IRSTI 68.75.02
UDC (338.43.02)
DOI 10.47649/vau.25.v78.i3.25

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FUNDAMENTALS OF THE STRATEGY OF MODERNIZATION OF THE AGRO-INDUSTRIAL COMPLEX IN THE CONTEXT OF CLIMATE CHANGE AND ECONOMIC CHALLENGES

Abstract

Modern climatic changes and global economic challenges pose the task of modernization for the agro-industrial complex of Kazakhstan. With the growing global demand for food and increasing environmental risks, the sustainable development of agriculture is becoming strategically important.

The purpose of the study is to identify the key elements of the agro–industrial complex modernization strategy aimed at adapting to climate change and overcoming economic challenges.

The research is based on the analysis of statistical data, scientific publications and examples of successful practices from international experience. As part of the work, the main problems of the Kazakh agro-industrial complex were identified, including soil degradation, reduced yields, water scarcity and high dependence on climatic conditions. At the same time, internal and external factors affecting the industry's development were analysed, including price instability in global markets, limited access to finance, and the need for digital transformation.

The results of the study show that an effective modernization strategy should include the following key areas:

The introduction of sustainable technologies, including the transition to precision farming systems, the use of energy- and water-saving technologies, and the development of organic agriculture.

Digitalization of the industry: creation of platforms for monitoring and managing agricultural production, the use of drones, satellite data and IoT to improve the accuracy of operations.

Strengthening government support: developing incentives for farmers and businesses adopting environmentally friendly technologies, including tax incentives and subsidies.

Development of the processing and storage infrastructure, which will ensure a reduction in crop losses and an increase in export potential.

The scientific novelty of the research lies in the development of an integrated approach to the modernization of agriculture, which combines technological innovations, adaptation to climate change and economic sustainability.

Keywords: agro-industrial complex, climate change, economic challenges, modernization, sustainable development, precision agriculture, digitalization.

Introduction

Modernisation of Kazakhstan's agro-industrial complex is the most crucial task for ensuring the country's food security, enhancing its economic sustainability, and adapting to global challenges. Previous studies (Smith, 2020; Zhang, 2021; Abdrakhmanova, 2023) have highlighted that while Kazakhstan possesses significant agricultural potential, the sector still lags behind international standards in terms of technological development, digitalization, and sustainable practices. Researchers note persistent problems such as low labour productivity, insufficient infrastructure, weak integration into global value chains, and limited access to innovation. However, most works have focused either on general trends in global agriculture or on narrow technological aspects, without offering a comprehensive analysis of modernization strategies adapted to Kazakhstan's regional specificities. This gap demonstrates the need for a more systematic and contextual study.

In the context of global climate change and economic instability (for example, fluctuations in agricultural prices, foreign economic sanctions and trade wars), agriculture faces serious threats such as declining yields, depletion of natural resources and deterioration of agricultural land quality. These factors are consistently emphasised in the works of international organisations (FAO, OECD), but there is a lack of country-specific studies that consider Kazakhstan's unique conditions. These challenges require the agricultural industry to implement innovative and sustainable solutions that can increase its competitiveness and efficiency.

In addition, Kazakhstan, with its vast territories, diverse natural resources and favourable climatic conditions, has significant potential for agricultural growth. However, to realise this

potential, it is necessary to carry out a deep modernisation of the sector, including digitalisation, the introduction of new technologies and strengthening environmental sustainability. Despite the recognition of these priorities, earlier studies often neglect the role of regional disparities and socio-economic factors, which limit the applicability of their recommendations. In modern conditions, such a transformation is becoming not only a necessity, but also a guarantee for the successful development of the rural economy in the future.

Materials and methods of research

Kazakhstan has significant agricultural land, but despite this, the efficiency of land use remains low. The structure of acreage in the country is traditionally focused on the cultivation of cereals, in particular wheat, which occupies more than 60% of the total area of crops. However, with the growing global demand for other agricultural products such as oilseeds, vegetables and fruits, it is necessary to diversify the acreage to increase the sustainability of production. Yields in Kazakhstan vary depending on the region and climatic conditions, but on average, they remain below the global level, due to the use of insufficient agricultural techniques and outdated farming methods.

The agro-industrial complex of Kazakhstan is characterised by a high share of the agricultural sector in the economy; however, the profitability of most farms remains low due to insufficient innovation, high dependence on climatic factors, and low mechanisation of production. The country's export potential is relatively high, especially in the segment of grain and meat products; however, there is a significant dependence on foreign markets and price fluctuations. It is expected that with the growth of export volumes of agricultural products such as wheat and sunflower, Kazakhstan will be able to take a more stable position in international markets.

The object of this research is the agro-industrial complex of Kazakhstan, which includes crop production, livestock, rural infrastructure, and the socio-economic conditions of rural territories. The sector was chosen as the object because of its decisive role in ensuring food security, employment, and the export potential of the national economy.

To study its current state and prospects for modernization, a combination of methods was applied:

- Statistical analysis – used to process data from the Bureau of National Statistics of the Republic of Kazakhstan, the Ministry of Agriculture, and international databases (FAO, OECD, World Bank). This made it possible to evaluate the dynamics of production, yields, and investment flows.
- Comparative analysis – applied to compare Kazakhstan’s indicators with global and regional benchmarks, as well as to identify structural gaps in productivity and resource use.
- Content analysis of scientific literature and policy documents – enabled the identification of trends and problems already described by other researchers, and helped reveal gaps (for example, insufficient attention to regional disparities and adaptation to climate change).
- Case study method – focused on selected regions of Kazakhstan with different climatic and infrastructural conditions, which allowed to assess how local factors influence the effectiveness of modernization measures.
- Expert evaluation – included the opinions of agricultural economists, policymakers, and practitioners, used to validate statistical findings and ensure the practical relevance of conclusions.
- System approach – applied to consider the agro-industrial complex as an integrated system where production, technology, environmental sustainability, and rural development are interconnected.

The choice of these methods is justified by the complexity of the problem: modernization of agriculture requires both quantitative assessment (statistics, comparisons) and qualitative understanding (expert evaluations, case studies). The system approach ensures that all factors — economic, technological, environmental, and social — are studied in their interaction.

The rural population makes up a significant part of the total population of Kazakhstan, and the agricultural sector remains the primary source of employment in many regions. However, the standard of living in rural areas remains lower than in urban areas, due to low incomes, limited

access to social infrastructure, and high rates of urban migration. Problems such as the shortage of qualified personnel, high workload and lack of investment in rural development are significant barriers to improving the standard of living of the rural population.

As noted by Doychinova J. and Stoyanova Z. in their research, "analyzes how the transformation of agriculture differs in different regions of Bulgaria and its impact on rural sustainability. Using data from the agricultural census and an analysis of the data set, the authors of the study revealed significant regional differences in effectiveness" [1]. Ultimately, the ISSA offers policy recommendations on agricultural strategies tailored to specific regions, aiming to enhance resource utilisation and promote sustainable rural development. The transformation of agriculture in Bulgaria is taking place unevenly, which affects the economic, social and environmental sustainability of various regions. These differences are due to access to resources, government support, and the level of infrastructure.

As noted by Mendes-Zambrano P. V., Tierra Perez L. P., Ureta Valdez R. E. and Flores Orozco A. P. in their research "dedicated to ICT and digital innovations in agriculture and how they can eliminate gaps in rural development and contribute to sustainable development" [2]. The authors summarise the results of 40 relevant studies on digital tools for managing soil, water and other resources. The review highlights how the introduction of ICT-based innovations can increase productivity and engagement in agriculture. It provides recommendations for policymakers to use these technologies for sustainable agricultural development.

The Action Plan for the implementation of the State Program for the Development of the Agro-industrial Complex 2017-2021 provides for the reconstruction of 41 emergency reservoirs, the main purpose of which is the safe operation of water resources management facilities. In addition, it is planned to build 22 new reservoirs with a total additional accumulation of water in the amount of 1.9 billion m3 in the amount of 57.2 billion tenge in 7 regions. In 2017, the National Company Kazakhstan Garysh Sapary planned to launch a geoportal for accounting water resources based on space monitoring data [3]. The State program provides for the reconstruction of emergency reservoirs and the construction of new reservoirs, which contributes to improving water resources management and safe operation. Additional accumulation of 1.9 billion m3 of water in 7 regions will increase the water availability of the regions. The introduction of a geoportal based on space monitoring is aimed at digitalisation and effective management of water resources.

At the moment, a local emergency regime continues to operate in eight regions of Kazakhstan, despite a gradual decrease in water levels. According to the Ministry of Agriculture, more than 8,000 cattle were killed, and the total amount of applications for damage compensation reached 22,475. Two hundred seventy-eight million tenge has already been allocated for this purpose, but the final amount of economic losses from floods is still being calculated. Experts warn that the damage could be much more severe than expected due to the long-term effects on the agricultural sector.

Large-scale floods have led to the loss of agricultural resources, including seeds, fuels, lubricants, and agricultural machinery, which will significantly reduce the readiness of farms for the sowing campaign. Farmers face difficulties in obtaining compensation, as it is often impossible to prove losses. The largest losses were incurred by small and medium-sized farms that do not have the resources to account for stocks and assets systematically.

As Hassoun A. notes in his study, "A comprehensive overview of how digital technologies (industry 4.0) are changing the agri-food sector, with an emphasis on the acceleration caused by COVID-19"[4]. It examines examples of innovations, such as blockchain for supply chains, artificial intelligence for agriculture, and Internet of Things sensors. It explores the role of the pandemic in accelerating the adoption of these tools. The article also identifies key issues (e.g. infrastructure, skills) and describes how broader digitalisation can enhance the sustainability and efficiency of the food system.

One of the major problems is the erosion of pastures and agricultural lands. Streams of water have brought seeds of weeds, including poisonous species, to the fields, which will lead to additional costs for their cleaning and lower yields. In addition, the boundaries of the fields have

been violated, which makes it difficult to account for and redistribute land resources. According to agroanalyst Kirill Pavlov, "late sowing and difficult weather conditions in 2024 may significantly reduce crop volumes, which will negatively affect the gross agricultural product." As noted by agroanalyst Kirill Pavlov, a decrease in crop volumes will directly affect the gross agricultural product. This may lead to a slowdown in the growth of the agro-industrial sector and negatively affect the overall state of the economy, especially in rural areas.

As noted by Deng F., Jia S., E. M. and Li Z. His research "explores the synergy between the transformation of agriculture (towards high-quality and sustainable production) and technological innovation in China's major grain regions" [5]. The study uses regional data to assess how advances in technology (e.g., new farming methods, "smart agriculture") complement structural changes in agriculture. The report notes that aligning innovation with farming practices is crucial to increasing productivity and sustainability. Policy implications include increased support for research and development, as well as encouragement of innovations that directly contribute to the modernisation of agriculture in these regions.

A recent analytical study (conference issue) that examines how AI-based solutions are contributing to the transformation of agriculture. It examines the applications of artificial intelligence in agriculture, from predictive analytics and crop monitoring to automated equipment, and assesses their potential to increase yields, resource efficiency, and decision–making[6]. The document identifies current trends in the introduction of artificial intelligence, barriers for small farmers, and recommends strategies for integrating AI innovations into agricultural development plans to ensure inclusive growth.

6. A comprehensive book that examines the role of agricultural information dissemination services in the transformation and development of agriculture. It provides a global overview and case studies by country on how information dissemination and advisory services help farmers innovate [7]. Key topics include improving the productivity and livelihoods of smallholder farmers, creating inclusive rural knowledge systems, and expanding and modernizing approaches. The book highlights best practices and challenges in making the expansion an effective catalyst for sustainable agricultural innovation and regional agricultural development.

A research monograph on the transition of EU agriculture to sustainable development and low-carbon technologies [8]. It analyses the role of renewable energy sources and green innovations in reducing the carbon footprint of agriculture, explores the development of a bio-based economy, and examines EU policies and frameworks for sustainable agriculture. The book examines climate change mitigation strategies in agriculture, such as precision farming, bioenergy, and carbon farming, and assesses their impact on regional rural development and farm competitiveness in Europe.

Despite government support, including financing of the sowing campaign of 580 billion tenge, many farmers express doubts about the sufficiency of these measures. The lack of clear compensation mechanisms, problems with the allocation of subsidies, and a shortage of credit resources can exacerbate economic instability in the agricultural sector.

Environmental experts point out that the floods have caused not only direct damage to agriculture, but also a threat to the environment. The erosion of cattle burial grounds, as well as the ingress of household waste and chemicals into the water, can lead to the spread of infections and soil contamination. It is necessary to conduct a comprehensive analysis of water and land pollution, as well as develop a national climate change adaptation plan. The absence of such measures may result in additional economic losses.

Over the past three decades, flood damage in Kazakhstan has increased substantially. If in 1993 the country faced losses of $60 million, then in 2024 this figure, according to experts, reached a record amount of $444 million. This indicates an increase in the frequency and intensity of natural disasters, as well as the need to strengthen the prevention and response system. Key natural disasters, such as the collapse of the Kizilagash dam in 2010, have highlighted the vulnerability of the infrastructure. This incident has become not only an economic, but also a humanitarian tragedy.

The direct damage amounted to $40 million, and more than 300 people were injured. Such cases require increased measures to protect critical facilities.

The floods of 2024 caused large-scale evacuations of the population. More than 111 thousand people were rescued, including 39 thousand children. Emergencies affected eight regions of the country, which led to significant social costs associated with the placement of people, the restoration of housing and assistance to victims.

More than 33,000 rescuers and over 4,000 pieces of equipment are involved in flood relief. This underlines the importance of organising the effective work of civil defence services. However, the scale of the consequences shows that existing resources are insufficient to prevent such significant losses. The increase in damage from natural disasters indicates the need to review natural risk management strategies. The introduction of modern monitoring technologies, the construction of protective structures and the implementation of preventive measures can significantly reduce the effects of floods.

The results and their discussion

Kazakhstan has diverse climatic conditions and geographical features, which directly affect the development of the agro-industrial complex in different regions of the country. Each region has its own strengths and weaknesses, which must be taken into account when planning modernisation and investing in agriculture.

Economic challenges:

- Low labour productivity: Poor technological equipment and a low level of innovation limit the opportunities for productivity improvement.

- Lack of investment: Limited access to financial resources hinders modernisation and the introduction of new technologies.

- Risks of global instability: Fluctuations in prices for agricultural products on world markets and inflationary processes in the national economy put pressure on the agro-industrial sector.

Climate change:

- Reduced yields: Changes in temperature conditions, increased droughts and natural disasters lead to a decrease in agricultural production.

- Soil degradation: Accelerated erosion and declining fertility threaten sustainable crop production.

- The need for adaptation: The need to develop climate-resistant agricultural technologies and plant varieties.

Infrastructure and personnel:

- Deterioration of the infrastructure for storage, transportation and processing of products.

- Shortage of qualified specialists in the field of agricultural technologies.

Results and their discussion.

The development of the agro-industrial complex in Kazakhstan differs depending on the geographical location and climatic conditions. The highest rates of agricultural production are typical for such regions as North Kazakhstan, Akmola and Pavlodar regions, where grain production prevails, as well as livestock and oilseed crops are developing. In the southern regions, such as Zhambyl and South Kazakhstan, the emphasis is on growing vegetables, fruits, and livestock. The eastern regions of the country, such as the East Kazakhstan region, are known for developed dairy farming and the processing of agricultural products. In turn, areas such as Atyrau and Mangystau regions face more serious problems due to dry climatic conditions and underdeveloped agriculture, despite the availability of natural resources.

- Identifying the strengths and weaknesses of each region. Northern regions: strengths include favorable climatic conditions for growing grain and industrial crops, as well as well-developed infrastructure. The weak side lies in the seasonal dependence of production and the limited development of animal husbandry. Southern and southeastern regions: the strong point is the possibility of year-round production of fruit and vegetable products, as well as the availability of traditional farming skills. However, the weak side is the high dependence on water resources and the intensive use of chemical fertilisers. Western regions: the strengths are the availability of

natural resources and opportunities for the development of agro ecological agriculture, the weaknesses are the lack of investment in agricultural technology and poor soils.

- Global trends and innovations in agriculture. In recent years, the agro-industrial complex has been undergoing significant changes related to the introduction of innovative technologies. These changes cover both digitalization and the use of biotechnologies and renewable energy sources, which significantly improve the efficiency and sustainability of agriculture.

- Digitalization of agriculture is becoming a key trend to increase productivity, reduce costs and improve agricultural management. Application of IoT, big data, and artificial intelligence

The Internet of Things (IoT) technologies are being actively introduced in agriculture, which make it possible to create smart farms with connected sensors, monitoring soil conditions, weather conditions and plant health. Big data and artificial intelligence (AI) are utilised to process and analyse this data, enabling the prediction of yields, optimisation of resource use, and informed decision-making. For example, AI-based systems can analyze images from drones to diagnose plant diseases, predict potential threats, and calculate the optimal time for harvesting.

Precision farming uses data gathered from GPS, satellites, and sensors to maximize the use of resources such as water, fertilizers, and pesticides. Precision farming systems can reduce costs, increase yields, and minimize environmental impacts. For example, the use of GPS technologies and automated tractors can improve the accuracy of sowing and harvesting operations.

This fundamental law establishes the legal, economic, and organisational framework for the state's support and regulation of agriculture and rural development in Kazakhstan. [9] It defines key concepts, the roles of government agencies, and measures to support the agro-industrial complex and farming communities. The law is at the heart of policies such as subsidies, rural lending, stimulating innovation, and infrastructure development, ensuring sustainable agricultural growth and improving rural living conditions in the country.

As outlined in the "Concept for the Development of the Agro-Industrial Complex of the Republic of Kazakhstan 2021-2030", a strategic program that sets out long-term goals and priorities for agricultural transformation in Kazakhstan until 2030, the aim is to improve agricultural production efficiency through exploiting national competitive advantages. This includes expanding export markets for Kazakhstani products, promoting organic farming, and increasing irrigated land area. Additionally, the concept aims to ensure sustainable development of the agricultural sector by considering various farm structures, enhancing rural infrastructure, and preserving the environment.

The concept defines the long-term goals of modernizing the agro-industrial complex, taking into account global climate change. It proposes measures to increase agricultural productivity and sustainability through the introduction of modern technologies. The document focuses on economic challenges such as market volatility and their impact on the industry. This strategic vision is aimed at ensuring food security and environmental stability [10]. The concept offers a comprehensive approach to modernizing the agro-industrial complex, taking into account the climate. It strengthens the strategy of adapting the industry to economic and environmental conditions.

The national project focuses on short-term measures to modernize agriculture in the face of climate change. It provides for investments in infrastructure and technology to increase resilience to environmental threats. The project also takes into account economic challenges such as rising costs and the need for exports. This contributes to the creation of a flexible strategy for the development of the industry in difficult conditions [11]. The project provides a practical basis for modernizing the agro-industrial complex, taking into account the climate. It promotes rapid adaptation to economic difficulties.

Modern approaches in agronomy make active use of data to predict plant growth, optimize crop rotation patterns, analyze soil quality, and address issues related to diseases and pests. Agronomic monitoring platforms collect data from sensors and satellites to provide farmers with tailored advice on crop management and process optimization.

Kazakhstan has diverse climatic conditions and geographical features, which, in turn, directly affect the development of the agro-industrial complex across different regions. It should be emphasized that each region demonstrates its own strengths and weaknesses, which, therefore, must be carefully considered when planning processes of modernization and investment.

Economic challenges remain particularly acute. Thus, low labor productivity continues to limit efficiency, as the level of technological equipment is insufficient and the pace of innovation remains slow. In addition, the lack of investment, caused by restricted access to financial resources, significantly hinders modernization. Moreover, global instability risks — including fluctuations in world market prices for agricultural products as well as inflationary pressures within the national economy — put serious pressure on competitiveness.

Climate change impacts have become increasingly evident. Reduced yields are observed due to more frequent droughts, floods, and temperature fluctuations, which negatively affect productivity. Equally important is the fact that soil degradation, expressed through accelerated erosion and loss of fertility, undermines the long-term sustainability of farming. Consequently, there arises an urgent need for adaptation, including the introduction of climate-resistant crop varieties and the implementation of innovative agricultural technologies.

Infrastructure and personnel problems also remain unresolved. The deterioration of storage, transportation, and processing facilities complicates the efficiency of agricultural supply chains. At the same time, a shortage of qualified specialists in agricultural technology and management further limits the sector's ability to modernize.

Nevertheless, positive digitalization trends can be observed. The introduction of modern IT solutions has reached 60% by 2024, reflecting the sector's gradual shift toward digital transformation. Furthermore, the number of startups in the agro-industrial sector increased from 50 in 2022 to 100 in 2024, which clearly illustrates the growing innovative potential. Similarly, investments in agriculture rose from 2.1 to 3.0 billion USD over 2022–2024. As a result, positive effects became visible in the growth of gross harvests, which increased from 17.5 to 19.0 million tons.

On the other hand, the consequences of natural disasters have created serious setbacks. The spring floods of 2024 caused large-scale damage: more than 8,000 cattle were lost, over 22,000 applications for compensation were submitted, and direct economic damage exceeded 444 million USD. In addition, 111,000 people, including 39,000 children, were evacuated. The destruction of agricultural machinery, seeds, and fuel reserves has significantly reduced readiness for the sowing campaign. Moreover, erosion of pastures and the spread of poisonous weeds increased production costs and lowered yields.

Equally alarming are environmental risks. Soil and water contamination, resulting from the erosion of cattle burial sites and the spread of household waste, threatens to provoke infectious diseases and long-term land degradation.

Finally, export potential risks should not be overlooked. A decline in grain and oilseed production reduces Kazakhstan's ability to maintain stable positions in global markets. At the same time, domestic food price increases may arise from shortages of certain crops, thereby contributing to inflationary pressures and directly affecting consumer welfare.

Nussipali R., Asilyan L.V., Grigoryan A.G. in their research analyzes "the transformation of the agro-industrial complex of Kazakhstan in the context of climatic and economic changes. The authors emphasize the need to introduce innovations to increase the efficiency and sustainability of the industry. The work examines the impact of global warming on production and ways to mitigate it. This supports a modernization strategy focused on environmental and economic realities" [12]. The transformation of the agro-industrial complex requires consideration of climatic factors for modernization. The study confirms the importance of innovation in addressing economic challenges. Various solutions are being considered, ranging from breeding new varieties that are more resistant to drought and changing the composition of crops, to improving water and soil management. It is noted that successful adaptation requires

comprehensive action at all levels (local, regional, national), as well as the removal of obstacles (such as lack of investment and knowledge) to implementing these measures.

Grigorieva E., Livenets A. and Stelmakh E. in their research presents "an overview of methods of adaptation of agriculture to climate change applicable to the agro-industrial complex of Kazakhstan. The authors discuss the impact of extreme weather conditions on production and propose technological solutions. The work highlights the economic consequences of climate change for the industry"[13]. This contributes to the development of a modernization strategy that takes into account environmental risks. The analysis confirms the need for the agro-industrial complex to adapt to the climate to modernize it. He emphasizes the connection between environmental and economic aspects.

Abdulkerimov, I., Ramazanova, A., and Saralinova, J. In his research, he examines the role of green investments in modernising Kazakhstan's agro-industrial complex. The authors note that such investments increase resilience to climate change and reduce costs. The work highlights the economic benefits of environmentally-oriented projects. This strengthens the industry's development strategy in the face of modern challenges [14]. Green investments are a key tool for modernizing the agro-industrial complex. They provide a balance between ecology and economics.

Baisholanov S.S., in his monograph analyzes the vulnerability of agriculture in Kazakhstan to climate change. The author suggests adaptation measures, including technology modernization and resource management. The work highlights the economic risks associated with climate and ways to minimize them. This creates the basis for the strategic renewal of the agro-industrial complex [14]. Consideration of climate vulnerability is necessary for the modernization of agriculture. The monograph substantiates adaptation as part of an economic strategy.

Modernizing Kazakhstan's agricultural industry requires an integrated approach to improving agricultural productivity, sustainability, and innovation. Considering modern challenges such as climate change and economic instability, as well as the need to increase competitiveness, modernization strategies should cover several key areas and utilize various implementation tools.

Improving the productivity and quality of agricultural products is essential for the success of any modernization efforts. This includes investing in research and development, implementing new technologies, and providing training for farmers and agricultural workers. By addressing these challenges, Kazakhstan can continue to grow and prosper in the face of changing climates and market conditions. One of the main goals of modernization in agriculture is to increase productivity and improve the quality of products. This can be accomplished through the introduction of new technologies, such as precision farming and process automation. Additionally, the use of genetically modified plant varieties and disease-resistant animal breeds can help to achieve these goals. The Food and Agriculture Organization of the United Nations strategy offers global approaches to adaptation of agriculture to climate change, applicable to Kazakhstan. The document focuses on the sustainable development of agriculture through innovation and resource conservation [15]. It takes into account economic challenges such as market instability and their impact on the industry. This serves as a guideline for modernizing the agro-industrial complex in the context of global changes. The strategy supports the modernization of agriculture, taking into account the climate. It offers solutions to overcome economic difficulties.

The use of modern OT solutions for monitoring agricultural production. Development of platforms for information exchange between farmers (Table 1).

Table 1 - Application of modern IT solutions for monitoring agricultural production by year (2022-2024)

Parameters	2022	2023	2024
Gross harvest (million tons)	17,5	18,2	19,0
Investments in agriculture (million $)	2,1	2,5	3,0
Technology adoption rate (%)	30	45	60

Number of new startups in the agro-industrial complex	50	75	100
Note: Compiled by the authors			

Table 1 clearly demonstrates the positive dynamics of digital transformation in Kazakhstan's agro-industrial sector. Thus, the gross harvest has been steadily increasing, rising from 17.5 million tons in 2022 to 19.0 million tons in 2024, which indicates gradual productivity improvements. Moreover, the growth of investments in agriculture, which expanded from 2.1 to 3.0 billion USD over the same period, reflects both state support and growing interest from private capital.

At the same time, the adoption rate of modern technologies shows even more striking progress: from only 30% in 2022, the figure reached 60% by 2024. This suggests that digitalization is becoming not just a supplementary tool but an integral part of production processes. Furthermore, the number of new startups in the agro-industrial complex doubled in just two years, increasing from 50 to 100. This dynamic may be interpreted as evidence of favorable conditions for innovation and the gradual formation of an entrepreneurial ecosystem in agriculture.

In general, the presented indicators confirm the hypothesis that the modernization of the agro-industrial complex in Kazakhstan is closely linked to digital transformation, investment attraction, and structural diversification. However, it should be emphasized that the quantitative growth of indicators still requires qualitative consolidation — for example, ensuring stable efficiency gains, expanding access to advanced technologies for small and medium-sized farms, and strengthening regional equity in modernization processes.

It is also important to develop domestic processing techniques to create added value for products and improve export opportunities. Conservation of natural resources and adaptation to climate change are also essential aspects of this process.

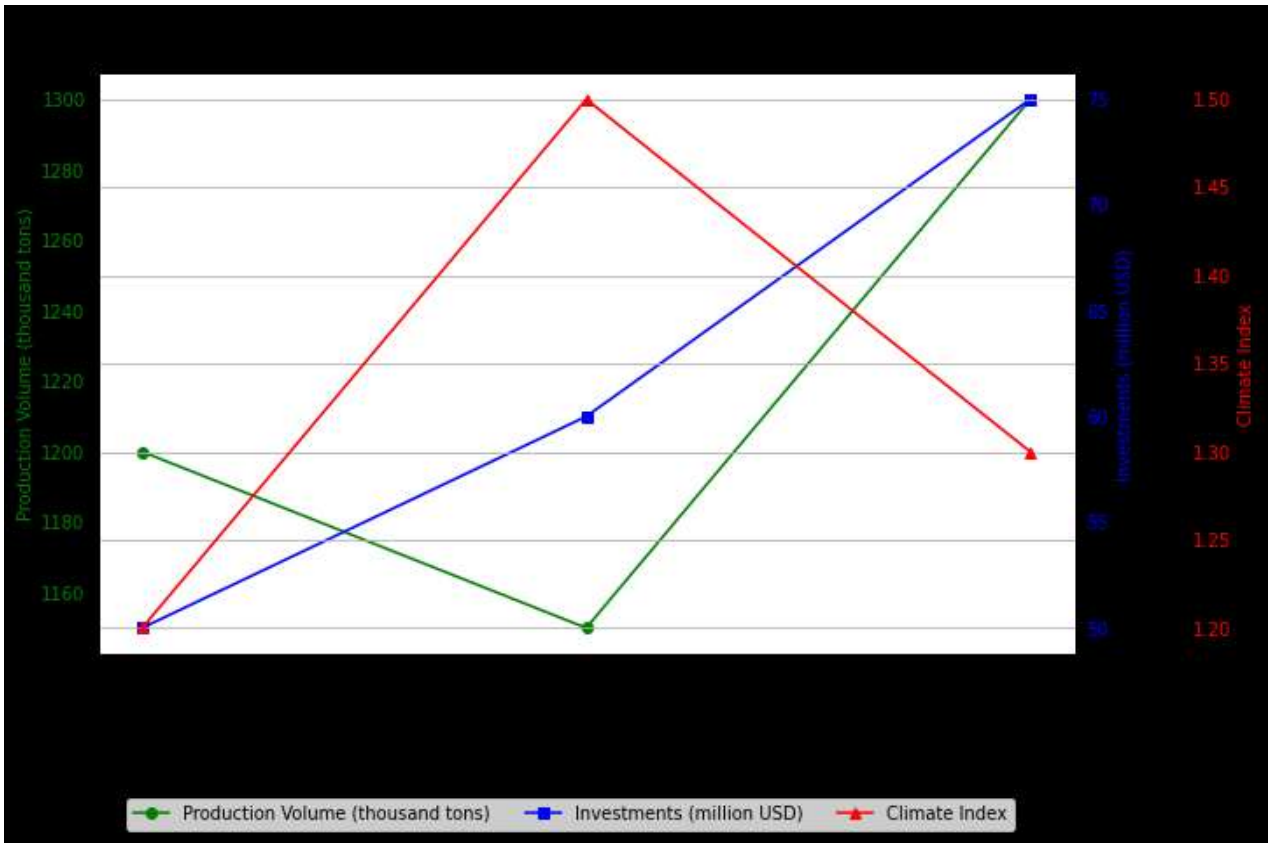

Figure 1 - Analysis of AIC Modernization (2022–2024) in the Context of Climate Change and Economic Challenges.

Note: Compiled by the authors.

This figure illustrates the relationship between production indicators, investment flows, and climate risks in Kazakhstan's agro-industry over the period 2020-2022. Despite a decrease in production volume in 2021 due to unfavorable climatic conditions (from 1,200 to 1,150 thousand tons), steady growth in investments (from $50 million to $75 million) laid the groundwork for recovery in 2022 when production increased to 1,300 thousand tons.

The climate index, which peaked at 1.5 in 2021, highlights the vulnerability of agriculture to external risks, but subsequent improvements demonstrate the beneficial impact of technological and financial modernization.

Adaptation to climate change and efficient use of natural resources, such as land, water, and biodiversity, requires the introduction of sustainable agricultural technologies. These include resource-efficient irrigation methods and improved soil quality through the use of organic fertilizers and biological plant protection. It is also crucial to develop water management technologies, especially in arid regions like Kazakhstan, where water is a limiting factor for agriculture.

For sustainable growth, it is essential to promote the development of the agro-industrial complex as a whole, including the processing of agricultural products, logistics, and the creation of modern storage and transportation infrastructure. Currently, only about 25% of agricultural products in Kazakhstan are processed, while in developed countries this figure reaches 70-80%. By increasing the share of processing to at least 50% by 2030, Kazakhstan could add more than $3 billion annually to its agricultural GDP. The development of agricultural parks and clusters would integrate various stages of production and increase efficiency by 15-20% across the industry.

Another important area is the support for small and family farms, which form the backbone of Kazakhstan's rural economy and account for over 60% of all agricultural producers. Currently, approximately 45% of rural households lack access to preferential financing, and only one in five small farms are involved in modern supply chains.

Expanding access to affordable credit, training programs, and improved logistics could boost small farm productivity by 30-40%, leading to increased agricultural diversification, enhanced food security, and the creation of up to 150,000 new rural jobs by 2030.

Government support is a crucial tool for modernizing the agricultural sector in Kazakhstan. In 2022, the country allocated 445 billion KZT in subsidies, which covered up to 25% of machinery purchases and 50% of seed costs. Farms that received these subsidies saw an increase in output of 12-15%.

The National Project for the Development of the Agro-Industrial Complex of Kazakhstan aims to modernize agriculture through various measures, including doubling agricultural exports and increasing the share of processed goods to 70%. By 2025, the project aims to increase labor productivity by 2.5 times and ensure 100% domestic food security.

To achieve these goals, we have planned over 900 investment projects in seven priority sectors: meat, milk, grains, fruits, vegetables, sugar, and oilseeds. These projects will involve up to 350,000 farms and small and medium-sized enterprises (SMEs) in the value chain. This will create approximately 500,000 new jobs and increase the income of one million rural residents by 2025.

We must take regional differences into account when planning these projects. In southern and central Kazakhstan, only 40% of potential arable land is currently irrigated. This leads to a loss of up to 25% of crops during drought years. Investing in irrigation and water management could increase yields by 35-40%. In northern and eastern regions, average grain productivity is 12-14 centners per hectare, significantly lower than the OECD average of 30-35 centners/ha. However, modern technologies could double yields within 5-7 years.

Clusters and specialized production zones play a crucial role in the development of agriculture in Kazakhstan. For instance, a fruit production and processing cluster in South Kazakhstan could process up to 500,000 tons of fruit annually, significantly reducing post-harvest

losses which currently average between 20% and 25% to less than 10%. This would create tens of thousands of direct jobs and indirectly benefit the rural service sector.

In East Kazakhstan, a dairy and meat production cluster could increase milk production from 850,000 to 1.2 million tons annually by 2030. This would ensure the local processing of over 80% of raw milk and create additional jobs. Both these clusters would contribute to the economic growth and prosperity of Kazakhstan.A project to improve the irrigation system and introduce water-saving technologies is currently being implemented in the South Kazakhstan region. This project aims to improve agricultural conditions in the face of water scarcity by introducing drip irrigation and other modern water management techniques, as well as biotechnological solutions such as drought-resistant crop varieties. These measures are expected to significantly increase crop yields and reduce water consumption, making agriculture more resilient to changing climate conditions. This project demonstrates the potential of innovative solutions to help agriculture adapt to climate change.

The agricultural cluster in the Pavlodar region, including grain production, processing, and logistics, has seen steady growth. In 2023 alone, grain processing facilities in the area processed over 600,000 tons of grain, representing an 18% increase from 2021. Thanks to modern storage technologies, post-harvest losses were reduced from 12-14% to 6-7%, significantly improving efficiency.

The development of the logistics infrastructure has allowed the region to increase grain exports by 22% in the past three years, enhancing its competitiveness on foreign markets. This has been achieved through the establishment of modern plants, which have created more than 1,200 new jobs and provided stable employment in rural areas.

In East Kazakhstan, a large-scale dairy project is underway. The region currently produces over 900,000 tons of milk annually, accounting for nearly 15% of Kazakhstan's total milk output. This project aims to increase production by 25% over the next five years while improving product quality to international standards.

The establishment of processing facilities and modern distribution networks will create approximately 1,500 new jobs, boosting local economic growth. Farmers are benefiting from access to advanced feeding systems and veterinary services, which are helping them increase milk yields from 3,500 liters per cow per year to 5,000 liters. This not only improves productivity but also ensures profitability for farmers.

However, the shortage of skilled professionals remains a significant challenge. According to recent estimates, Kazakhstan faces an annual shortfall of over 5,000 professionals in the fields of agronomy, agricultural engineering, and farm management. Surveys have shown that only 35-40% of rural workers possess the skills necessary to operate modern agricultural equipment and utilize digital technologies. Unless there is systematic investment in vocational education and training, the gap between the available human resources and the demands of modern agriculture is likely to continue to grow.

Additionally, legislation lags behind technological advancements. While more than 200 farms in the country have started using drones and precision farming techniques, existing legal frameworks do not clearly define the use of aerial surveillance technologies or the handling of large data sets. Similarly, initiatives in the field of biotechnology are underutilized, as less than 5% of farms apply bio-based solutions due to ambiguous regulatory mechanisms.

Institutional fragmentation further complicates the process of modernization. According to analysis, at least 20-25% of agricultural projects experience delays due to poor coordination among the Ministry of Agriculture, local authorities, and research institutions. This lack of integrated strategies leads to the duplication of initiatives and the inefficient use of budget resources. In 2022 alone, overlapping regional and national programs resulted in an estimated 8 billion tenge of inefficient spending.

To address these issues, we recommend that government agencies work together to establish a more coordinated approach. They should identify common goals and objectives, share information and resources, and collaborate on projects that promote the modernization and

development of the agro-industry. This will help to create a more efficient and effective system that benefits all stakeholders involved.

- Develop and implement flexible and adapted legislation to take into account the new challenges and opportunities in agriculture, including support for innovation in biotechnology and water resources management.

- Strengthen cooperation between government agencies responsible for agricultural policy at the central and local levels.

- Provide more accessible forms of government support for farmers, such as subsidies for new technologies, preferential loans, and training programs.

For businesses:

- Invest in precision farming, biotechnology, and data-driven agriculture to increase productivity and competitiveness in foreign markets.

- Foster cooperation and the formation of agro-clusters to reduce costs, improve logistics, and create unified sales channels for smaller farmers.

- Focus on long-term investments in sustainable agriculture, taking into account the needs of climate change adaptation and long-term profitability.

For farmers:

- Actively participate in training and professional development programs to adapt to new technologies and effectively use innovations to increase yields and improve product quality.

- Cooperate with other farmers in cooperatives and agricultural clusters to pool resources for the effective implementation of new technologies and access government subsidies.

- Implement sustainable agricultural practices such as water-saving irrigation methods and organic farming to improve the environment and increase profitability.

In the long term, the agro-industrial complex of Kazakhstan has significant potential for development if modernization strategies are implemented. Through the introduction of innovative technologies, improvement of infrastructure, and promotion of sustainable agriculture, Kazakhstan can become a key player in the global food market.

The proposed strategies for modernization of the agro-industrial sector aim to achieve significant results, including increased productivity, attraction of investment, adaptation to climate change, and development of human resources. To successfully achieve these goals, an integrated approach is needed, including government support, infrastructure development, and the introduction of innovative technologies.

Table 2 - Presents forecasts for the main areas of modernization

Direction	Goals	Forecast for 5 years	Forecast for 10 years
Technological modernization	20% increase in productivity%	Increased efficiency by 35%	Automation of processes by 50%
Investment	Increase in funding by 15%	Attracting 10 large investors	Export increase by 25%
Climate adaptation	Reduction of crop losses by 10%	Increasing soil stability by 15%	Stabilization of the production level
Personnel development	Training of 5,000 specialists	Professional development by 30%	Increasing the number of scientific studies
Note: Compiled by the authors			

Analyzing the data on the modernization of the agricultural sector in Kazakhstan, several significant aspects stand out. First and foremost, the government has been actively collaborating with businesses to attract investments and finance innovative projects. This has led to the establishment of modern infrastructure, including logistics, processing, and storage facilities for agricultural products. The government has also provided support to farmers through subsidies, tax benefits and access to new technologies. Additionally, educational programs have been implemented to enhance the skills of agricultural professionals and introduce new techniques.

Despite the positive progress made in the modernization of Kazakhstan's agro-industrial complex, there are still several challenges and risks that need to be addressed. One of the most

significant issues is the lack of financial resources to implement programs. Another challenge is the slow adoption of innovative farming practices by farmers, largely due to a lack of skilled specialists and training opportunities. Additionally, the increasing impact of climate change necessitates continuous adjustments to development strategies and the implementation of resilient agricultural methods.

Long-term success in Kazakhstan's agriculture depends on effectively adapting to climate change, improving soil fertility, and managing water resources, as well as implementing environmentally friendly and resource-efficient production practices. These measures are crucial for achieving sustainable growth and enhancing the competitiveness of the industry. Sustainable agricultural development will depend on the pace and effectiveness of reforms in education, social welfare, and natural resource management. Modernization of the agro-industrial sector in Kazakhstan necessitates an integrated approach and collaboration among all parties involved to enhance the sector's competitiveness and improve the socio-economic conditions in rural areas.

These efforts will ensure long-term sustainable development and contribute to the overall prosperity of the country.

Conclusion

The modernization of the agro-industrial complex in Kazakhstan is crucial for ensuring food security, sustainable economic growth, and strengthening the country's position in international markets. Based on our analysis, we have drawn the following conclusions:

- The need for a comprehensive strategy: Successful modernization requires combining technological advancements with increased productivity, resource conservation, and adaptation to climate change. It is essential to take into account regional differences in the use of irrigation, water-saving techniques, and focus on improving grain yields and livestock production.

- The central role of innovation and digitalization in modernizing agriculture: Innovation and digital technologies are essential for the modernization of the agro-industry. These technologies can help increase efficiency, reduce costs, and enhance productivity. They also contribute to improved traceability and transparency in food production, which are crucial for ensuring food safety and quality.

For example, the introduction of precision farming, IoT, AI, and biotechnology has already demonstrated positive impacts on agriculture. Between 2022 and 2024, gross harvests increased from 17.5 million tons to 19 million tons, while technology adoption reached 60%. These statistics show that these technologies have been effective in boosting crop yields and enhancing efficiency.

Expanding the use of these technologies will further enhance agriculture's resilience to climate risks and improve its cost-effectiveness. Government support plays a crucial role in this process. Subsidies, preferential loans, tax incentives, and training programs are essential tools that can stimulate innovation in the agricultural sector. However, it is also necessary to improve the legislative framework in areas such as biotechnology, water resources, and environmental sustainability to accelerate modernization and ensure long-term success.

Despite the potential benefits of using new technologies in agriculture, some challenges and risks need to be carefully considered. For example, there are concerns about data privacy and security as well as potential misuse of AI. Additionally, there could be concerns about the impact on local economies and labor markets.

It is essential to balance the potential benefits with these risks and challenges when considering the use of new technologies. The floods of 2024 highlighted the vulnerability of agriculture to climate change and underscored the need for preventive measures and enhanced infrastructure. It is crucial to implement better risk management systems to protect our agricultural sector from future disasters.

Human capital development is crucial for the modernization of agriculture. The lack of skilled professionals in the fields of agricultural engineering, management, and digital technology is hindering progress. Expanding vocational training programs and establishing knowledge transfer centers in rural areas is essential for long-term transformation.

To enhance competitiveness, it is recommended that investments be increased in precision agriculture, biotechnology, and renewable energy. Government cooperation should be strengthened and legislation adapted to global technological advancements. Small and medium-sized farms should receive support through training, financial assistance, and integration into agricultural clusters.

Adaptation measures should be implemented to minimize losses due to climate change. This includes creating drought-resistant plant varieties and installing advanced irrigation systems. Future research opportunities exist in these areas.

Research should focus on quantifying the impact of climate change on agriculture, evaluating the effectiveness of digital tools for optimizing resources, and assessing the economic feasibility of large-scale biotechnological solutions.

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КЛИМАТТЫҢ ӨЗГЕРУІ ЖӘНЕ ЭКОНОМИКАЛЫҚ СЫН ҚАТЕРЛЕР ЖАҒДАЙЫНДА АГРОӨНЕРКӘСІПТІК КЕШЕНДІ ЖАҢҒЫРТУ СТРАТЕГИЯСЫНЫҢ НЕГІЗДЕРІ

Аңдатпа

Заманауи климаттық өзгерістер мен жаһандық экономикалық сын-қатерлер Қазақстанның агроөнеркәсіптік кешенін жаңғырту міндетін қойып отыр. Азық-түлікке әлемдік сұраныстың өсуі және экологиялық тәуекелдердің артуына байланысты ауыл шаруашылығының тұрақты дамуы стратегиялық маңызға ие болуда.

Зерттеудің мақсаты – климаттың өзгеруіне бейімделуге және экономикалық қиындықтарды жеңуге бағытталған агроөнеркәсіптік кешенді жаңғырту стратегиясының негізгі элементтерін анықтау. Зерттеу статистикалық деректерді, ғылыми жарияланымдарды және халықаралық тәжірибеден алынған табысты тәжірибелердің мысалдарын талдауға негізделген. Жұмыс аясында қазақстандық агроөнеркәсіптік кешеннің негізгі проблемалары, оның ішінде, топырақтың деградациясы, өнімділіктің төмендеуі, су тапшылығы және климаттық жағдайларға жоғары тәуелділік анықталды. Бұл ретте саланың дамуына әсер ететін ішкі және сыртқы факторлар, мысалы, әлемдік нарықтардағы бағаның тұрақсыздығы, қаржыландыруға қолжетімділіктің шектелуі, цифрлық трансформацияның қажеттілігі талданды.

Зерттеу нәтижелері модернизацияның тиімді стратегиясы келесі негізгі бағыттарды қамтуы керек екенін көрсетеді:

- Тұрақты технологияларды енгізу: дәлме - дәл егіншілік жүйелеріне көшу, энергия мен суды үнемдейтін технологияларды қолдану, органикалық ауыл шаруашылығын дамыту.
- Саланы цифрландыру: ауылшаруашылық өндірісін бақылау және басқару үшін платформалар құру, операциялардың дәлдігін арттыру үшін дрондарды, спутниктік деректерді және Заттар Интернетін пайдалану.
- Мемлекеттік қолдауды күшейту: экологиялық таза технологияларды, соның ішінде салықтық жеңілдіктер мен субсидияларды енгізетін фермерлер мен кәсіпорындарды ынталандыруды дамыту.
- Өңдеу және сақтау инфрақұрылымын дамыту, бұл дақылдардың шығынын азайтуды және экспорттық әлеуетті арттыруды қамтамасыз етеді.

Зерттеудің ғылыми жаңалығы технологиялық инновацияларды, климаттың өзгеруіне бейімделуді және экономикалық тұрақтылықты біріктіретін ауыл шаруашылығын жаңғыртудың кешенді тәсілін әзірлеуде жатыр.

Негізгі сөздер: агроөнеркәсіптік кешен, климаттың өзгеруі, экономикалық проблемалар, модернизация, тұрақты даму, нақты ауыл шаруашылығы, цифрландыру.

ОСНОВЫ СТРАТЕГИИ МОДЕРНИЗАЦИИ АГРОПРОМЫШЛЕННОГО КОМПЛЕКСА В УСЛОВИЯХ ИЗМЕНЕНИЯ КЛИМАТА И ЭКОНОМИЧЕСКИХ ВЫЗОВОВ

Аннотация

Современные климатические изменения и глобальные экономические вызовы ставят перед агропромышленным комплексом Казахстана задачу модернизации. В условиях растущего мирового спроса на продовольствие и возрастающих экологических рисков устойчивое развитие сельского хозяйства становится стратегически важным.

Целью исследования является выявление ключевых элементов стратегии модернизации агропромышленного комплекса, направленной на адаптацию к изменению климата и преодоление экономических вызовов.

Исследование основано на анализе статистических данных, научных публикаций и примеров успешных практик из международного опыта. В рамках работы были выявлены основные проблемы агропромышленного комплекса Казахстана, включая деградацию почв, снижение урожайности, дефицит воды и высокую зависимость от климатических условий. В то же время были проанализированы внутренние и внешние факторы, влияющие на развитие отрасли, такие как нестабильность цен на мировых рынках, ограниченный доступ к финансированию и необходимость цифровой трансформации.

Результаты исследования показывают, что эффективная стратегия модернизации должна включать следующие ключевые направления:

- Внедрение устойчивых технологий: переход к системам точного земледелия, использование энерго- и водосберегающих технологий, развитие органического сельского хозяйства.
- Цифровизация отрасли: создание платформ для мониторинга и управления сельскохозяйственным производством, использование беспилотных летательных аппаратов, спутниковых данных и Интернета вещей для повышения точности операций.
- Усиление государственной поддержки: разработка стимулов для фермеров и предприятий, внедряющих экологически чистые технологии, включая налоговые льготы и субсидии.
- Развитие инфраструктуры переработки и хранения, которая обеспечит снижение потерь урожая и увеличение экспортного потенциала.

Научная новизна исследования заключается в разработке комплексного подхода к модернизации сельского хозяйства, который сочетает в себе технологические инновации, адаптацию к изменению климата и экономическую устойчивость.

Ключевые слова: агропромышленный комплекс, изменение климата, экономические вызовы, модернизация, устойчивое развитие, точное земледелие, цифровизация.

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