correlate with total population (K8) (0.98), CO2 emissions (K10) (0.99), domestic renewable freshwater resources (K11) (0.96), and methane emissions (K19) (0.99). The results obtained indicate a significant environmental burden associated with economic growth.

2. Agriculture indicators (K3 and K4):

Agricultural value added (K3) has a negative correlation with nominal GDP (K1) (-0.60) and GDP by PPP (K2) (-0.60). The results obtained indicate that the share of agriculture in the economy decreases with the growth of total GDP.

Agricultural land (K4) is negatively correlated with nominal GDP (K1) (-0.78) and PPP GDP (KK2) (-0.77). The results obtained emphasize the need to improve the efficiency of agricultural land use.

3. Production indicators (K5 and K6):

The crop production index (K5) positively correlates with the food production index (K6) (0.97). The results obtained indicate the synchronous development of these two indicators, which is important for ensuring food security.

Grain yields (K7) have a significant negative correlation with agricultural land (K4) (-0.58). The results obtained indicate the need to optimize the use of land to increase productivity.

Social and environmental indicators (K9 and K10):

The under-5 mortality rate (K9) has a negative correlation with nominal GDP (K1) (-0.40) and PPP GDP (K2) (-0.41). The results obtained indicate that children's health improves as the economy grows.

CO2 (K10) and methane (K19) emissions show high positive correlations with economic indicators, highlighting the environmental impact of agriculture.

Industrial indicators (K13):

Industrial value added (K13) is negatively correlated with agricultural value added (K3) (-0.82). The results obtained indicate their opposite directions of development in the economy.

The correlation matrix emphasizes the importance of an integrated approach to the development of the AIC and ensuring food security in the EAEU countries. Economic development is linked to environmental and social aspects, which requires the integration of new practices and innovative technologies in agriculture. Positive correlations between production indicators (K5 and K6) indicate the importance of synchronous development of agricultural production for achieving stability in food security.

3.4. Results of Cluster Analysis of the EAEU Countries

The analysis was performed using several clustering methods, such as K-means, agglomerative clustering, Gaussian mixture models (GMM), and spectral clustering. Each method used key indicators to identify groups of countries with similar characteristics.

The elbow method was used to determine the optimal number of clusters that can best describe the data. Figure 4 shows that inertia (vertically) decreases sharply as the number of clusters increases from 1 to 3 (horizontally), after which the decrease becomes less noticeable.

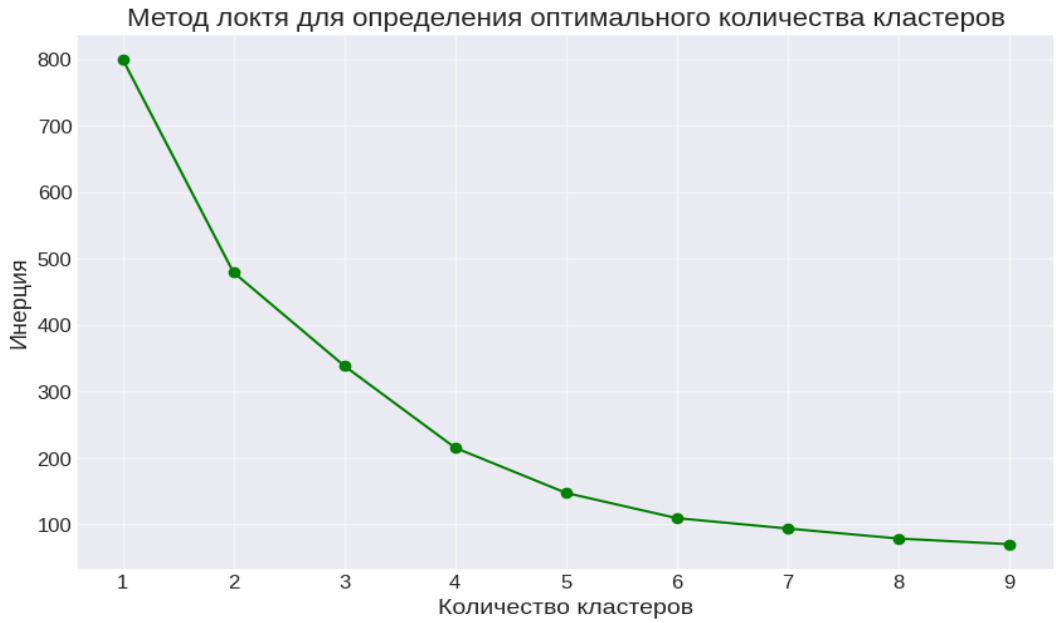

Figure 4. Elbow method for determining the optimal number of clusters

3.4.1. K-means Clustering

Cluster 0 includes Russia; cluster 1 consists of Armenia, Belarus, and Kyrgyzstan; and cluster 2 includes Kazakhstan and Russia. Clustering quality metrics for K-means include the silhouette score (0.38), the Davies–Bouldin score (1.07), and the Calinski–Harabasz score (21.04). The results indicate moderate clustering quality, with Russia being singled out as a separate cluster or combined with Kazakhstan.

3.4.2. Agglomerative Clustering

Cluster 0 includes Belarus and Kazakhstan; cluster 1 includes Russia; and cluster 2 contains Armenia and Kyrgyzstan. The clustering quality metrics for this method were slightly higher: silhouette score = 0.41, Davies-Bouldin score = 1.08, and Calinski–Harabasz score = 26.03. The results obtained indicate that agglomerative clustering can better reflect the data structure, highlighting Russia as a separate cluster.

3.4.3. Gaussian Mixture Models and Spectral Clustering

The clustering method based on Gaussian mixture models (GMM) and spectral clustering showed similar results to K-means. Both methods also identified three clusters: cluster 0 includes Russia; cluster 1 includes Armenia, Belarus, and Kyrgyzstan; and cluster 2 includes Kazakhstan and Russia. The quality metrics for these methods are similar: silhouette score = 0.38 and 0.41, Davies–Bouldin score = 1.07 and 1.08, and Calinski–Harabasz score 21.04 and 26.03, respectively. The results highlight the similarity of the methods and confirm the general trends identified when using K-means.

3.4.4. Generalized results

Cluster analysis methods, such as K-means and Gaussian mixtures (GMM), allowed us to identify three main clusters of the EAEU countries by levels of agribusiness development and food security. Table 3 shows the results of cluster analysis.

Table 3. Results of cluster analysis of the EAEU countries

Method	Silhouette Score	Davies–Bouldin Score	Calinski–Harabasz Score	Clusters
K-means	0.38	1.07	21.04	0: [RU], 1: [AM, BY, KG], 2: [KZ, RU]
Agglomerative	0.41	1.08	26.03	0: [BY, KZ], 1: [RU], 2: [AM, KG]
Gaussian Mixture	0.38	1.07	21.04	0: [RU], 1: [AM, BY, KG], 2: [KZ, RU]
Spectral Clustering	0.41	1.08	26.03	0: [AM, KG], 1: [RU], 2: [BY, KZ]

The results of the cluster analysis confirm that the EAEU countries can be grouped into three main clusters, which highlights significant differences in the level of agribusiness development and food security. This approach allows for a more accurate orientation in the development of strategies and policies to strengthen food security and the sustainability of the AIC in the region.

4. Conclusion

The sustainability of the AIC in the EAEU countries is crucial for ensuring food security and solving socioeconomic problems. The study shows that economic indicators, such as nominal GDP and GDP based on purchasing power parity, are highly correlated with environmental and demographic indicators, which indicates the interrelated nature of economic growth and environmental impact. For example, the high correlation with CO2 and methane emissions highlights the need for sustainable agricultural practices to balance economic development and environmental conservation.

During the cluster analysis, three main clusters of the EAEU countries were identified, depending on the level of their agricultural development and food security. Methods such as K-means, agglomerative clustering, Gaussian mixture models (GMM), and spectral clustering have consistently identified similar groupings, demonstrating that Russia often stands out either separately or in combination with Kazakhstan. Quality indicators such as the silhouette score and the Davis–Bouldin score indicate moderate-to-good clustering performance, highlighting the distinctiveness of these groupings and their importance for policy development.

In conclusion, the analysis emphasizes the importance of an integrated approach to the development of the AIC and ensuring food security in the EAEU. Economic growth must be combined with environmental mitigation strategies, and targeted investments in agricultural technology and infrastructure are also needed. Cooperation and integration within the EAEU can improve food security, reduce dependence on imports, and promote sustainable agricultural practices. The results obtained lay the foundation for strategic planning and policy development aimed at achieving long-term stability and resilience in the agro-industrial sector of the Eurasian region.

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