АГРООНЕРКӘСІПТІК КЕШЕН ЭКОНОМИКАСЫ
ЭКОНОМИКА АГРОПРОМЫШЛЕННОГО КОМПЛЕКСА
ECONOMICS OF THE AGRO-INDUSTRIAL COMPLEX

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THE ROLE OF ARTIFICIAL INTELLIGENCE IN ADVANCING KAZAKHSTAN'S AGRICULTURAL INDUSTRY: INNOVATION AND ECONOMIC OPPORTUNITIES

Abstract

This study investigates the transformative potential of artificial intelligence (AI) in advancing Kazakhstan's agricultural industry, emphasizing its role in addressing persistent challenges and fostering economic opportunities. The research identifies critical factors influencing the adoption of AI technologies, including digital infrastructure readiness, technological awarenessand skills, access to financial resources, availability and quality of agricultural data, the legal and regulatory framework, integration with existing agricultural systems, public-private sector collaboration, and perception and cultural acceptance. Utilizing a mixed-methods approach, the study combines quantitative and qualitative data derived from surveys and expert interviews. A robust sample of 140 respondents was selected through multi-stage stratified sampling to ensure comprehensive representation. Additionally, expert assessments were employed to evaluate the weight and contextual relevance of each identified factor in Kazakhstan. The findings provide insights into two core hypotheses: first, the impact of perception and cultural acceptance on AI adoption, and second, whether access to financial resources constitutes the primary barrier to implementation. Results highlight both opportunities and obstacles, offering actionable recommendations for policymakers, agricultural enterprises, and technology providers. The study underscores the importance of fostering technological skills, enhancing data ecosystems, and promoting cross-sectoral collaboration to harness AI's potential in achieving sustainable agricultural growth and economic resilience in Kazakhstan.

Keywords: Agriculture Industry, Artificial Intelligence, Business Opportunity, Agricultural Innovation, Sustainable Farming, Technological Adoption, AI Implementation Barriers.

Introduction

The agricultural sector remains a cornerstone of Kazakhstan's economy, employing a significant portion of the population and contributing to national food security and export potential. However, the industry faces persistent challenges such as labor shortages, climate variability, inefficient resource use, and limited access to modern technology. In this context, the integration of Artificial Intelligence (AI) presents a timely and transformative solution. Globally, AI applications in agriculture—from precision farming and predictive analytics to automated machinery—are reshaping how food is produced, processed, and distributed. Yet, in Kazakhstan, the level of AI adoption remains uneven, hindered by infrastructural, financial, and educational barriers.

This article explores the role of AI in advancing innovation and unlocking economic opportunities in Kazakhstan's agricultural industry. The object of the research is the agricultural sector of Kazakhstan, while the subject is the integration and impact of AI technologies within this sector. The study aims to identify key drivers, barriers, and opportunities associated with AI adoption in agriculture. Specific objectives include analyzing current AI applications, assessing readiness levels, and proposing strategies to enhance adoption. The article is structured as follows: a review of

literature on AI in agriculture, methodology, analysis of findings, and policy and business recommendations aimed at sustainable, tech-enabled agricultural growth in Kazakhstan.

Methods and Materials

This study employed the expert factor evaluation method to identify and assess the key barriers to the implementation of Artificial Intelligence (AI) in Kazakhstan's agricultural sector. The expert method is widely used in applied research to obtain informed judgments on complex issues where statistical data may be limited or incomplete. The core objective was to determine both the weight (importance) and significance (extent of manifestation) of selected barriers to AI adoption, as evaluated by industry stakeholders.

To collect primary data, semi-structured interviews were conducted with 140 farmers and agricultural professionals from various regions of Kazakhstan. Respondents were selected using purposive sampling to ensure the inclusion of individuals with direct experience in agricultural production and decision-making processes.

Each expert was asked to evaluate eight predetermined criteria (barriers) based on two scales:

Weight (w): the perceived importance of the factor in the general context of AI adoption;

Significance (s): the degree to which the factor is currently manifested in Kazakhstan's agricultural environment.

The final score for each criterion was calculated by multiplying its weight and significance, providing a composite measure of practical impact.

To ensure validity and consistency of expert evaluations, statistical reliability measures were applied. Specifically, the coefficient of concordance (Kendall's W) was used to assess the degree of agreement among experts. A high concordance value indicated a strong consensus. Additionally, the dispersion index was calculated for each factor to evaluate the variability in expert responses, supporting the robustness of the findings.

Economic Factors Shaping AI Adoption in Agriculture

Artificial intelligence (AI) is increasingly recognized as a game-changer in agriculture, transforming the sector through advancements like machine learning, data analytics, and predictive modeling. These technologies have significantly improved efficiency, optimized resource allocation, and enabled precision farming to meet the growing need for sustainable agricultural practices [1]. In developing nations such as Kazakhstan, agriculture faces familiar challenges, including resource constraints, infrastructure shortcomings, and the necessity to transition from traditional to modern farming methods. The development of environmental culture through continuous ecological education is essential for achieving sustainable development and a "green transformation" of society. In this context, artificial intelligence plays a key role in agriculture by enabling the use of sustainable technologies, optimizing resource efficiency, and reducing environmental impact [2].

Globally, AI has demonstrated its capacity to boost agricultural productivity, minimize waste, manage risks, and streamline supply chains [3]. Kazakhstan offers a unique case for exploring these possibilities due to its expansive farmlands and agriculture's vital role in the national economy. To capitalize on these opportunities, the Kazakhstani government has taken steps to incorporate AI into the agricultural sector. These efforts include investments in advanced farming infrastructure, partnerships with private sector innovators, and pilot initiatives utilizing AI technologies in areas such as crop health monitoring, soil diagnostics, and pest management.

AI provides innovative solutions to critical agricultural issues in Kazakhstan, such as enhancing productivity in isolated and underserved areas. Tools like precision agriculture, weather forecasting models, and automated equipment can significantly increase yields while reducing reliance on manual labor. Furthermore, AI-powered systems improve decision-making by providing real-time data and actionable insights, which are crucial for managing climatic unpredictability and optimizing water and resource use in arid regions [4].

However, despite its potential, the adoption of AI in Kazakhstan's agricultural sector is slowed by several obstacles. Limited financial resources, inadequate digital infrastructure, and a shortage of skilled professionals are among the primary barriers to implementation [5]. Additionally, cultural resistance and concerns over the security and privacy of agricultural data add further complexity.

Many farmers and stakeholders express hesitation regarding the impact of AI on traditional practices and human-centered decision-making. Building trust and addressing these cultural concerns are essential to facilitating broader acceptance and successful adoption of AI.

This research explores the benefits and challenges associated with AI integration in Kazakhstan's agricultural industry. By examining the economic factors and contextual barriers, the study provides actionable insights for decision-makers and industry stakeholders. Ultimately, it sheds light on AI's transformative potential, offering scalable and effective solutions to address the current and future needs of Kazakhstan's agricultural sector.

Research Hypotheses

Grounded in an extensive review of the literature, this study seeks to evaluate key factors influencing the adoption of artificial intelligence (AI) in Kazakhstan's agricultural sector. Specifically, it examines how socio-cultural and economic conditions shape the integration of AI technologies. Drawing on existing research, two primary hypotheses have been formulated to guide the investigation.

The first hypothesis addresses the role of cultural and societal perceptions in determining AI adoption. While AI has the potential to transform agricultural practices, cultural acceptance and perceptions among farmers and stakeholders often serve as significant barriers. Thus, **Hypothesis 1** tests whether these socio-cultural factors hold a measurable influence:

- **H0**: Perception and cultural acceptance do not significantly influence the acceptance of AI in the agricultural industry.
- **H1**: Perception and cultural acceptance significantly influence the acceptance of AI in the agricultural industry.

The second hypothesis focuses on financial constraints as a potential barrier. Access to financial resources is often cited as a critical determinant of technology adoption, particularly in developing economies. This hypothesis evaluates whether such economic factors are a primary obstacle:

- **H0**: Access to financial resources is not the main barrier to AI adoption in the agricultural industry.
- **H1**: Access to financial resources is the main barrier to AI adoption in the agricultural industry.

These hypotheses provide a structured framework for understanding the dynamics of AI adoption. The findings aim to contribute to both theoretical discussions and practical solutions, offering insights to policymakers and industry leaders to promote sustainable agricultural growth in Kazakhstan.

Results and Discussion

Demographic Profile

As detailed in Table 1, this study included 140 respondents from Kazakhstan's agricultural sector, focusing on individuals directly involved in agricultural activities. The age distribution highlights that the majority of respondents fall within the 31–45 age group, representing 40.0% (n = 56) of the total sample. This is followed by the 46–60 age group at 27.1% (n = 38), with the 18–30 and 60+ groups constituting 24.3% (n = 34) and 8.6% (n = 12), respectively. This distribution reflects the active participation of middle-aged individuals in the agricultural sector, likely due to their experience and role in decision-making processes.

In terms of gender, the sample shows a male majority, with 60.7% (n = 85) being men and 39.3% (n = 55) being women. This aligns with traditional gender roles in Kazakhstan's agriculture, where men are more likely to engage in physically demanding tasks and management roles, while women often contribute to support functions.

The geographic distribution reveals a significant rural dominance, with 70.0% (n = 98) of respondents residing in rural areas and only 30.0% (n = 42) from urban regions. This heavy rural representation aligns with the study's focus on agriculture and ensures relevance to the challenges and opportunities faced by those living in rural settings, where agriculture remains a primary livelihood.

This demographic composition underscores the critical role of middle-aged rural men in shaping the adoption of AI technologies in agriculture. It also highlights the importance of addressing region-specific needs and fostering gender-inclusive policies to ensure equitable access to AI-driven innovations in Kazakhstan's agricultural sector.

Table 1. Demographic Profile of Respondents (N = 140)

Demographic Variable	Category	Frequency (N)	Percentage (%)
Age	18–30 years	34	24.3%
	31–45 years	56	40.0%
	46–60 years	38	27.1%
	60+ years	12	8.6%
Gender	Male	85	60.7%
	Female	55	39.3%
Living Region	Rural	98	70.0%
	Urban	42	30.0%

Source: Primary data collected through a structured survey

Results and Discussions

The analysis of the factors influencing AI adoption in Kazakhstan's agricultural sector, based on the weight (Table 2) and significance (Table 3) of various determinants, provides insightful results that merit discussion.

Table 2

factor	dispersion	concordation	mean	weight
Digital infrastructure readiness	0,62	0,93	4,3	4
Technological awareness and skills	2,25	0,73	3,6	3
Access to financial resources	1,76	0,79	3,8	3
Availability and quality of agricultural data	1,49	0,82	4,1	3
Legal and regulatory framework	2,09	0,75	4,1	3
Integration with existing agricultural systems	1,69	0,80	3,9	3
Public-private sector collaboration	1,82	0,78	3,7	3
Perception and cultural acceptance	2,69	0,67	2,9	2

Source: Done by author

Table 3

factor	dispersion	concordation	mean	significance
Digital infrastructure readiness	1,07	0,87	4,5	4
Technological awareness and skills	1,20	0,85	4,0	3
Access to financial resources	1,07	0,87	3,5	3
Availability and quality of agricultural data	1,07	0,87	4,5	4
Legal and regulatory framework	1,42	0,83	4,7	4
Integration with existing agricultural systems	1,25	0,85	4,6	4
Public-private sector collaboration	3,09	0,63	4,9	3
Perception and cultural acceptance	1,00	0,88	5,0	4

Source: Done by author

Digital Infrastructure Readiness and Legal and Regulatory Framework both scored the highest in weight (4) and significance (4-4.7). This suggests these factors are seen as pivotal for the successful adoption of AI in agriculture. The low dispersion (0.62 and 1.07) and high concordation (0.93 and 0.87) values in these categories reflect strong agreement among respondents regarding their importance. The critical role of infrastructure in enabling the application of AI technologies, such as

sensors and data platforms, highlights its fundamental position. Similarly, a robust legal framework ensures the regulated and secure deployment of these technologies.

Factors such as Technological Awareness and Skills, Access to Financial Resources, Integration with Existing Agricultural Systems, and Public-Private Sector Collaboration exhibited moderate weights (3) and significance (3.5–4.6). These factors underline the need for both technical expertise and financial support, as well as the importance of collaboration between sectors to ensure scalability. However, higher dispersion values (1.20–3.09) in some cases indicate varied perceptions about their criticality.

Perception and Cultural Acceptance consistently received the lowest scores in both weight (2) and significance (4). While this factor achieved the highest concordation (0.88), it was ranked lower due to a relatively lower mean (2.9 in weight and 5.0 in significance). This reflects that cultural and social attitudes, while important, are seen as less immediate barriers compared to structural and technical challenges.

The results highlight a clear prioritization of structural enablers such as infrastructure and regulatory systems over softer factors like cultural acceptance. This aligns with the idea that robust digital infrastructure is a prerequisite for AI deployment, as it directly supports the technologies involved, such as IoT devices and machine learning algorithms. The emphasis on legal frameworks underscores the need to mitigate risks like data privacy breaches and ensure trust among stakeholders.

Conversely, the lower weight attributed to Perception and Cultural Acceptance might be indicative of an underlying assumption that technical solutions can overcome cultural resistance. However, while this factor received the lowest weight, its significance ranking (5.0) underscores that social acceptance could still be a critical determinant in ensuring long-term success. It suggests that even if infrastructure and financial barriers are addressed, resistance to change among farmers and stakeholders may delay adoption.

The moderate performance of Public-Private Sector Collaboration reflects Kazakhstan's current policy initiatives, which emphasize partnerships for innovation. However, the high dispersion (3.09) highlights varying levels of confidence in the effectiveness of these collaborations.

The study also reveals some notable challenges. For instance, the relatively higher dispersion in Technological Awareness and Skills (2.25) and Legal and Regulatory Framework (2.09) suggests inconsistent levels of preparedness and confidence across different regions or groups in Kazakhstan.
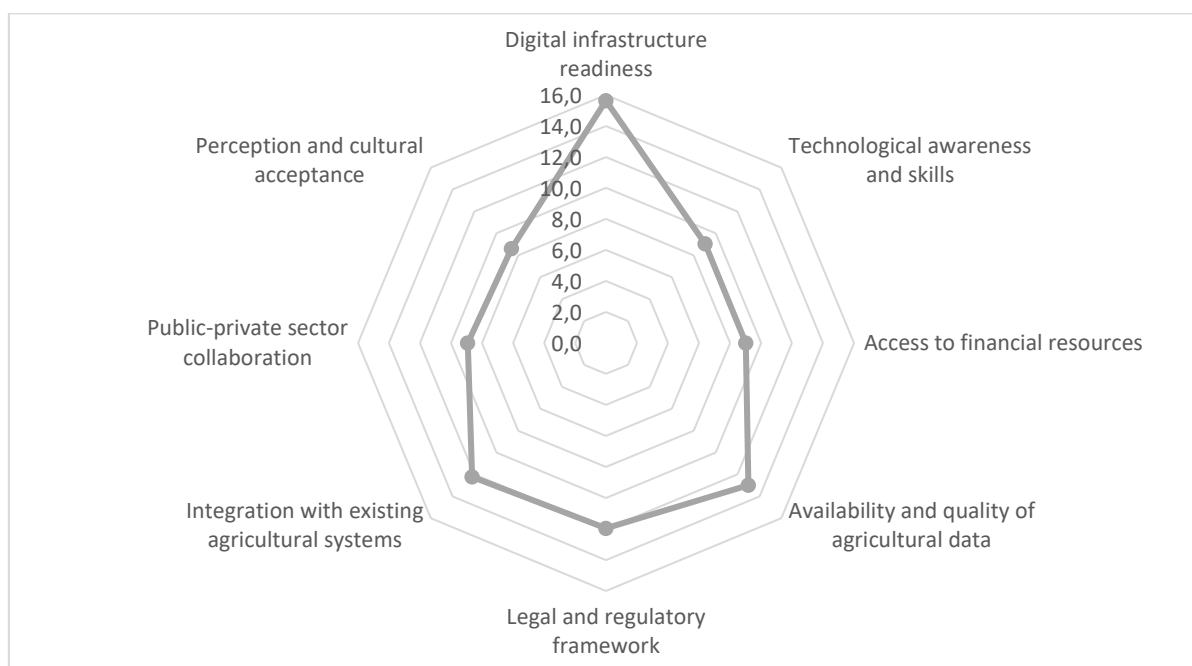

Figure 1 – Importance and Expression of Factors Influencing AI Adoption in Kazakhstan's Agricultural Sector

Figure 1 represents the importance and expression of various factors influencing AI adoption in Kazakhstan's agricultural sector. The radar chart was generated by calculating the composite scores of each factor, derived by multiplying the respective weight and significance values. These scores provide insights into the relative importance and expression of each factor within the agricultural context of Kazakhstan [6].

Digital infrastructure readiness scored the highest with a total of 16, emphasizing its critical role in AI adoption. The reliability of internet access, digital tools, and connectivity is foundational to implementing AI technologies in agriculture. Similarly, the availability and quality of agricultural data received a high score of 12, underscoring the importance of data-driven decision-making in precision farming. This factor enables predictive analytics and resource optimization, both of which are essential for improving productivity and sustainability.

The legal and regulatory framework also scored 12, reflecting the need for clear guidelines to foster trust and ensure compliance. Strong legal structures are essential for the secure and ethical use of AI. Integration with existing agricultural systems, which also scored 12, highlights the necessity for AI solutions to complement traditional farming practices. Farmers are more likely to adopt AI technologies when they seamlessly integrate with established methods.

Technological awareness and skills scored moderately at 9, indicating the need for capacity-building initiatives to enhance the technological competence of farmers and agricultural workers. A similar score of 9 was recorded for access to financial resources, pointing to the financial barriers many farmers face when adopting AI technologies. Efforts to provide subsidies, grants, or low-interest loans could help address this challenge, particularly for smallholder farmers. Public-private sector collaboration also scored 9, indicating the importance of partnerships in pooling resources and driving innovation. Although some efforts are in place, there is significant potential to strengthen these collaborations further.

Perception and cultural acceptance recorded the lowest score of 8, reflecting cultural skepticism and resistance to change among certain groups of farmers. This suggests a need for targeted awareness campaigns and the dissemination of success stories to increase trust and acceptance of AI in agriculture [7].

Overall, the findings emphasize that digital infrastructure, agricultural data, and regulatory frameworks are the most critical areas for the successful adoption of AI. Conversely, the lower scores for cultural acceptance and technological skills highlight the need for focused efforts in education, outreach, and training. Addressing these factors systematically will enable Kazakhstan to maximize the benefits of AI technologies in its agricultural sector [8].

The findings presented in Figure 1 allow us to analyze and compare the results with the proposed hypotheses, determining whether each hypothesis is supported or rejected.

Hypothesis 1:

H0: Perception and cultural acceptance do not significantly influence the acceptance of AI in the agricultural industry.

H1: Perception and cultural acceptance significantly influence the acceptance of AI in the agricultural industry.

The results indicate that perception and cultural acceptance scored the lowest among all factors, with a total score of 8. This suggests that while cultural acceptance is an important factor, it does not appear to play a dominant role in influencing AI adoption in Kazakhstan's agricultural sector, at least in comparison to other factors like digital infrastructure or data availability. Therefore, Hypothesis 1 is rejected, as the findings support the null hypothesis that perception and cultural acceptance are not significantly influential.

Hypothesis 2:

H0: Access to financial resources is not the main barrier to AI adoption in the agricultural industry.

H1: Access to financial resources is the main barrier to AI adoption in the agricultural industry.

Access to financial resources scored moderately at 9, placing it behind digital infrastructure readiness, data quality, regulatory frameworks, and system integration. While financial constraints

are a relevant barrier, they are not the primary limitation to AI adoption, as indicated by their lower overall score. Therefore, Hypothesis 2 is rejected, as the findings support the null hypothesis that access to financial resources is not the main barrier to AI adoption

Conclusion

This study provides a comprehensive analysis of the factors influencing AI adoption in Kazakhstan's agricultural sector, presenting a nuanced understanding of the challenges and opportunities within this context. Based on the research results, the findings reveal that digital infrastructure readiness, the availability and quality of agricultural data, and legal and regulatory frameworks are the most critical factors determining the successful integration of AI technologies in agriculture. These findings align with existing literature, which highlights infrastructure and data quality as key enablers of AI adoption in various industries [9,10].

A noteworthy contribution of this research is its evaluation of perception and cultural acceptance, which scored the lowest among all factors. This challenges some studies that emphasize cultural acceptance as a primary barrier to AI adoption. Similarly, access to financial resources, often cited as a significant obstacle, was found to be less influential than previously assumed, further underscoring the sector-specific nuances of AI implementation in agriculture [1]. These findings provide a fresh perspective by emphasizing the relative importance of systemic and structural readiness over socio-cultural and financial concerns in Kazakhstan.

The scientific novelty of this research lies in its contextual specificity. By focusing on Kazakhstan's agricultural sector, the study contributes to the limited body of knowledge addressing AI adoption in agriculture within a post-Soviet, developing economy. Unlike studies conducted in more technologically advanced or resource-rich countries, this research provides a localized analysis that highlights unique challenges such as infrastructure deficiencies and gaps in data availability, which may not be as prominent in other contexts. The quantification of factors through a weight-significance matrix further enhances the methodological rigor and offers a replicable approach for future studies in similar contexts.

The practical implications of the study are significant. Policymakers and stakeholders in Kazakhstan's agricultural sector can leverage these findings to prioritize investments and interventions. For instance, enhancing digital infrastructure, ensuring high-quality and accessible agricultural data, and streamlining legal and regulatory frameworks should take precedence in national AI strategies. Moreover, the study underscores the need for targeted initiatives to address cultural skepticism and improve technological awareness, though these efforts should complement rather than overshadow foundational developments.

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ҚАЗАҚСТАННЫҢ АУЫЛ ШАРУАШЫЛЫҒЫН ДАМЫТУДА ЖАСАНДЫ ИНТЕЛЛЕКТІҢ РӨЛІ: ИННОВАЦИЯЛАР ЖӘНЕ ЭКОНОМИКАЛЫҚ МҮМКІНДІКТЕР

Аңдатпа

Бұл зерттеуде Қазақстанның ауыл шаруашылығын дамытудағы жасанды интеллектінің (ЖИ) түрлендіруші әлеуеті қарастырылады. Зерттеу ЖИ технологияларын енгізуге әсер ететін маңызды факторларды анықтайды: цифрлық инфрақұрылымның дайын болуы, технологиялық сауаттылық пен дағдылар, қаржылық ресурстарға қолжетімділік, ауыл шаруашылығы деректерінің қолжетімділігі мен сапасы, заңнамалық және нормативтік база, ауыл шаруашылығы жүйелерімен интеграция, мемлекет пен жеке сектор арасындағы ынтымақтастық, қабылдау мен мәдени бейімделу. Аралас әдіснаманы қолдана отырып, зерттеу сауалнамалар мен сарапшылармен сұхбат арқылы алынған сандық және сапалық деректерді біріктіреді. Көпсатылы стратификацияланған таңдау арқылы 140 респонденттен тұратын өкілді іріктеме қалыптастырылды. Сонымен қатар, әрбір фактордың маңыздылығы мен контекстік өзектілігін бағалау үшін сараптамалық бағалау жүргізілді. Зерттеу екі негізгі гипотезаны тексереді: біріншісі — қабылдау мен мәдени бейімделудің ЖИ енгізуге әсері, екіншісі — қаржылық ресурстарға қолжетімділік негізгі кедергі болып табыла ма. Нәтижелер мүмкіндіктер мен кедергілерді айқындап, саясаткерлерге, ауыл шаруашылығы кәсіпорындарына және технология жеткізушілерге арналған нақты ұсыныстар береді. Зерттеу технологиялық дағдыларды дамыту, деректер экожүйесін жетілдіру және салалық ынтымақтастықты нығайту арқылы ЖИ әлеуетін тиімді пайдаланудың маңыздылығын көрсетеді, бұл Қазақстандағы ауыл шаруашылығының тұрақты дамуына және экономикалық төзімділікке қол жеткізуге мүмкіндік береді.

Кілт сөздер: Ауыл шаруашылығы, Жасанды интеллект, Экономикалық мүмкіндік, Ауыл шаруашылығы инновациясы, Тұрақты егіншілік, Технологияны енгізу, ЖИ енгізуге кедергілер.

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РОЛЬ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА В РАЗВИТИИ СЕЛЬСКОГО ХОЗЯЙСТВА КАЗАХСТАНА: ИННОВАЦИИ И ЭКОНОМИЧЕСКИЕ ВОЗМОЖНОСТИ

Аннотация

В данном исследовании рассматривается трансформационный потенциал искусственного интеллекта (ИИ) в развитии сельского хозяйства Казахстана с акцентом на его роль в решении насущных проблем и создании экономических возможностей. Выявлены ключевые факторы, влияющие на внедрение ИИ-технологий, включая готовность цифровой инфраструктуры, технологическую осведомлённость и навыки, доступ к финансовым ресурсам, наличие и качество аграрных данных, правовую и нормативную базу, интеграцию с существующими сельскохозяйственными системами, сотрудничество государственного и частного секторов, а также восприятие и культурное принятие. Применяя смешанный метод исследования, были объединены количественные и качественные данные, полученные в результате опросов и интервью с экспертами. Была сформирована репрезентативная выборка из 140 респондентов с использованием многоступенчатого стратифицированного отбора. Также использовались экспертные оценки для определения значимости и контекстной релевантности каждого фактора. Результаты дают представление по двум основным гипотезам: первое — влияние восприятия и культурного принятия на внедрение ИИ, второе — является ли доступ к финансовым ресурсам основным барьером к реализации. Результаты подчеркивают как возможности, так и препятствия, предлагая практические рекомендации для политиков, сельскохозяйственных предприятий и поставщиков технологий. Исследование акцентирует внимание на важности развития технологических навыков, совершенствования экосистем данных и укрепления межсекторального взаимодействия для раскрытия потенциала ИИ в обеспечении устойчивого роста сельского хозяйства и экономической устойчивости Казахстана.

Ключевые слова: Сельское хозяйство, Искусственный интеллект, Экономические возможности, Аграрные инновации, Устойчивое земледелие, Внедрение технологий, Барьеры реализации ИИ.