Climate Adaptation Strategies or The Agricultural Sector in Transition Economies

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Abstract

This article examines the processes of climate adaptation in the agricultural sphere of countries with transition economies, with particular reference to Ukraine, in the context of the growing risk of climate change and the need to develop alternative models of more sustainable development. It shows that the processes of soil degradation, growing aridity, and the scarcity of water resources are increasingly affecting food security and the competitiveness of agricultural production. The purpose of the research is to assess the adaptive potential of the agricultural sector of Ukraine and identify the areas for its enhancement based on the experience of other countries with transition economies, such as Georgia, Azerbaijan, and Kazakhstan. The methodology of the research is based on the principles of the systemic and comparative analysis of the subject matter. The results obtained demonstrate that the impact of climate change on the agriculture sector in Ukraine is quite significant, making it extremely vulnerable and exposed. On the basis of the experience accumulated in the countries with developing economies, it can be stated that the problems identified can be overcome with the joint application of biotechnologies, digital technologies, and institutional measures. On the basis of the results obtained, it is suggested that an integrated model for adapting the agriculture sector in Ukraine to the effects of climate change be implemented, which would unite digital technologies, scientific potential, and joint efforts of the government and business organizations. This approach can be used as the basis for enhancing the climate resilience of the agriculture sector and developing new mechanisms for controlling the processes of adaptation, which can be implemented up to 2030.

Keywords: adaptation; strategy; climate change; agricultural sector; countries with economies in transition; digitalization; biotechnology; sustainable development

1. Introduction

One of the main challenges to agricultural production is climate change. Climate change affects crop yields, soil composition, and water balance, thus triggering a wide range of environmental and socioeconomic consequences. The impact of these changes is particularly negative on the socioeconomic stability of rural areas. The results of the study by the Intergovernmental Panel on Climate Change (2022) show that these trends are of great importance on a global and regional scale.Countries with emerging economies, such as Ukraine, Azerbaijan, Kazakhstan, and Georgia, are faced with a double-edged sword: on the one hand, the increase in risks associated with climate changes requires urgent adaptation; on the other hand, economic constraints, a lack of investment opportunities, and the failure to apply scientific approaches to economic policies hinder this adaptation process. Low- and middle-income countries are particularly vulnerable to the consequences of climate changes. The situation is particularly acute in Ukraine. According to estimates by the European Commission's Joint Research Centre (2025), more than 40% of arable land is already eroded, and water shortages are being exacerbated by rising temperatures and reduced precipitation. These conditions call for the formulation of climate adaptation strategies that incorporate analysis tools, digital monitoring tools, and effective management systems that can effectively

support proactive strategies. Consistent with the latest trends and recommendations from international environmental agreements, such as the European Green Deal, the UN's Sustainable Development Goals, and the Climate Agreement, Ukraine's agricultural policies should incorporate climate-resilient and innovative digital solutions not just for increasing productivity but also for making the agricultural industry less vulnerable to climate risks. In this regard, the formulation of a new climate-smart transformation of the agricultural industry based on the principles of sustainable development, innovation, and cooperation between science, government, and business is particularly significant. Adaptation strategies are not just for coping with climate risks but also for modernizing the socio-economic structure of the country while adhering to global environmental standards.

2. Objectives and tasks of the study

This study aims to assess the adaptive capacity of Ukraine's agricultural sector in the face of climate change and ensure its resilience through a comparative analysis with countries with economies in transition, such as Azerbaijan, Kazakhstan, and Georgia. Accordingly, the main objectives of the study are as follows:

– Analysis of global and regional climate risks associated with agricultural production, based on the FAO (2024); IPCC (2022); OECD-FAO (2024); OCR (2025);
– analysis of the situation and adaptation of the Ukrainian agricultural sector to climate change based on statistics provided by the State Statistics of Ukraine (2023), the Ukrainian Hydrometeorological Center (2023), the National Strategy for Adaptation to Climate Change until 2030 (Ministry of Environment, 2021);
– conducting a comparative analysis of adaptation models in transition economies (Georgia, Azerbaijan, Kazakhstan) in order to identify similarities and differences in political, technological and institutional adaptation models that can be adopted;
– creation of a comprehensive, unified integrated climate adaptation model for Ukraine's agricultural sector using new development models that are ready for climate change, combining digital technologies, scientific understanding, and institutional risk management models.

3. Materials and methods

The study uses methodological and comparative analytical approaches to analyze the adaptive potential of Ukraine's agricultural sector in the face of climate change and identify opportunities for strengthening it. The analysis draws on the experience of countries with transition economies—Azerbaijan, Kazakhstan, and Georgia.

3.1. Data sources

The study is based on the integration of information from key international and national institutions:

– FAO (2024) data on weather-related agricultural losses caused by natural disasters and models for climate-resilient agriculture;
– IPCC (2022) – climate change scenarios and their impact on crop yields and food security (RCP 4.5, RCP 8.5);
– OECD–FAO (2024) – forecasts for the development of the agricultural sector in transition economies;
– Joint Research Centre (JRC, 2025) – regional assessment of climate risks and land degradation in Ukraine;
– State Statistical Service of Ukraine (2023) – official data on the state of agricultural production;
– Ministry of Environmental Protection and Natural Resources of Ukraine (2021) National Strategy for Adaptation to Climate Change until 2030;
– Ukrainian Hydrometeorological Center (2023) Meteorological and Climate Indicators for Ukraine.

3.2. Research methods

A comparative analysis is used to compare climate risks, as well as political and technological approaches to adaptation in countries with economies in transition (Ukraine, Georgia, Azerbaijan and Kazakhstan).

Statistical analysis used to assess trends in crop yields, agricultural production structure and the extent of land degradation based on data from the State Statistics of Ukraine (2023), FAO (2024) and OECD-FAO (2024).

A content analysis of policy documents based on the National Strategy for Adaptation of Ukraine to Climate Change until 2030 (2021), as well as reports from the FAO, OECD, and OCR, was conducted to identify key areas of adaptation policy.

A SWOT analysis is used to systematize the strengths and weaknesses of Ukraine's adaptation policy, as well as external opportunities (investments, international projects) and threats (droughts, soil degradation, infrastructure damage).

3.3. Validity and limitations.

The methodological integration of international and national data ensured the objectivity of the assessment and allowed for the alignment of global scenarios (FAO, IPCC, OECD-FAO) with the regional characteristics of Ukraine (RCC, Ukrainian Hydrometeorological Center, State Statistics of Ukraine). The main limitation of the study is limited access to field observations in the southern regions of Ukraine due to ongoing military operations, which was partially offset by the use of satellite and statistical data from international sources.

4. Research Results

4.1. Global Trends in Climate Risks for the Agricultural Sector

FAO data for 2024 show that from 2007 to 2022, agriculture accounted for a whopping 23% of all global economic losses from natural disasters, 65% of which were from droughts. This creates a pressing need for science-based adaptation models that integrate economic instruments, digital technologies, and institutional relationships. In the context of the contemporary scientific discourse on adaptation, this phenomenon is viewed as a deep organizational and institutional transformation of agribusiness rather than a short-term reaction to climate risks. This suggests that water scarcity is still the dominant destabilizing factor of agricultural production. The organization states that the agricultural and food sectors are facing an "increasing threat of loss and damage" due to climate change, and more than a third of the world's countries have already recognized this risk in their Nationally Determined Contributions (NDCs). Thus, the phenomenon of climate shocks is perceived as a systemic component of the world economic process rather than a random event. In its Sixth Assessment Report (2022), the Intergovernmental Panel on Climate Change reports that agriculture is approaching the limits of adaptation in various parts of the world. This suggests that, despite the achievements of science and technology, there are areas where losses cannot be fully compensated for.

This has significant impacts, particularly on low- and middle-income countries, which may lose up to a quarter of their grain crops in the event of a 2°C increase in average temperatures, thus posing a direct threat to food security. According to the OECD/FAO joint forecast (2024) for 2033, the global agricultural and fishery products are expected to increase by approximately 14% due to technological advances in emerging economies; however, in the absence of a timely introduction of climate-neutral technologies, greenhouse gas emissions are expected to increase by 5-6%. This is a clear paradox in terms of economic growth and environmental sustainability, as economic growth continues to gain momentum, so do environmental pressures.

According to JRC (2025) estimates from the PESETA III project under the RCP 8.5 scenario, grain yields in Southern Europe could decline by 10–22% by the middle of the 21st century, while in Eastern

Europe, including Ukraine, climate risks are exacerbated by anthropogenic factors such as soil degradation, soil pollution and the destruction of irrigation infrastructure as a result of war. Climate risks are thus complex and interrelated, simultaneously affecting natural resources, economic productivity, and social stability in rural areas.

For countries with transition economies such as Ukraine, Kazakhstan, Azerbaijan and Georgia, the situation is exacerbated by insufficient investment, weak policy coordination and limited integration of scientific knowledge into decision-making processes. This reinforces the urgent need for science-based adaptation strategies that integrate economic instruments, digital technologies, and strong institutional ties. Today, researchers perceive adaptation not as a quick fix to climate change, but rather as a rethinking of the organization and management of agribusiness. Spikuluk and Shelenko (2024) emphasize that the transition to a European green transition framework cannot be limited to technical solutions alone. They argue that ensuring circularity, decarbonization, and digitalization of production requires effective collaboration between government, business, and science. Kifyak and Dubinsky (2024) support this position. In their work, they emphasize the importance of developing a flexible institutional architecture that promotes the harmonization of economic, environmental and social development goals.

These issues are also relevant at the international level. Kimo et al. (2025) demonstrate how the CCAFS Climate Analogue tool enables both forecasting future agroclimatic conditions and enabling local farmers to adapt to these changes. However, Sanz and Perea Blazquez (2025) note that AFOLU sectors lack effective global governance mechanisms, hindering the implementation of adaptation policies in developing countries. In our view, the findings verify that technology tools alone do not suffice to achieve systemic resilience. Even with methodologically sound climate analogs and forecast models, their effectiveness will not go very far without institutional coordination, financially viable models, and the inclusion of scientific data within national-level management decisions. Hence, the adaptation of the AFOLU sector should not only be considered from a technological perspective but, above all, from a managerial and institutional perspective that facilitates the transfer of scientific progress to real agricultural production systems.

Based on the scientific achievements achieved, three types of adaptation can be distinguished:

1. Institutional – creation of regulatory and political frameworks for the application of sustainable development principles;

2. Organizational and economic "use of technologies and digital management systems";

3. Social development of human potential capable of disseminating climate-friendly practices at the local level.

In the case of Ukraine, adapting to climate change represents a double challenge, both ecological and economic. It appears that the synergy between scientific prediction, digital modeling of risks, and the development of human capital represents the essential base of a new management paradigm where the resilience to climate change represents a new indicator of the effectiveness of policies.

4.2. Climate risks and consequences for the agricultural sector of Ukraine

The analysis confirmed that Ukraine represents one of the countries which face the highest risks of climate change. The JRC report on the 2025 scenarios underlines that "in the last three decades, the average temperature rose by 1.3–1.5°C. Steppe areas receive 15–25% less precipitation. Looking to the future under the RCP 4.5–8.5 scenarios, we expect that by 2030, the shortage of moisture might affect over 40% of the southern steppe."

The ICOSG NAAS field observations (Shabatura et al., 2025) underlined that "yields losses in the southern regions exceed 20% for wheat and even 25% for maize, with over 13.5 million ha of arable land deteriorating." Irrigation area has been reduced by nearly 40%, leading to a significant loss of adaptive resources in the region following the destruction of the Kakhovka Hydroelectric Power Plant. Economic

calculations using the OECD–FAO (2024) methodology show that without modernization of water infrastructure, annual losses to the agricultural sector could reach US$3.5 billion due to drought.

4.3. Responses to adaptation models in Georgia, Azerbaijan and Kazakhstan: regional findings

In Georgia, biotechnologies coexist with traditional approaches to land management. Geladze (2024) points out that FAO programs to revive local wheat varieties play an essential role in maintaining genetic diversity and improving the protection of crops against drought and heat. The modernization of breeding and the use of precision agriculture have helped to increase yields by 12-15 percent and reduce the use of fertilizers (Ujmaguridze, 2025). The FAO-EU working group in Georgia (2025) supports the use of biotechnology and financial incentives. Agrarian reform is directly related to economic growth, as indicated by Tsopurashvili (2023), where agricultural GDP growth has reached 5 percent.

In Azerbaijan, the emphasis is on the improvement of the genetics of plants for better adaptation, as well as digital management systems. Walieva and Huseynova (2024) show the role of molecular genetic technologies in the development of drought-tolerant wheat varieties. The State Strategy (2025) of the Ministry of Agriculture of Azerbaijan ranks the adaptation of the farm sector in the liberated lands by 2030 at the top. According to the State Strategy (2025) of the Ministry of Agriculture of Azerbaijan, the adaptation of the farm sector in the liberated lands by 2030 ranks first. Salaev (2023) states that digitalization really drives the agricultural economy, and Alvarez (2025) confirms this, stating that the application of climate technologies reduces crop losses by 10-12%.

For example, in Kazakhstan, as demonstrated by the research of Karabasov et al. (2022), the Organic Agriculture and Digital Irrigation 2030 program was gradually developed based on the increasing challenges faced by the agricultural sector regarding water supply and sustainability of agricultural production. Today, this program already covers more than 25% of irrigated land, which not only speaks of the scale of the program's implementation but also of the agricultural sector's interest in the implementation of digital technologies. The implementation of this program has already led to a decline in water losses by a fifth of the total volume and has resulted in an increase in crop yields on average by 14%, thus demonstrating the effectiveness of this program. This is a great example of how a digital program can offer not only economic benefits but also environmental ones, thus demonstrating that digitalization is not only a way to increase crop yields but also a way to make agriculture more resistant to changes in the climate. Summarizing regional experience allows us to systematize the main climate challenges and adaptation strategies in transition economies. For clarity, comparative results are presented in Table 1.

Table 1. Key climate challenges and adaptation strategies in transition economies

Country	Main climate risks	Key adaptation directions	Examples of initiatives
Ukraine	Droughts, soil degradation, water scarcity	Digital modeling, smart irrigation, biotechnology	DigitalAgro, Copernicus, Climate Hub NAAS
Georgia	Changing precipitation patterns, soil erosion	Conservation of local crop varieties, biotechnology	FAO Local Wheat Programme
Azerbaijan	Aridity, declining soil fertility	Molecular breeding, digital	Azerbaijan Climate Data Platform

Country	**Main climate risks**	Key areas of adaptation.	Examples of initiatives.
			monitoring platforms
Ukraine	Droughts, soil degradation, water scarcity.	Digital modeling, smart irrigation, biotechnology.	DigitalAgro, Copernicus, NAAS Climate Center.
Georgia	Changes in precipitation, soil erosion.	Preservation of local crop varieties, biotechnology.	FAO local wheat program.
Azerbaijan	Aridity, decline in soil fertility.	Molecular selection, digital monitoring platforms.	Azerbaijan Climate Data Platform.
Kazakhstan	Aridization, water deficit.	Digital irrigation 2030, organic farming.	Smart Farming Kazakhstan

Sources: Compiled by the author based on FAO (2024); OECD-FAO (2024); JRC (2025); Kimo et al. (2025); Dzeladze (2024); FAO-EU Task Force Georgia (2025); Valiyeva & Huseynova (2024); Salayev (2023).

4.4. Comparative analysis and the role of Ukraine

A comparative analysis with Georgia, Azerbaijan and Kazakhstan shows that Ukraine has the most developed scientific and institutional base (the Institute of Climate-Oriented Agriculture of the National Academy of Sciences of Ukraine, the Ukrainian Hydrometeorological Center, the Institute of Soil Science), but it suffered the greatest environmental losses as a result of the war (Shabatura et al., 2025). The Ukrainian agricultural model is characterized by a consistent and integrated approach: climate modeling (Euro CORDEX, RCP 4.5–8.5), data analysis and phytoremediation technologies complement each other and together form the basis of climate-smart agriculture.

The use of digital risk management platforms – AI models, satellite imagery, and IoT sensors – enables the development of a unified adaptive monitoring system that can be applied at the regional level across Eastern Europe.

4.5. Synthesis of Results: Integrated Adaptation Model

This paves the way for Ukraine to establish regional climate expertise centers. A comparative analysis shows that successful adaptation to climate change in the agricultural sector requires the integration of technological, institutional, and scientific solutions into a unified risk management model. Based on the results of this study, we consider an integrated adaptation model that combines three key elements – biotechnology, digital technology, and the institutional-organizational side. Their synergy can support the development of mechanisms for enhancing the climate resilience of agricultural systems in countries with

transition economies. The structure of an integrated climate adaptation model for the agricultural sector is presented in Table 2, which includes the main components, objectives, implementation tools, and expected results.

Table 2. Integrated model of climate adaptation for Ukraine's agricultural sector

Model component	Objective	Implementation tools	Expected outcomes
Biotechnological	Enhance crop resilience and soil fertility	Drought-resistant varieties, phytotechnologies, modernized seed systems	Reduced yield losses, increased biodiversity and productivity
Digital-technological	Improve forecasting and climate-risk management	IoT sensors, satellite monitoring, AI-based analytics	Efficient water management and climate-resilient planning
Institutional-organizational	Strengthen coordination among science, policy, and business	Strategic partnerships, state programs, educational initiatives	More effective adaptation policy and increased investment capacity

Sources: Author's generalization based on FAO (2024); JRC (2025); OECD-FAO (2024); Ministry of Environmental Protection of Ukraine (2021); Shabatura (2024); Shabatura, Stepanova & Yakovenko (2025).

Biotechnology Dimension (Georgia, Azerbaijan). Research by the FAO-EU working group in Georgia (2025), combined with the work of Valieva and Huseynova (2024), shows that the incorporation of local genetic resources helps increase crop resilience to drought, pests, and diseases, while protecting and conserving biodiversity**.** These practices are of particular importance to the agricultural industries of Azerbaijan and Georgia, in which low water resources and aridification are a threat to stability. The biotechnological component of the model provides a basis for the creation of a stable agroecosystem, capable of independently reacting to changes in the climate.

Digital-technological dimension (Ukraine, Kazakhstan). Today, this approach is viewed as a key component of efficient adaptation to the current environment. In practice, this involves the use of digital technology to make on-the-spot decisions, as opposed to reacting to a situation after it has occurred. This is similar to the Kazakh Digital Irrigation 2030 program, in which water efficiency is to be improved, water loss reduced by 20%, and grain yield increase by 14%.

Institutional and organizational dimension (all countries). This institutional dimension describes the state's ability to support collaboration between science, business, and government in implementing climate policy. Adaptation in the agricultural sector is not limited to the implementation of technological solutions and largely depends on institutional synergies created through the coordinated interaction of government regulatory mechanisms, financial support instruments, and scientific expertise (**S**hpykuliak and Shelenko, 2024). In transition economies, institutional weaknesses often limit innovation. Therefore, this component of the integrated model calls for the creation of a coordinated climate adaptation governance system based on open data, stakeholder engagement, and sustainable financing. This, in turn, facilitates the convergence of adaptation processes in the political and technological spheres.

Integrated model of Ukraine for the region. The study shows that the Ukrainian climate adaptation model incorporates elements from three complementary perspectives, allowing it to contribute to the development of a regional benchmark in Eastern Europe and the Caucasus. The model is characterized as follows:

– climate risk monitoring and land use management using digital tools (AI, satellite mapping and Copernicus programming systems);

– a solid scientific basis for data validation and development of adaptation strategies;

– institutional cohesion, including the public policy framework and the participation of key government institutions, such as the Institute of Climate-Smart Agriculture of the National Academy of

Agricultural Sciences and the Ukrainian Hydrometeorological Centre, as well as research institutions and local communities.

This brings us to the creation of the conditions under which Ukraine might become a "regional hub" for climate knowledge, bringing together scientific research, technological solutions, and practical experience to help agricultural adaptation to climate change. In this context, the proposed integrated adaptation model consists of three levels that interact with each other: biotechnology, digital technology, and institutionally. It is evident that the proposed integrated adaptation model possesses a flexible structure that responds to climate risks, thus enhancing agricultural productivity and the socio-economic resilience of agriculture.

The experience of Ukraine indicates that the key to agricultural adaptation to climate change lies not in the application of individual technical solutions, but rather in the combined application of technology, scientific knowledge, and management culture.

5. Discussion

Data from the transition countries suggests that there is little room for neutral interpretation. While these countries are subject to broadly similar climatic pressures—water scarcity, soil degradation, and increased temperature—all are experiencing different agricultural responses. These are not only the result of the availability of resources and technology, but also the level at which adaptation is considered strategically necessary, as opposed to being formally necessary.

Georgia is an example of an approach in which adaptation is based on the respect for local agricultural traditions. The FAO programs re-introducing drought- and disease-resistant wheat strains are not taken lightly but are considered a serious approach to maintaining genetic strength and putting food on the table (Dzeladze, 2024). The use of biotechnology, precision agriculture, and tracking technologies are all critical elements in maintaining the foundation (Ujmaguridze, 2025).

On the other hand, the experience of the FAO-EU Working Group (2025) proves at least one thing: the answer lies not only in the technological field. Tsopausashvili (2023) is absolutely right to stress that these changes should be compatible with the goals of a climate-neutral development. Otherwise, the adaptation process might become disjointed and temporary.

Azerbaijan's policy is slightly different. In this country, the emphasis is placed on the development of genetic technologies to create more drought-resistant wheat. Such a policy might be seen as a reasonable answer to the growing climate aridity (Walieva & Huseynova, 2024). Making the agriculture of the occupied territories more adaptable by 2030 is not only a matter of environmental protection but a purely national concern. The National Climate Data Platform unites satellite, hydrometeorological, and economic data, making it possible to consider all these elements together.

In this regard, the role of digitalization cannot be overstated. According to Saeva (2023), better data management results in better natural resource efficiency and economic resilience. While Azerbaijan is still in the process of building up the institutional framework for adaptation, it has already achieved rapid development in the public digital sphere. In turn, Ukraine has a good scientific basis for its activities, especially with the contribution of the Risk Management Institute of the National Academy of Sciences of Ukraine (Shabatura et al., 2025). This creates the opportunity for a learning experience between the two countries, with the methodological contribution from Ukraine and the experience from Azerbaijan.

Kazakhstan, however, has chosen another route, focusing on organic agriculture as a means of building resilience to climate change. Cutting back on the use of mineral fertilizers, focusing more on biotechnology, and implementing eco-certification form the basis of this strategy (Karabasov et al., 2022). Consider, for example, the Digital Irrigation 2030 program, which demonstrates how digital technologies can pay for themselves with less water waste and better grain yields, "proving that you do not have to choose between going green and going profitable" (Kimo et al., 2025).

In this respect, Ukraine is an exemplary case. Ukraine possesses an impressive scientific potential, extensive agricultural areas, and opportunities to use advanced digital technologies. The previous studies carried out by Shabatura et al. (2025) have indicated that Ukraine's main strength is found in the integration of these opportunities. Satellite monitoring with the use of Copernicus and Sentinel, as well as AI technologies and climate risk management, increasingly integrate into one adaptive system. Such an integrated system allows connecting local observations with global data, which helps to better understand real climate risks.

However, Ukraine is different from Georgia and Azerbaijan not in the absence of local initiatives but in the development of the national scientific and technological system. Such a system is the basis not only for national but also for regional cooperation. All these cases lead us to one very simple conclusion: adaptation does not work not due to the absence of technologies but due to the parallel work of institutions, science, and economic incentives.

This is why the institutional aspect is truly important. This is where adaptation strategies are translated into real policies, regulations are properly designed, and everyone—government, business, and society—shares the burden of climate risks (Shpykuliak & Shelenko, 2024; Tsopausashvili, 2023). In the scientific and technical sphere, everything comes down to the implementation of digital platforms, the study of genetic research, and the improvement of water resource management systems (Valiyeva and Huseynova, 2024; Shabatura et al., 2025). This, as an economic component, includes financial support for farmers, investments in green technologies, and incentives for innovation (FAO-EU Task Force Georgia, 2025; Alvarez, 2025). Ukraine has all the necessary conditions to become a regional hub for climate expertise, capable of integrating the experience of the Caucasus and Central Asia into its own climate-smart governance model. The methodologies developed by ICOSG NAAS for climate modelling, risk assessment and digital monitoring could serve as a basis for the creation of an Eastern European Climate Databank under the auspices of FAO or the European Union.

Summarizing the results of the comparative analysis allows us to identify priority areas for improving the climate resilience of Ukraine's agricultural sector by 2030. These areas encompass technological, organizational, and educational measures that form the foundation of national adaptation policy. The structure of these areas is presented in Table 3.

Table 3. Main directions for strengthening climate resilience of Ukraine's agricultural sector by 2030

Direction	Priority actions	Expected effect
Digitalization	Expansion of climate-monitoring systems and risk-management platforms	Reduced uncertainty, improved decision-making efficiency
Biotechnology	Introduction of adapted varieties, bioengineering methods, and soil restoration	Increased yields and food security
Institutional integration	Science–policy–business partnerships, development of climate programs	Policy coherence and stable agricultural growth
Educational component	Climate education for farmers, training in precision agriculture and sustainability	Formation of adaptive management culture and local resilience

Sources: Author's generalization based on FAO (2024); JRC (2025); OECD-FAO (2024); Ministry of Environmental Protection of Ukraine (2021); Shabatura (2024); Shabatura, Stepanova & Yakovenko (2025).

Ukraine's transition to adaptive agriculture is not an isolated phenomenon; Ukraine is, in fact, a part of a larger geostrategic context in which agricultural policies are closely interrelated to regional and global climate challenges. Climate change, depletion of water resources, and soil salinization are threats to almost all countries, irrespective of their level of economic development. But it is precisely in these conditions that new opportunities emerge, and it is in this context that it is possible to pass from local actions

to a coordinated approach, which may become a basis for developing a regional model of climate resilience, in which Ukraine can play a prominent role of a leader.

6.Conclusion

Climate change is no longer an abstract external factor for Ukrainian agriculture. It is seen in the form of crop loss, changes in the level of income received by farmers, and the level of risk associated with agricultural production. Weather instability is not only affecting the efficiency of agricultural development but is also affecting the ability of farms to stay in the market for some years to come. These conclusions are not based on any particular publications, but rather on the similarities of these assessments made by different international organizations. The analytical materials published by the FAO, IPCC, OECD-Fao, and the Joint Research Centre, although differing in their methodology and scope, show one common trend. Agriculture is one of the most vulnerable areas of the economy. Increasing aridity, temperature variability, and soil degradation are direct threats to food security, particularly in those areas where the level of economic and environmental resilience is already compromised.

At the same time, Ukraine has considerable potential for developing climate-resilient agriculture. Yet, much of it remains underestimated. Water scarcity, the extent of degraded land that exceeds 13.5 million hectares, and the persistent knowledge-action gap continue to hinder the process. In such conditions, coping with climate-related shocks only after the fact can bring only limited relief. A new model of action, which focuses on anticipating risks and mitigating them before losses become inevitable, appears increasingly imperative.

Examining the experiences of Georgia, Azerbaijan, and Kazakhstan helps to clarify this shift. These countries differ in institutional capacity, policy priorities, and resource availability, but their adaptation paths reveal several common themes. Where progress is achieved, it is rarely the result of a single intervention, but rather the result of a combination of technological innovation, sustained public support, and active local engagement. In Georgia, adaptation efforts are closely linked to biotech solutions. Azerbaijan places particular emphasis on digital climate platforms and data-driven decision support. Kazakhstan's "Digital Irrigation 2030" program illustrates how water resource management can be coordinated system-wide. Taken together, these examples demonstrate that effective adaptation requires a solid scientific and technological foundation.

In this context, the current research introduces an integrated adaptation framework specifically for Ukrainian farms. While adaptation is often considered an individual process, the proposed framework integrates these elements into three interrelated areas. The first area is biotechnology, including the use of biotechnology for the improvement of the state of the soil and the introduction of crop varieties resistant to drought. The potential of digital technologies is not seen in the direct observation of climate change processes. Their real potential is the transformation of complex information into decisions. However, adaptation is impossible without coordination. Only through the harmonious work of government agencies, researchers, and businesses can the policy on climate change become not only declarative but also executable.

The integrated climate change adaptation model for the agricultural industry of Ukraine is based on digital technology, science, and collaboration between government and business entities. The proposed approach will lay the foundation for increasing the resilience of agricultural production to climate change and developing new mechanisms for managing adaptation processes until 2030.

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