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Agriculture in the Era of Global Crises: Technologies, Climate, and Sustainability

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Abstract: *Agriculture in the era of global crises faces multifaceted challenges driven by climatic changes, technological advancements, and geopolitical shifts. This study examines the sustainability of agrifood systems by conducting an extensive literature review, analyzing statistical data from international organizations, and performing content analysis of relevant texts. The research highlights the dual impact of these challenges: while climate-induced extreme weather events and geopolitical instabilities threaten agricultural productivity and food security, digital transformation and innovative agro-technologies offer viable solutions to enhance system resilience. Special emphasis is placed on the role of digitalization in optimizing resource use and production efficiency, as well as the adaptation of government strategies to emerging economic and environmental conditions. The findings yield actionable recommendations to mitigate climate risks and reinforce global food security, charting a pathway toward a more sustainable future for the agro-food sector.*

Keywords — agriculture, agrifood sector, food security, sustainable development, climate change, agro-technologies, government support, digitalization.

1. Introduction

Agriculture remains the backbone of the global food system, accounting for over 26% of global employment and up to 4% of global GDP (1). Yet, over the past few decades, this sector has faced significant challenges. On one hand, climate change is increasing the frequency of droughts, floods, and altering rainfall patterns, thereby reducing crop yields and heightening the vulnerability of food systems (2). On the other hand, rapid technological advances – from artificial intelligence and robotics to CRISPR crop editing – offer new solutions while also requiring large-scale investment and adaptation of agricultural practices (3, 4).

The key issue remains the growing gap between the food needs of the population and agriculture's capacity to meet them. According to UN forecasts, by 2050 the world's population will reach 9.7 billion, and the demand for food will increase by 60% (5). Yet, more than 33% of the world's arable land has already been degraded [6], and in certain regions, such as the Indo-Gangetic Plain, aquifers are rapidly depleting (7). Moreover, geopolitical instability and disruptions to global supply chains following the COVID-19 pandemic have further exacerbated the vulnerability of the agrifood sector (8).

Nonetheless, the potential for transformation in the sector is significant. Modern technologies, including precision farming, vertical farms, alternative proteins, and bioengineering, can not only boost yields but also reduce the carbon footprint of agriculture. Their successful implementation, however, requires a rethinking of institutional arrangements, government support, and adaptation strategies.

2. Research Methodology

This study uses an integrated approach, combining data analysis from international organizations such as FAO, the World Bank, and OECD with a review of peer-reviewed scientific publications in the field of agriculture and food security. In addition, content analysis of text materials was used to assess current trends and prospects for the development of the industry.

3. Literature Review

Global agriculture today faces a number of fundamental challenges caused by globalization, climate change, technological transformation and external economic shocks, including the COVID-19 pandemic. Over the past decades, agrifood systems have changed significantly: global trade and innovative technologies contribute to increased production efficiency, but growing dependence on imported technologies and resources makes the agricultural sector vulnerable to external shocks (9).

One of the key sources reflecting the current state of food security is the report of FAO, IFAD, UNICEF, WFP and WHO "The State of Food Security and Nutrition in the World 2024" (10). It provides a detailed analysis of how climate change, armed conflicts and economic crises affect the availability and quality of nutrition in different regions of the world. The document shows that, despite the preservation of the basic functions of the food system, the sustainability of agricultural systems has been significantly undermined, which requires the adoption of comprehensive adaptation measures.

On the other hand, the FAO report "The State of Food and Agriculture 2021: Making agrifood systems more resilient to shocks and stresses" (11) focuses on the need to increase the

resilience of the agricultural sector. The authors of this study analyze how modern technologies – such as precision farming, digitalization, and early warning systems – can reduce the vulnerability of agricultural systems to extreme climate and economic shocks. Particular attention is paid to supply diversification and the transition to more localized production models, which is a response to the problems revealed by the COVID-19 pandemic (11, 14).

An equally important area is the consideration of long-term scenarios for the development of agricultural systems. The FAO report "The Future of Food and Agriculture 2018: Alternative Pathways to 2050" (12) examines possible paths for the development of agriculture, taking into account the growing global demand for food, as well as changes related to climate and new technologies. The document notes that the global agricultural sector may change radically in the coming decades, with a transition to more sustainable production methods and the integration of innovative solutions in resource management. This analysis emphasizes the importance of strategic planning for shaping the future of the global food system and ensuring food security.

Digitalization of agriculture, as shown by the research of Wolfert et al. (17), opens up new opportunities for optimizing production processes, allowing farmers to use data to make operational decisions, which is especially important in the context of an unstable external environment. The use of big data, the Internet of Things and artificial intelligence is becoming a powerful tool for increasing productivity and reducing costs, as well as for adapting to climate change.

An important aspect is the impact of climate change on agriculture. Puma et al. (15) assess how extreme weather events – droughts, floods, storms – negatively affect crop yields and the stability of agricultural systems. The authors emphasize the need to integrate climate models into strategic decisions in the agricultural sector, which allows for a timely response to threats and reduction of losses.

No less relevant is the topic of changes in consumer demand. Global population growth and the transition to more saturated, processed diets require the modernization of production processes. The IFPRI report "Global Food Policy Report 2021" (18) notes that changes in the structure of demand are forcing producers to adapt to new requirements, which is associated with increased production costs and the need to implement innovative solutions to ensure food security.

The COVID-19 pandemic has become a catalyst for rethinking traditional supply chains. Research by Laborde et al. (14) shows that the just-in-time model, previously considered effective, has proven to be highly vulnerable to global crises. Disruptions in the supply of raw materials, fertilizers, and labor have forced the industry to seek more flexible and resilient production models, including localization and diversification of supplies.

Another important area is the role of technological innovation in increasing the sustainability of agricultural systems. The study by Mok, Tan and Chen (13) examines the experience of Singapore, where the introduction of hydroponics, aquaculture and remote monitoring systems has significantly increased productivity with minimal inputs. This approach demonstrates that even in conditions of limited availability of agricultural land, it is possible to ensure a high level of food security using modern technologies.

In addition, adapting agricultural systems to external shocks requires a comprehensive approach that includes both technological and socio-economic measures. The review by Swinnen and McDermott (16) provides recommendations for developing social protection policies, supporting small farmers and improving agricultural infrastructure, which helps reduce the negative impact of crises on food security.

Taken together, the presented studies provide grounds to believe that modern agrifood systems are on the threshold of transformation. The need to integrate digital technologies, adapt to climate change and rethink global supply chains is becoming the cornerstone for the future sustainable development of the sector. An integrated approach combining innovation, government support and new models of production organization is key to ensuring food security in the face of ongoing global challenges.

4. Analysis And Main Results

In recent decades, global agriculture has undergone significant changes driven by technological innovations, climate change, and global economic processes. According to the FAO report "World Food and Agriculture – Statistical Yearbook 2024," the total added value of agriculture, forestry, and fisheries increased by 89% in real terms between 2000 and 2022, reaching approximately 3.8 trillion US dollars (1). At the same time, the share of the agricultural sector in global GDP has remained stable at about 4% (Fig. 1). This indicates a rise in sector productivity that aligns with the overall dynamics of the global economy.

Agriculture remains one of the most important sectors of the global economy and a way of life for a significant portion of the world's population. In 2023, according to estimates by the International Labour Organization, the agricultural sector employed around 26-27% of the global workforce, although this figure varies significantly depending on a country's level of economic development (19) (Fig. 2). In highly developed regions such as North America and Western Europe, the share of employment in agriculture usually does not exceed 5–10%, whereas in developing countries in Africa and Asia, the agrisector still provides jobs for more than 50% of the working population. Between 2000 and 2022, global employment in agrifood systems declined from 40% to 26%, indicating a gradual shift of the workforce to other economic sectors (1). Nonetheless, in developing countries, these sectoral shifts have essentially stagnated since 2015, and employment in agriculture remains high. Moreover, considering the low level

of mechanization and poor working conditions in traditional smallholder farms outside developed economies, it is evident that the working poor and those in informal employment have not benefited from the shift toward industry and modern service sectors.

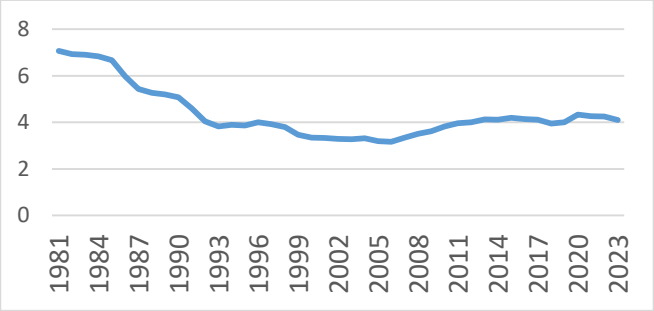

Fig. 1. *Agriculture, forestry, and fishing, value added (% of GDP)*

Source: World Bank national accounts data, and OECD National Accounts data files.

Changes in land use and irrigation also deserve attention. The total area of global agricultural land is about 4.9 billion hectares, of which approximately 30% is devoted to arable and permanent crops, and 70% to meadows and pastures. The greatest increase in agricultural land over recent decades has been observed in Asia, especially in China and India, whereas in Europe and some regions of North America the area of cultivated land is decreasing. The proportion of irrigated land is increasing, particularly in Asia; however, in Africa the level of irrigation remains low (around 7% of cultivated land), underscoring the need for investments in infrastructure and water management technologies.

The production of major agricultural crops such as grains, oilseeds, and legumes continues to grow, though the growth rates vary by region. This increase in production is accompanied by a rise in the use of fertilizers and pesticides: between 2000 and 2022, the volume of pesticide use increased by 70%, and total fertilizer consumption reached 185 million tonnes, of which 58% are nitrogen fertilizers. This trend points to an intensification of agricultural practices, which necessitates careful monitoring of environmental impacts and adherence to sustainable development principles.

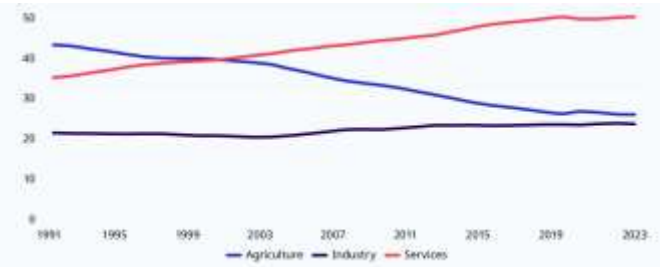

Fig. 2. *Global employment by economic sector (% of total employment)*

Source: ILOSTAT, ILO modelled estimates, November 2024. - https://www.ilo.org/sites/default/files/2025-01/WESO25_Trends_EN_WEB5.pdf

One of the key directions for sustainable development is reducing the dependence on chemical fertilizers and pesticides by adopting organic farming and biotechnologies. For example, under the European Union's "Farm to Fork" strategy, it is planned to reduce pesticide use by 50% and increase the share of organic agricultural land to 25% by 2030 (20). However, in developing countries where access to such technologies is limited, intensification of production remains the primary means of meeting the growing food demand, thereby heightening environmental risks.

Gender remains a critical issue in agrifood systems. Women make up a significant proportion of the workforce in the sector, yet their access to resources, education and technology remains limited. In 2024, FAO launched the Commit to Grow Equality (CGE) programme to strengthen gender equality and empower women in agrifood systems. The initiative aims to mobilise funding and partnerships to improve the status of women in agrifood systems and transform them. CGE is expected to benefit up to 54 million women worldwide, representing more than 10% of women employed in agrifood systems. It is planned to mobilise around US$1 billion in investment to achieve this goal (21).

The primary function of agriculture is to provide food for humanity. An increasing amount of raw materials undergoes industrial processing before reaching end consumers, as highlighted in recent FAO reviews. In addition to traditional processing sectors – such as milling, sugar, and oil industries – the production of biofuels from carbohydrate-rich crops (including sugarcane, sugar beet, corn, and sorghum) is also actively developing. According to the OECD-FAO forecast for 2023-2032, these crops are increasingly used for ethanol production, which serves both as a substitute for and an additive to gasoline, enhancing its octane rating.

However, agriculture is facing new challenges related to climate change, post-pandemic logistical disruptions, and rising resource costs. In many regions, extreme weather events such as droughts and floods significantly affect crop yields, while geopolitical conflicts and export restrictions complicate the supply of fertilizers and agricultural machinery. Nevertheless, thanks to improvements in irrigation methods, the adoption of precision agriculture, and higher yields of new crop varieties, overall production of grains, legumes, and oilseeds continued to grow in 2023, albeit at varying rates across countries.

Agriculture remains one of the sectors most vulnerable to climate fluctuations. According to the IPCC report (2), by 2023 the global temperature had increased by 1.2°C compared to pre-industrial levels, leading to a 40% rise in extreme weather events over the past 30 years. This has a direct impact on yields; for example, the drought of 2022-2023 severely affected agriculture in Eastern Africa. In southern Somalia and

the marginal zones of Kenya, corn production is estimated to have declined by 60-70% compared to the long-term average (22). Livestock numbers also fell, particularly in Somalia, where losses amounted to about 20%. Reports indicate that around 23 million people experienced acute hunger (23).

The 2022 floods in Pakistan caused significant damage to agriculture, particularly in the Sindh province, where approximately 1.1 million hectares of agricultural land were inundated. The total damage exceeded 14.9 billion US dollars, with economic losses reaching 15.2 billion US dollars (24). Rice losses in Sindh amounted to about 1.9 million tonnes, representing 80% of the province's projected production (25).

In Europe, the abnormal heat in 2023 reduced olive yields in Spain by 43% compared to the average (26). Climate disruptions not only reduce yields but also destabilize global supply chains. For instance, the reduction in olive production in Spain – the world's largest exporter of olive oil – led to a 50% increase in prices in 2023, reaching an all-time high of €9 per liter (27).

Amid increasing climate risks, such as droughts in Somalia and floods in Pakistan, traditional agricultural methods are facing significant challenges. However, modern technologies – including digitalization, genome editing via CRISPR, vertical farming, and artificial intelligence – offer promising solutions for enhancing the resilience of the agri-industrial complex to climate change.

In Eastern Africa, where droughts severely impact corn yields, farmers are beginning to adopt drought-resistant hybrids developed using modern breeding techniques. These hybrids show improved adaptation to arid conditions, thereby reducing crop losses. In Pakistan, where floods pose a serious threat to agriculture, farmers are starting to implement innovative drainage systems managed via mobile applications. These technologies enable effective control of water levels in the fields, preventing waterlogging and its associated issues.

Modern technologies play a crucial role in adapting agriculture to changing conditions. Precision agriculture – based on the use of satellite data, drones, and artificial intelligence – enables optimization of water, fertilizer, and pesticide applications, thereby reducing costs and environmental impact. Various studies indicate that the implementation of precision agriculture, including smart irrigation and variable rate fertilizer technologies, can increase yields by 10–15%, reduce water consumption by 20-30%, and cut fertilizer usage by 15-25%.

Another promising direction is the development of vertical farming, which allows crops to be grown under controlled conditions, minimizing dependence on natural factors. In 2023, the global vertical farming market was valued at 6.92 billion US dollars and is forecasted to grow at an average annual rate of 20.1% from 2023 to 2030 (28). This growth is driven by the increasing adoption of environmentally friendly methods for producing fruits and vegetables, as well as by the rising demand for urban agriculture amid rapid population growth. Although this technology is currently predominantly used in developed countries, its adaptation in regions with high levels of food insecurity could be a significant step toward sustainability.

These innovations not only help address current climate challenges but also lay the foundation for a future in which agriculture can adapt to changing conditions and reduce its environmental footprint. The transition to technologically advanced agrosystems is becoming not merely a choice, but a necessity for ensuring food security in a changing climate.

Modern global crises – from the COVID-19 pandemic to geopolitical conflicts – undermine the resilience of food systems, especially in developing countries. Until 2022, the Russian Federation and Ukraine played key roles in global grain trade. In 2021, their combined wheat exports accounted for about 30% of total global supplies. Ukraine's share of the global corn market averaged 15% between 2016-2017 and 2020–2021, ranking it fourth among exporters of this crop (29). However, the conflict led to a significant reduction in exports from Ukraine. According to an FAO report, grain production in Ukraine decreased by 36% in 2022-2023 compared to the previous year (30).

The reduction in grain supplies from Ukraine and the Russian Federation has resulted in a substantial increase in global wheat prices. In March 2022, the average FAO Food Price Index reached 159.3 points – 12.6% higher than the February figure – and represented the highest level since 1990. Prices for grains and vegetable oils, for which Ukraine and Russia hold a significant share in production, increased by 17.1% and 23.2%, respectively, compared to February 2022 (31).

Countries in Africa and the Middle East, which are heavily dependent on wheat imports from Ukraine and Russia, experienced a significant surge in food inflation. In some of these countries, inflation reached between 25% and 40%, further exacerbating food security challenges. Despite a partial restoration of supplies via a humanitarian corridor in the Black Sea, regional instability persists, highlighting the vulnerability of global supply chains.

To mitigate the effects of such crises, enhanced international cooperation is required. Initiatives such as the Agricultural Market Information System (AMIS), established under the auspices of the FAO, contribute to increased transparency in grain markets and better coordination between producing and importing countries. In 2023, AMIS expanded its data coverage on wheat, corn, rice, and soybeans, enabling more effective forecasting of shortages and prevention of price shocks (32).

5. Conclusion

Global agriculture is at the intersection of economic, environmental and social challenges. Increases in added value and productivity in the sector are accompanied by increasing environmental risks and vulnerability to climate and

geopolitical factors. Innovations such as precision agriculture, drought-resistant varieties and vertical farming offer ways to adapt, but their implementation requires significant investment and international coordination. Sustainable development of the agricultural sector is possible only with a balanced approach that takes into account both economic efficiency and social and environmental impacts.

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