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ADAPTATION OF AGRICULTURE TO CLIMATE CHANGE

АУЫЛ ШАРУАШЫЛЫҒЫНЫҢ КЛИМАТТЫҢ ӨЗГЕРУІНЕ БЕЙІМДЕЛУІ

АДАПТАЦИЯ СЕЛЬСКОГО ХОЗЯЙСТВА К ИЗМЕНЕНИЮ КЛИМАТА

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Abstract. Climate change is one of the global environmental and socio-economic problems. In recent decades, significant impacts have been exerted by the increase in greenhouse gas levels in the atmosphere, global warming, and the growing frequency of natural disasters, which directly affect many sectors, including agriculture, as they pose a threat of reduced productivity and deterioration of land fertility. The *purpose* is a comprehensive study of the dynamics of carbon emissions and the determination of the impact of hydrometeorological phenomena on the performance and stability of the agrarian sector. *Methods* — analysis and synthesis, and the economic-statistical method to identify indicators of adaptation of agro-industrial production to various climatic conditions. The empirical basis of the research consists of data from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan on annual precipitation for 2019–2023, as well as information on carbon dioxide emissions for 2020–2024. *Results* indicate the relevance of introducing climate-resilient methods into AIC production processes, effective land resource management practices, and a multi-faceted approach to addressing food security challenges. The conceptual model reflects climate transformation and the effects of social and economic factors on the agrarian sphere and food systems, and demonstrates their interconnection and interdependence. This concept serves as a practical basis for developing strategies to enhance adaptability and optimize the agro-industrial complex. *Conclusions* – the established facts correspond to the Sustainable Development Goals (poverty eradication, combating adverse climate impacts, and environmental protection) and are aimed at creating reliable prospects for food provision.

Аңдатпа. Климаттың өзгеруі-жаһандық экологиялық және әлеуметтік-экономикалық мәселелердің бірі. Соңғы онжылдықтарда атмосферадағы парниктік газдардың көбеюі, жаһандық жылыну және табиғи апаттардың көбеюі айтарлықтай әсер етті, бұл көптеген

салаларға, соның ішінде ауыл шаруашылығына тікелей әсер етеді, өйткені олар өнімділіктің төмендеуіне және жер құнарлылығының төмендеуіне қауіп төндіреді. *Мақсаты* – көміртегі шығарындыларының динамикасын кешенді зерттеу және гидрометеорологиялық құбылыстардың аграрлық сектордың нәтижелі қызметі мен тұрақтылығына әсерін анықтау. *Әдістер* - талдау және синтездеу, агроөнеркәсіптік өндірістің әртүрлі климаттық жағдайларға бейімделу көрсеткіштерін анықтау үшін экономикалық-статистикалық. Ғылыми жұмыстың эмпирикалық негізін Қазақстан Республикасы Стратегиялық жоспарлау және реформалар агенттігінің ұлттық статистика бюросының 2019-2023 жылдардағы атмосфералық жауын-шашынның жылдық мөлшері туралы деректері, сондай-ақ 2020-2024 жылдардағы көмірқышқыл газының бөлінуі туралы ақпарат құрайды. *Нәтижелер* – АӨК өндірістік процестеріне климатқа төзімді әдістерді енгізудің өзектілігін, Жер ресурстарын тиімді басқару практикасын және азық-түлік қауіпсіздігін қамтамасыз ету міндеттерін көп аспектілі шешуді айғақтайды. Тұжырымдамалық модельде климаттық трансформация және әлеуметтік-экономикалық бағыттағы факторлардың аграрлық салаға және азық-түлік жүйелеріне әсері, сондай-ақ олардың өзара байланысы мен өзара тәуелділігі көрсетілген. Бұл тұжырымдама агроөнеркәсіптік кешеннің бейімделуін арттыру және оңтайландыру стратегияларын әзірлеу үшін практикалық негіз болып табылады. *Қорытындылар* – белгіленген фактілер тұрақты даму мақсаттарына сәйкес келеді (кедейлікті жою, қолайсыз климаттық көріністермен күресу және қоршаған ортаны қорғау), азық-түлікпен қамтамасыз етудің сенімді перспективаларын құруға бағытталған.

Аннотация. Изменение климата - одна из глобальных экологических и социально-экономических проблем. За последние десятилетия значительное влияние оказывают рост уровня парниковых газов в атмосфере, глобальное потепление и учащение природных катастроф, которые напрямую затрагивают многие отрасли, в том числе сельское хозяйство, поскольку несут угрозу снижению продуктивности и ухудшению плодородия земель. *Цель* – комплексное исследование динамики выбросов углерода и определение воздействия гидрометеорологических явлений на результативную деятельность и стабильность аграрного сектора. *Методы* - анализа и синтеза, экономико-статистический для выявления показателей адаптации агропромышленного производства к различным климатическим условиям. Эмпирическую основу научной работы составляют данные Бюро национальной статистики Агентства по стратегическому планированию и реформам Республики Казахстан о годовом количестве атмосферных осадков за 2019–2023 годы, а также информация о выделении диоксида углерода за 2020–2024 годы. *Результаты* свидетельствуют об актуальности внедрения климатоустойчивых методов в производственные процессы АПК, практике эффективного управления земельными ресурсами и многоаспектном решении задач обеспечения продовольственной безопасности. В концептуальной модели отражены климатическая трансформация и действие факторов социальной и экономической направленности на аграрную сферу и продовольственные системы, а также показаны их взаимосвязь и взаимозависимость. Эта концепция служит практической основой для разработки стратегий повышения адаптивности и оптимизации агропромышленного комплекса. *Выводы* – установленные факты соответствуют целям устойчивого развития (ликвидация бедности, борьба с неблагоприятными климатическими проявлениями и защита окружающей среды), нацелены на создание надежных перспектив продовольственного обеспечения.

Keywords: agriculture, climate change, carbon emissions, greenhouse gases, precipitation, adaptability and resilience, food provision.

Түйінді сөздер: ауыл шаруашылығы, климаттың өзгеруі, көміртегі шығарындылары, парниктік газдар, атмосфералық жауын-шашын, бейімделу және тұрақтылық, азық-түлікпен қамтамасыз ету.

Ключевые слова: сельское хозяйство, климатические изменения, углеродные выбросы, парниковые газы, атмосферные осадки, адаптивность и устойчивость, продовольственное обеспечение.

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Introduction

Agriculture, forestry, and other land use sectors account for about one-third of global greenhouse gas emissions. At the same time, soil is considered the largest carbon reservoir, storing three times more carbon than terrestrial biomass and twice as much as the atmosphere.

Climate change is mainly caused by human activities such as deforestation and greenhouse gas emissions, posing a direct and complex threat to global food security. Since the beginning of industrialization, climate change has been characterized by long-term climatic fluctuations resulting from deforestation and greenhouse gas emissions. This phenomenon negatively affects agricultural outcomes, leading to reduced yields, soil degradation, and increased water scarcity (Atakunda P., Eide B., Kardel K. et al.) [1].

Amid growing geopolitical instability, climate change, and the weakening of logistical chains, food security has become one of the key strategic priorities at the global level. For Kazakhstan, addressing these challenges involves large-scale modernization of agriculture, including the introduction of innovative technologies, efficient use of natural resources, and enhancement of climate adaptation capacity. This approach is aimed at ensuring the sustainability of agricultural production and strengthening the country's food independence and environmental security.

It is characterized by long-term changes in the climate resulting from human activities. Climate change negatively affects agricultural outcomes, leading to decreased productivity, soil degradation, and drought. Therefore, the intersection of climate and agriculture issues requires defining the direction for developing the link between food security and climate resilience (Awhari P., Jamal D., Muhammad M. et al.) [2].

In recent years, the growing impacts of climate change, environmental degradation, and resource scarcity have highlighted the need for a fundamental transformation of economic systems. In this context, the green economy has emerged as a strategic approach to achieving sustainable economic growth while minimizing adverse environmental effects. Its primary goal is to harmonize economic development with environmental protection through the rational use of natural resources and the preservation of ecological balance.

The concept of the green economy encompasses several key dimensions, including improving energy efficiency, promoting renewable energy sources, reducing waste, and introducing environmentally friendly production technologies. For Kazakhstan, the transition to a green economy is particularly relevant, as it contributes to enhancing the country's climate resilience, ensuring food security, and maintaining natural capital. Moreover, it serves as a foundation for integrating sustainability principles into national development strategies and agricultural modernization efforts.

Based on this foundation, the study analyzes the impact of climate change and green economy initiatives on food security. It examines the effects of climate change on food security and evaluates the role of green economy initiatives in mitigating its negative consequences. Using a dataset covering the period from 2020 to 2024 period, the research conducts a statistical analysis of carbon dioxide emissions, green economy policies, and related management measures in relation to food security.

Literature Review

Climate change poses significant threats to agriculture, as its impacts exacerbate existing vulnerabilities within agricultural systems. In this context, rain-fed agriculture is particularly susceptible to climate variability, with droughts adding direct risks - a concern highlighted in numerous studies by both foreign and domestic researchers. For example, researchers Molotoks A., Smith P., Dawson T. [3] noted in their study that climatic disruptions significantly increase the risks of crop failure and pest outbreaks, making agricultural production highly variable.

According to Bolatova Zh., Bulkhairova Zh. [4] weather-related risks play an important role in agriculture, as crop yields are directly influenced by weather conditions. They noted that unfavorable weather often leads to feed shortages, resulting in decreased livestock productivity and a reduction in herd size. However, researchers Bjornlund V., Bjorlund H., Van Rooyen A. [5] emphasized in their work that the vulnerabilities within agricultural systems stem not only from current climatic challenges but also from a long historical process that began more than two centuries ago and continues to this day.

The vulnerability of the agricultural sector to climate change is largely compounded by its dependence on subsistence farming and limited access to technology and financial resources. Paul C., Bartkowski C., Donmez A. et al. [6] and other authors demonstrated that the unpredictability of seasonal rainfall and the intensification of droughts severely weaken agricultural production and food availability, potentially exacerbating hunger crises.

Climate conditions and land quality have a significant impact on agricultural development. Greenwell M., Johnson T. [7] showed that in the age of advanced technology, it is possible to regulate these factors through the use of fertilizers. Olajide O., Oluwadamilola A. [8] emphasized that agricultural development should

not rely solely on adopting programs or conducting short-term campaigns.

Although growth in the agricultural sector has been criticized, the promotion of sustainable practices and green economy initiatives provides opportunities to improve resource use and food production. Chen Y., Miao J., Zhu Z. [9] explained in their research that such measures often fail if they are not adapted to local economic needs. This situation highlights the need for policies that integrate environmental sustainability with social and economic development to help communities adapt to climate change and achieve long-term success.

Despite numerous studies by both foreign and domestic researchers on the adaptation of agriculture to the green economy and the issue of agricultural product safety under climate change conditions, this topic still remains highly relevant.

Materials and methods

In accordance with the research objective, economic-statistical methods, analysis and synthesis, as well as economic analysis of the dynamics of key factors, were applied. One of the justifications for selecting the research indicators was to conduct a comprehensive analysis of the interrelated issues between green economy policy, environmental impact, and food security. This approach makes it possible to quantitatively assess the scientific aspects, identify the main research directions, the most significant factors, as well as emerging scientific trends.

Carbon emissions and the amount of atmospheric precipitation play an important role in the analysis as indicators of climate change, due to their direct impact on the safety of agricultural products and the sustainability of agriculture.

In analyzing and conducting the research, the study relied on the annual atmospheric precipitation data for Kazakhstan from 2019–2023 and carbon dioxide emissions data for 2020–2024 period provided by the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan, as well as on the works of both foreign and domestic researchers in the field of agricultural development and improvement. Although the review indicated a slowdown in the rate of emission reductions and showed that the overall impact of climate change measures has been positive, it also revealed that the agricultural sector remains a weak link.

Results

Climate change has a significant impact on agriculture, creating numerous challenges for both global food production and the agricultural sector. Rising temperatures, changes in atmospheric precipitation patterns, and the increasing frequency of extreme weather events make farming and livestock production increasingly difficult. Heat stress and prolonged droughts reduce crop productivity, while excessive rainfall and flooding lead to intensified soil erosion and waterlogging. Table 1 presents data from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan on environmental indicators, specifically the average annual amount of atmospheric precipitation for the years 2019–2023.

Table 1 – Annual amount of atmospheric precipitation in Kazakhstan, mm

	2019	2020	2021	2022	2023	2024	2024 versus	
							2019	2023
Annual amount of atmospheric precipitation, mm	297.4	270.7	271.5	311.2	359.4	317.74	20.34	-41.66
Note: data from the (Bureau of National Statistics…) [10]								

According to table 1, the annual amount of atmospheric precipitation across Kazakhstan increased from 297.4 mm in 2019 to 317.74 mm in 2024, representing a growth of 20.34 mm or approximately 6.8%. When comparing 2024 to 2023, precipitation rose by 41.66 mm, which corresponds to an increase of about 15.1%.

Overall, the 20.9% rise in precipitation during the period 2019–2024 may have both positive and negative implications for agriculture. On the positive side, higher precipitation enhances soil moisture, improving conditions for crop growth and potentially increasing yields. On the negative side, excessive precipitation can lead to waterlogging, soil erosion, and a higher incidence of plant diseases and pests, thereby raising the risk of yield losses.

In the long term, it is essential to consider regional disparities in rainfall distribution. In arid regions, such as southern Kazakhstan, even a modest increase in precipitation may contribute positively to soil productivity.

However, in the northern and foothill areas, excessive rainfall could trigger agroecological risks, including soil degradation and reduced agricultural stability.

Carbon emissions are one of the main factors driving climate change, and their impact on agriculture - and consequently on food security - is clearly evident. Carbon emissions and greenhouse gases intensify the rate of global warming, leading to droughts. Such changes result in decreased soil fertility, water scarcity, and a decline in agricultural productivity. As a result, food prices rise, leading to socio-economic challenges. Table 2 presents environmental data from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan, specifically regarding carbon emissions in agriculture for the years 2020–2024 period.

Table 2 – Carbon dioxide emissions in Kazakhstan, million tons per year

	2020	2021	2022	2023	2024	2024 versus	
						2020	2023
Carbon emissions	263.5	257.7	245.8	239.8	240.0	-23.5	-23.7
Carbon emissions in the agricultural sector	41.42	42.85	41.2	41.4	42.0	0.58	-0.02
Note: data from the (Bureau of National Statistics…) [10]							

Based on the data presented in table 2, several important trends in Kazakhstan's carbon emissions can be identified. The total amount of carbon emissions across all sectors amounted to 263.5 million tons in 2020**,** while by 2024 a consistent downward trend was observed, reaching 240 million tons**,** which represents a reduction of approximately 9.0 %**.** This decline reflects the gradual effectiveness of national climate policies, improvements in industrial efficiency, and the expansion of renewable energy sources.

In contrast, the agricultural sector demonstrated an opposite dynamic. Carbon emissions increased from 41.42 million tons in 2020 to 42.0 million tons in 2024, indicating a modest growth of about 1.4%. This increase may be associated with the intensification of agricultural production, the expansion of livestock farming, and limited adoption of low-carbon technologies in rural areas.

Furthermore, the similarity between the 2023 and 2024 figures indicates a slowdown in the overall rate of decarbonization. While the national mitigation efforts have produced a positive cumulative effect, the persistence of high agricultural emissions suggests structural challenges in the transition toward a sustainable, low-carbon agricultural model. These findings emphasize the need for targeted climate adaptation policies, increased investment in green technologies, and the promotion of knowledge-based practices in agriculture to enhance climate resilience and ensure long-term sustainability.

The formation of hazardous waste from various types of economic activities in agriculture is closely related to climatic factors. Climate change — including rising temperatures, fluctuations in precipitation patterns, and the increasing frequency of droughts - affects both the quantity and composition of organic and chemical waste generated in agriculture.

Table 3 presents data on the formation of hazardous waste by types of economic activity in the agricultural sector of the Republic of Kazakhstan for the period 2020–2024.

Table 3 - Formation of hazardous waste by types of economic activity, thousand tons per year

	2020	2021	2022	2023	2024	2024 versus	
						2020	2023
Agriculture, Forestry, and Fisheries	2 144.4	1 052.7	766.8	1 143.3	1 250.2	-894.2	106.9
Note: data from the (Bureau of National Statistics ….) [10]							

Between 2020 and 2024, the volume of hazardous waste in the Agriculture, Forestry, and Fisheries sector shows an overall decreasing trend (~42 %). During 2023–2024, a slight upward trend (~9 %) is observed, indicating the recovery of production and economic activity. The volume of hazardous waste is closely linked to sectoral activity: in 2020, the highest level was recorded, followed by a sharp decline until 2022. The decrease in 2020–2022 may be associated with reduced production due to economic or pandemic-related constraints, stricter

environmental regulations, and the adoption of safer agricultural practices. Conversely, the growth observed in 2023–2024 reflects economic recovery and an increase in agricultural production.

The average hazardous waste volume for the 2020–2024 period was approximately 1271.48 tons, serving as a baseline for assessing sectoral waste generation. These trends underline the environmental implications of hazardous waste accumulation, including potential impacts on soil, water resources, and ecosystems. If production continues to grow, hazardous waste volumes may further increase, emphasizing the need for sustainable waste management strategies. Strengthening monitoring systems, modernizing production technologies, and implementing “green” practices are essential measures to mitigate environmental risks and ensure sustainable sectoral development.

Hossain M., Amin M., Sultana J. et al. [11] indicated that rising temperatures and unstable rainfall contribute to a decline in agricultural productivity, thereby worsening food security. They also noted that climate variability further exacerbates the challenges faced by farmers, particularly in regions where most irrigated land is used for cultivating export-oriented crops. In such circumstances, farmers who lack access to modern irrigation systems, resilient seed varieties, and climate-adapted technologies are left with insufficient resources.

The successful development of the agricultural sector largely depends on its material and technical base. In Kazakhstan, the current number of agricultural machines is significantly lower than the actual demand. Therefore, strengthening the technical base of agriculture requires targeted measures aimed at improving and modernizing agricultural machinery and equipment.

In the context of climate change and the need to reduce the carbon footprint, the modernization of the agricultural technical base has acquired strategic importance. Modern energy-efficient machinery and precision farming technologies can significantly reduce fuel consumption, optimize the use of fertilizers and water, and thus enhance the environmental sustainability of the sector. Furthermore, insufficient mechanization leads to lower labor productivity, higher production costs, and yield losses, particularly under conditions of climatic stress. Addressing these challenges requires not only the renewal of the machine and tractor fleet but also the development of service infrastructure, the digitalization of production processes, and the introduction of advanced agrotechnical services (Kaliev G.A., Moldashev A.B.) [12].

Government support in the form of investment subsidies, leasing programs, and the localization of agricultural machinery production could become a key factor in accelerating the modernization of Kazakhstan’s agricultural sector and ensuring its long-term resilience.

Although green economy practices offer several advantages, they also pose certain challenges to the sustainability of agricultural systems. Additionally, green economy practices may have unintended environmental and socio-economic consequences. For example, large-scale biofuel cultivation can reduce biodiversity and require more land, while small-scale farmers may face difficulties adopting new technologies due to higher costs and training needs. Prioritizing energy crops can also affect local food security by reducing land available for food production.

Therefore, an integrated approach that balances environmental protection, economic growth, and food security is essential for sustainable agricultural development. While these practices stimulate economic growth and contribute to environmental protection, they can sometimes have adverse effects on agriculture. In this regard, researcher Kinda S.R. [13] noted that biofuel production intensifies competition for land and water resources, reduces the amount of food available to local communities, and contributes to rising prices.

The growth of the green economy may have unintended consequences for the promotion of food security. For example, researchers He J., Osabohien R., Yin W. et al. [14] showed that green economy policies may increase competition for land and, at the same time, raise demand for agricultural products, leading to higher food prices. Additionally, green economy initiatives may create trade-offs for food security. Large-scale bioenergy crops can reduce land availability for food production, impact soil fertility, and lower biodiversity. Smallholder farmers may face difficulties competing for resources, and short-term yield reductions can occur without proper adaptation. Policies should therefore balance green economy growth with measures to protect food security, such as sustainable land use, crop diversification, and support for small-scale farmers.

Researchers Bjornlund V., Bjornlund H., Rooyen A. [15] noted in their study that the implementation of green economy practices may place additional burdens on already fragile agricultural systems. Therefore, they suggested that future strategies should focus on ensuring equitable resource distribution, improving

governance quality, and enhancing the use of knowledge. In this regard, the authors recommend that future strategies for sustainable agriculture should focus on ensuring the equitable distribution of natural and financial resources, improving the quality of governance, developing monitoring and knowledge systems, and strengthening the scientific and educational base in the field of climate change adaptation. Such a comprehensive approach will help reduce the risks of socio-economic vulnerability and enhance the resilience of the agricultural sector in the long term.

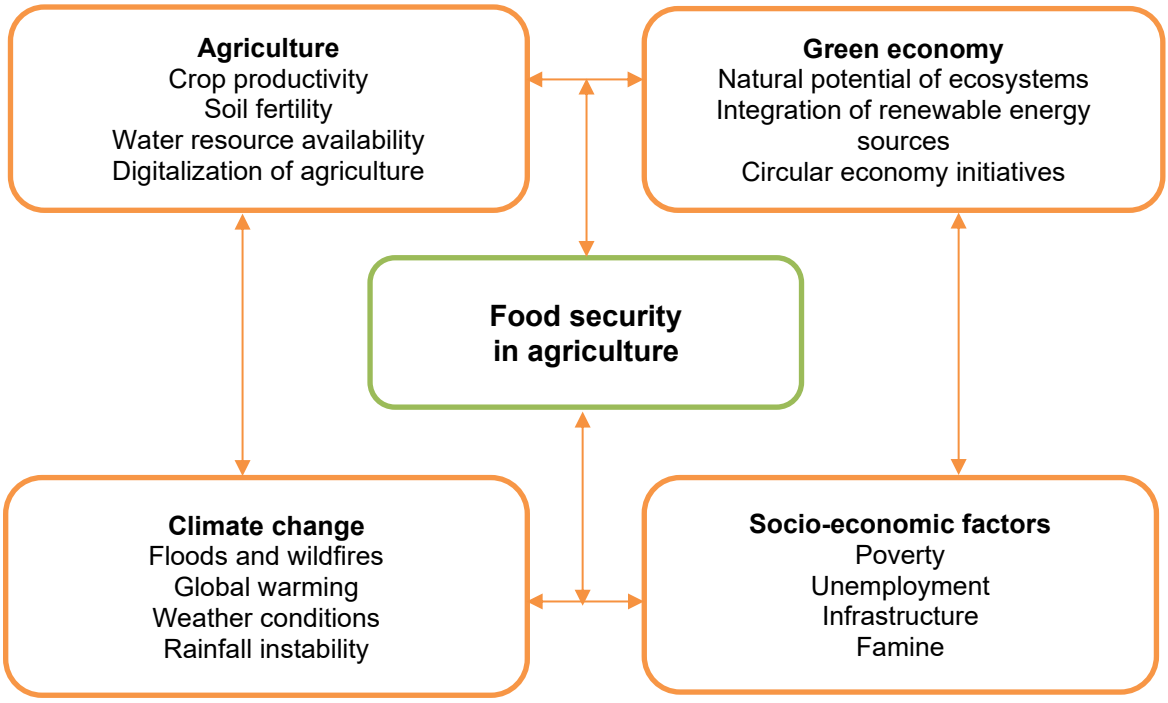
Discussion

The green economy seeks to address issues of agricultural product safety by harmonizing environmental conservation with economic growth. Adopting green economy practices such as climate-resilient agriculture, renewable energy integration, and sustainable land management can help mitigate the adverse impacts of climate change on agricultural production. However, the success of these initiatives depends on addressing deep-rooted socio-historical factors and external influences that continue to shape agricultural and economic systems.

Understanding the interconnections between climate change, green economy initiatives and agricultural practices is essential. The conceptual model presented in figure 1 illustrates these relationships and highlights the need for an integrated approach to ensuring the safety of agricultural products. This conceptual model aims to demonstrate how climate change and socio-economic factors affect agricultural production systems, as well as how green economy strategies can help mitigate these impacts.

The model begins with climate change, which represents the main challenge for agriculture. Changes such as increased frequency of droughts, unstable rainfall and rising temperatures directly reduce crop yields, degrade soil fertility and decrease the availability of water resources. These impacts also influence labor resources and the adaptive capacity of agricultural systems. Therefore, it is evident that supporting farmers and implementing adaptation strategies are crucial for enhancing the safety and resilience of agricultural production.

Figure presents the need for an integrated approach to addressing the issue of agricultural product safety, illustrating the interconnections among key factors.



Note: compiled based on the authors' research

Figure – Conceptual model illustrating the interrelation between agriculture, the green economy, climate change, and socio-economic factors

Figure presents the need for an integrated approach to addressing the issue of agricultural product safety, illustrating the interconnections among key factors. The figure explains how climate change and socio-economic factors influence agriculture and agricultural sys-

tems, while also showing how green economy strategies can help mitigate these impacts.

Conclusion

In conclusion, the study demonstrates that national progress and prosperity are directly dependent on environmental sustainability.

1. While green economy initiatives offer potential opportunities to ensure climate resilience and sustainable food production, their success depends on addressing socio-economic inequalities and adapting to local conditions and needs.

2. It is necessary to implement green measures such as pollution prevention, afforestation, and the development of sustainable agriculture primarily aimed at domestic food provision and security, as well as reducing greenhouse gas emissions.

3. The green economy requires strong institutions, a robust legal and regulatory framework, and socio-economic mechanisms.

4. Increased atmospheric precipitation significantly affects agriculture, necessitating a reassessment of its climate resilience. This change is closely linked to the Sustainable Development Goals, including poverty eradication, hunger reduction, climate action, and the development of sustainable communities.

5. Balanced and adequate rainfall enhances agricultural productivity and strengthens food security, while excessive or poorly timed precipitation increases environmental and economic risks. Therefore, introducing climate-adapted agro-technologies, managing water resources efficiently, and improving farmers' environmental literacy are key directions for ensuring a resilient and sustainable food future.

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