







# Microwave-Assisted Foam Drying of Cauliflower Leaf Puree for Sustainable Waste Valorization

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**Abstract.** Various crises that have occurred recently demonstrate the instability of the existing model of economic development. A significant drawback of this model is the absolutization of economic growth to the detriment of solving social and environmental problems. At the same time, the problem of climate change requires studying the socio-ecological and economic aspects of sustainable development of agriculture, increasing productivity while protecting natural resources, transitioning to the production of environmentally friendly agricultural products, studying local and foreign knowledge and experience in this area. The purpose of the study is to substantiate the theoretical, methodological and practical aspects of ensuring sustainable development of agriculture, study and assess the problems in this area in Azerbaijan, as well as identify areas for improving development prospects in accordance with world experience. The concept of sustainable development of agriculture is inextricably linked with the efficient use of economic and intellectual resources, improving the well-being and quality of life of the rural population, sustainable and balanced nature management. Only with a balance of economic, social and environmental components can sustainable development of this sphere of production be ensured in the long term. To achieve sustainable development of agriculture, it is necessary to systematically take into account all three factors, and on this basis it is advisable to develop mechanisms and tools that allow for quantitative and qualitative transformations.

**Keywords:** Sustainable Development, Agriculture, Green Economy, Rural Development.

## 1 Introduction

The crises of recent years have shown the instability of the existing model of economic development both in the world and in Azerbaijan. A significant drawback of this model is that it ensures economic growth at the expense of solving social and environmental problems. New economic models are reflected not only in scientific research, but also in the priorities of practical activities of many states and private business structures. Thus, The European Union has launched initiatives aimed at developing a “green” and sustainable economy, as well as a bioeconomy, within the framework of its 2030–2050 strategy (EC, 2019).

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In the modern world, the problem of climate change has actualized the social, ecological and economic aspects of sustainable development of agriculture. The limited resources that form the basis of sustainable development of agriculture and their efficient use are the demands of the time. The transition to sustainable agriculture will create new opportunities for the development of rural areas by increasing and diversifying agricultural production, as well as increasing the level of well-being in non-agricultural activities.

The purpose of the study is to substantiate the theoretical, methodological and practical aspects of ensuring sustainable development of agriculture, study and assess the problems in this area in Azerbaijan, as well as identify areas for improving development prospects in accordance with world experience.

## **2 Materials and Methods**

The research base consists of the works of domestic and foreign researchers devoted to this problem, their conceptual views and methodological approaches to the issue, as well as decrees and orders of the President of the Republic of Azerbaijan, state programs, data from the Ministry of Agriculture and other official documents. The article used the annual reports of the OECD and the WB. The analyses were carried out on the basis of statistical data for 2019-2023 on the agricultural sector of the State Statistical Committee of the Republic of Azerbaijan.

Given the diversity of indicator systems for assessing agricultural sustainability, we used a generalized indicator system in our study. The methodology we use will allow us to analyze all three aspects of agricultural sustainability: economic, social, and environmental.

Various methodological approaches are used to study sustainable development of agriculture. In this case, a systemic approach to the problem is used, with the use of comparative economic and statistical analysis, relative and absolute calculation methods.

### **2.1 Methodological approach to assessing sustainable agricultural development**

The emergence and development of the theory of sustainable development began with the understanding of the socio-economic and environmental problems of modern society and the search for possible solutions. The rapid growth of the planet's population determines the need to meet the growing demand for consumer goods. This, in turn, has led to an increase in production volumes, growth in resource consumption and environmental pollution. In addition, the prevalence of easily accessible non-renewable fuels and mineral resources in production has led to the emergence of such negative global trends as biosphere degradation and climate change.

The need to solve these problems and eliminate negative trends has led to the creation of a new paradigm, the basis of which is the comprehensive balanced

development of the economic, social and environmental spheres and the justification of the corresponding imperatives (requirements and laws).

Sustainable agriculture is generally understood as an agricultural production system that focuses on producing agricultural products that meet the needs of the present generation while preserving resources for future generations (Allen et al., 2018) . It is based on the principles of interrelated environmental, economic and social sustainability with the aim of minimizing destructive impacts on the environment, while increasing the efficiency of agricultural production and activating scientific work, preserving biodiversity and ensuring a stable income for farmers. Sustainable agriculture also includes the use of new technologies such as precision farming, the use of renewable energy sources and innovations in agronomy. Its goal is to create a balanced system that takes into account both food production and the needs of the ecosystem (Abbasova, Ibrahimov, 2024) .

It should be noted that the objective prerequisites for the formation of the concept of sustainable agricultural development are unresolved problems of a global nature. In particular, the problems of eliminating hunger and malnutrition in a number of underdeveloped countries, eliminating rural poverty, global warming, degradation of land resources, pollution of groundwater in rural areas, destruction of natural ecosystems, etc. are relevant.

In general, the listed objective circumstances predetermine the characteristics of the target guidelines for ensuring sustainable development of agriculture at the global and national levels (Table 1).

**Table 1.** Institutional objectives for ensuring sustainable development of agriculture

Benchmark	Level of achievement of sustainable development	
	Global	National
Authorities regulating the development of the agricultural sector	Food and Agriculture Organization of the United Nations (FAO)	Ministry of Agriculture of the Republic of Azerbaijan
Key documents in the field of sustainable agricultural development	Declaration of the World Summit on Food Security, Madrid Declaration, Resolution "Agricultural Development and Food Security"	Strategic Roadmap for Production and Processing of Agricultural Products in the Republic of Azerbaijan, 2016; Azerbaijan 2030: National Priorities for Socio-Economic Development
<b>The objectives in this area are:</b> economic development	Improved food security; sustainable growth in production volumes	Increasing the economic efficiency of the agro-industrial complex, increasing export potential
social development	Providing employment to the population and	Improving the standard and quality of life of the rural

	increasing its income level; improving nutrition and raising the standard of living; improving the living conditions of the rural population	population, increasing employment, improving rural infrastructure, increasing the prestige of living in rural areas
ecological development	Efficient use of natural resources, environmental protection	Efficient use of natural resource potential of agriculture, protection and improvement of ecology of rural areas

*Source:* Authors 'own elaboration based on global and national priorities.

Many economists include ecological sustainability (protecting and restoring the health of agricultural ecosystems), economic productivity (ensuring economic profitability and competitiveness of agricultural activities) and social justice (improving the living conditions of people working in agriculture, ensuring the social well-being of the rural community) as the main principles of sustainable agriculture (Kociszewski, Karol, 2018; Roszkowska, Filipowicz-Chomko, 2021):

- Organic farming: the production of crops using natural processes, without the use of chemical fertilizers and pesticides.
- Agroecology: the design and management of agricultural systems based on ecological principles.
- Conservation agriculture: using techniques such as minimum tillage, mulching and crop rotation.
- Integrated Pest Management: A balanced approach to pest control using a combination of chemical and biological methods.
- Water resources management: implementation of efficient irrigation technologies and sustainable water resources management.

As the analysis shows, the modern approach to sustainable development emphasizes the use of resource-saving technologies. This approach allows preserving soil fertility, preventing ecological imbalance, improving the forms of organization of agricultural systems and ensuring sustainable development (Matvieieva et al., 2023). In short, ensuring sustainable development of agriculture requires serious changes in economic systems. According to researchers, sustainable agriculture contributes to a healthier environment. Thus:

- natural ecosystems and biodiversity will be protected;
- soil conservation will prevent the depletion of arable land;
- water and air pollution will slow down;
- non-renewable resources will be protected.

The analysis shows that since sustainable agriculture is a dynamic process, it is impossible to measure it (Ikerd, 1993). However, some authors note that by assessing some of its parameters, it is possible to form an opinion about the direction of development of this process (Pretty, 1995). For example, if soil erosion occurs, productivity and living standards in rural areas decrease, this means that the development of the agricultural sector is not sustainable.

In almost all countries, the agricultural sector is predominantly small-scale. Small farms take the necessary steps to ensure sustainability. Indeed, farmers themselves decide how to use land and new technologies. Therefore, most researchers, when talking about the sustainability of agriculture, prefer to consider sustainability at the farm level. Some researchers use the “Environmental Sustainability Index” (ESI) to assess the sustainability of agriculture. This index consists of 15 sub-indices and covers soil depth and groundwater. This indicator covers soil fertility, water use, fertilizer use, input efficiency and other indicators (Sands & Podmore, 2000).

The Organisation for Economic Cooperation and Development has developed a system of indicators for measuring the sustainability of the agricultural sector in the PSR (Pressure-State-Response) model (OECD, 1999).

This indicator system also includes indicators developed by the UN Commission on Sustainable Development. It should be noted that these indicators allow assessing the sustainability of agriculture as a whole. The DSR (driving force – government response) indicator system developed by the OECD introduces new indicators and allows assessing the sustainability of agricultural enterprises, such as farmers. The DSR indicator system combines 39 indicators, including financial resources for agriculture, agricultural management, use of fertilizers and pesticides, soil and water quality, biodiversity and landscape, access to information needed for farms, and other indicators. The OECD indicator system is very extensive, and even most European countries cannot cover all of these indicators (Table 2).

**Table 2.** Key indicators used in various studies

Indicators		
Economic	Social	Ecological
average production volume; total production costs; non-agricultural income; farm income; degree of economic efficiency; rate of profit; the level of wages paid to employees; employment opportunities;	level of education of family members in rural areas; housing conditions of households; level of education in the field of agriculture; health status of family members; improving the decision-making process; improving the quality of life in rural areas; working and living conditions;social income;	improving water resources management; volume of pesticide use; volume of use of organic fertilizers; volume of green manure use; physical costs of production and their efficient use; physical performance; diversity of agricultural crops; use of alternative plant products; application of crop rotation in agriculture;

availability of markets for agricultural products; level of entrepreneurship; land use management and other indicators.	social equality, etc.	direction of change in climatic conditions; use of chemical fertilizers; erosion control; energy use; Pesticide management indicators and other indicators are widely used.
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*Source:* Authors 'own elaboration based on the research.

One of the major challenges in measuring the sustainability of the agricultural sector is that most sustainability indicators cannot be successfully implemented in all countries. Researchers have shown that an indicator that is successfully applied in one country may be useless in another (Norman et al., 1997). Sustainability largely depends on the nature of the agricultural sector and the socio-economic situation in the country. It is necessary to distinguish between the specific level of agriculture or livestock production, the level of farmers, the level of the rural population, the level of country development, and the international level. Sustainability at each of these levels can be highly dependent on decisions made at subsequent levels (Dumanski & Pieri, 1996; Parkhomenko, 2016; Suleymanov, 2019). For example, the sustainability of farmers largely depends on the standard of living of the rural population or on decisions made within the country on economic, social and environmental issues (Kazkova-Mateva, 2020). Decisions on changing environmental requirements at the national level should be made by economic entities throughout the country, including agricultural enterprises.

## 2.2 Institutional goals of sustainable development in the Republic of Azerbaijan

Although Azerbaijan went through a difficult historical period at the end of the last century, it has confidently gone through a path of great evolution in its socio-economic and cultural life and has become known in the world as a country that has provided a stable, safe and modern standard of living. The country's international authority has increased significantly, the traditions of statehood in society have strengthened, and the construction of a modern socio-economic infrastructure has been successfully implemented. High financial opportunities arising from economic development have made a significant contribution to macroeconomic stability and growth for many years and created a powerful potential for ensuring security. The adopted state programs for the socio-economic development of the regions (for 2004-2008, 2009-2013, 2014-2018, 2019-2023, 2022-2026) are of great importance in raising the country's socio-economic development to a new qualitative level. In accordance with the Order of the President of the Republic of Azerbaijan No. 1897 dated March 16, 2016 "On approval of the main directions of the strategic road map for the national economy and key sectors of the economy" and issues arising from them, a total of 12 strategic road maps for the national economy and 11 sectors of the economy have been prepared. The strategic road

map for the national economy covers short-term, medium-term and long-term periods and consists of the strategy and action plan for economic development until 2020, long-term vision for the period until 2025 and target vision for the period after 2025.

The Strategic Roadmap "On the production and processing of agricultural products in the Republic of Azerbaijan" is aimed at further increasing the achievements in the field of socio-economic development of the country's regions, including rural areas, achieving high competitiveness and sustainable development of agriculture:

- ✓ regional and sectoral development of agricultural production with competitive advantages, facilitating access of agricultural producers to means of production, information and consulting services, domestic and foreign markets, formation of farmers' associations in agriculture, development of agribusiness and processing of agricultural products, development of science and technology, education in the agricultural sector;

- ✓ increasing the share of import-substituting basic food products on the domestic market, strengthening food reserves and food security;

- ✓ expanding employment, improving social security and raising the standard of living in rural areas;

- ✓ ensuring sustainable progress in the agricultural sector through the development of agriculture that adapts to climate change and uses advanced technologies to improve the efficiency of water and land use, protect the environment and conserve soil and water resources (SRM, 2016).

The strategic document "Azerbaijan 2030: National Priorities of Socioeconomic Development" dated February 2, 2021, reflects the areas important for the country over the next 10 years and provides for the implementation of five National Priorities: 1. a steadily growing competitive economy; 2. a dynamic, inclusive and socially just society; 3. competitive human capital and space for modern innovation; 4. greater return on liberated territories; 5. a country with a clean environment and "green growth" (NPSSED, 2021).

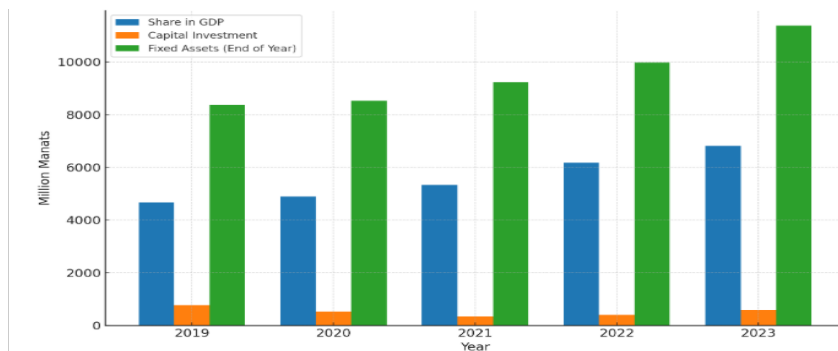
### **2.3 Analysis and assessment of sustainable development of agriculture in Azerbaijan from the point of view of economic, social and environmental components**

We will conduct a statistical analysis of the economic activity of the sector based on the system of economic factors of sustainable development of agriculture in the Republic of Azerbaijan.

Figure 1 presents some economic indicators of agriculture, forestry and fisheries for 2019-2023. The share of agriculture, forestry and fisheries in GDP in 2023 increased by 46.1% compared to 2019 - from 4.6 billion manat to 6.8 billion manat. Compared to 2022, it increased by 10.3% in 2023. The sector's share in GDP in 2023 was 5.5%.

Compared with 2019, fixed capital investments in the sector in 2023 decreased by 24.8%, i.e. from approximately 7.7 billion manat to 5.8 billion manat. Compared with 2022, there was an increase of 41.7% in 2023. The deterioration of the economic situation in recent years due to the onset of the coronavirus pandemic and further

aggravation of the crisis amid political tensions may slow down the growth of agricultural production and threaten food security. In this regard, it is important to increase investment support for agriculture. Investments are the most important factor in the sustainable development of the sector. (Fig. 1)



**Fig. 1.** Economic indicators of agriculture, forestry and fisheries for 2019-2023.

Effective management of fixed assets in any economic conditions requires a deep understanding of long-term assets, their value and technical requirements. The book value of fixed assets in agriculture, forestry and fisheries at the end of the year increased by 35.8% from 8.4 billion manat in 2023 to 11.4 billion manat compared to 2019. Analysis of the dynamics of fixed assets in agriculture indicates a high level of reproduction of fixed assets. The share of renewal of fixed assets is increasing. Fixed assets, as is known, are the basis that allows producing more gross domestic product, therefore, a quantitative and qualitative increase in fixed assets directly affects the pace of development of the state economy.

In 2023, the share of agriculture, forestry and fisheries in the economy was 5.5% of GDP, 2.7% of fixed capital investment and 4.1% of the book value of fixed assets. We consider the quantitative and qualitative composition of land resources as one of the most important ecological and economic factors of the sustainability of agricultural development, since, unlike other important factors of production, the land fund in agriculture is limited in quantity and area, and its expansion occurs significantly slower than the possible growth of labor and material resources.

The use of land resources necessitates taking into account environmental factors in agricultural production. Thus, land, as a unique natural resource, is a factor that directly influences the final results of agricultural activity and is difficult to regulate.

One of the main ecological and economic factors for the effective and stable functioning of agriculture in the Republic of Azerbaijan is the structure of the land fund. Arable land, that is, the most intensively used part of systematically cultivated land resources, is of particular importance for agricultural production. The area of arable land in 2023 was 2037.4 thousand hectares, which is 42.6% of land suitable for agriculture. In the structure of agricultural land, the share of sparse land, perennial plantings and forested areas has increased over the compared years. Although this will lead to a

temporary reduction in the area of arable land, it will have a positive impact on soil productivity.

Another global challenge to sustainable development is water scarcity. According to the World Health Organization, 2.2 billion people will not have access to clean drinking water in 2022. More than half of the world's population, or 4.2 billion people, do not have access to safe sanitation and hygiene services. 2 billion people live in countries with water scarcity. 80% of wastewater returns to the ecosystem without treatment.

The country with limited water resources in the South Caucasus region is mainly Azerbaijan. The total volume of renewable fresh water resources in our country is 26.2 billion cubic meters, of which 8.4 billion cubic meters are groundwater, 4.6 billion cubic meters are local river flows and 13.2 billion cubic meters are transboundary surface water. According to statistics, the volume of water withdrawal from natural sources during 2010-2023 increased by 10.7 percent, and water consumption increased by 26.7 percent. Unfortunately, it can be noted that according to the annual water balance, 50 percent of the water withdrawn from water sources for irrigation of agricultural lands in the country and 37 percent of the water withdrawn for drinking water supply of the population does not reach the end user. This means that the average annual volume of water loss is approximately equal to the surface water reserves formed in the country. The total area of crops and perennial plantings in the country is 2.2 million hectares, of which 1.5 million hectares are irrigated. The basis for sustainable agricultural development is innovation in irrigation technologies.

In order to address issues related to the application of innovative approaches in water resources management to achieve sustainable development goals, the “National Strategy for the Efficient Use of Water Resources” was developed and approved by the Decree of the President of the Republic of Azerbaijan dated October 10, 2024 (NSEU WR, 2024).

Azerbaijan is increasing government support measures to stimulate innovation among agricultural producers. To compensate farmers for part of the investment costs associated with the installation of modern irrigation systems, the state subsidizes 40% of the cost of equipment. The state also applies a 40% discount on the sale of drones, robotics and equipment with intelligent control technologies intended for use in agriculture. Innovative irrigation technologies provide significant environmental benefits. These technologies prevent soil erosion and promote uniform distribution of water across all soil layers. Drip irrigation systems protect the top layer of soil, ensure water penetration into the lowest layers, reduce water demand and maintain ecological balance. On the other hand, auxiliary systems evenly distribute water over arable land, creating conditions for maintaining and increasing soil productivity, which helps ensure the balance of agricultural ecosystems. New irrigation systems are already being used in many regions. For example, in the Shirvan region, a significant increase in crop yields was achieved through the use of drip irrigation technology. In Ganja, pivot irrigation systems have been introduced that automate the irrigation process, reduce labor costs, and increase the accuracy and controllability of irrigation work (Fikratzade, 2022; Abasova, 2017; Ismailov and Budagova, 2016).

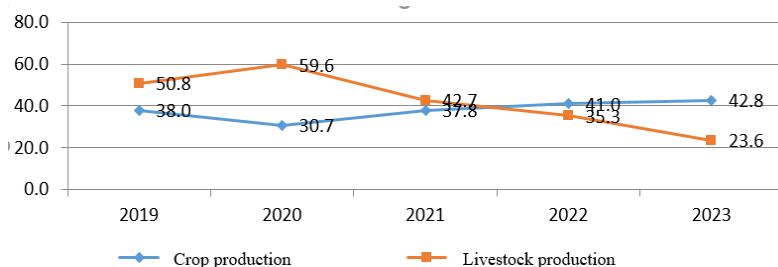
In 2023, the value of gross agricultural output at actual prices amounted to 12,210.6 million manats, of which 6,276.7 million manats were livestock products, and 5,933.9 million manats were crop products. Compared with 2019, the gross volume of agricultural production in 2023 increased by about 1.6 times, including crop products -

1.6 times, and livestock products - 1.5 times. As a result, the share of crop production in the structure of gross agricultural output over the comparable period increased from 47.9% to 48.6%, and the share of livestock decreased from 52.1% to 51.4%.

As we have already noted, crop yield is one of the main indicators of agricultural intensity. According to data, in 2019-2023, crop yield increased in all categories of agricultural crops (legumes, tobacco, potatoes, vegetables, melons) with the exception of cotton. The greatest increase in yield was observed in tobacco and melons.

During the analysis of the main economic indicators of individual entrepreneurial farms in Azerbaijan, it was revealed that the average annual value of fixed assets of agriculture in individual entrepreneurial farms throughout the country decreased by 11.5% in 2023 compared to 2019. One of the main ways to improve the efficiency of using production assets is to accelerate the asset turnover process. This is possible by reducing the time spent on both production and circulation. To reduce the time spent on production, it is necessary to create relatively fast-growing varieties of plants and animal breeds, achieve their introduction into production, shorten the harvesting period, increase the productivity of plants and animals, etc. In the compared years, total output increased by about 7.6%, profit by 4.7%, income by 16.3%, and labor productivity by 6.4%. However, the amount of losses increased by about 4 times.

Sustainable development of farms is based on financial indicators, that is, on the level of profit and profitability. In addition to natural conditions and the general economic situation, the profit and profitability of farms depend on the available production factors (labor, land and capital), market conditions, in particular the prices of raw materials and finished products, and other factors. As can be seen from the graphical analysis of the profitability of product sales in farms of individual entrepreneurs for 2019-2023, the level of profitability of livestock products has been decreasing since 2021 (Figure 2.). Thus, profitability, which was 59.6% in 2020, decreased by about 2.5 times to 23.6% in 2023. In crop production, on the contrary, it increased by 12.1 points from 30.7% to 42.8%. The analysis shows that the decrease in profitability is due to the increase in the cost of production. These include rising prices for feed and vitamins, as well as transport and logistics costs.



**Fig. 2.** Profitability of sales of products in the farms.

The Azerbaijani government is interested in the development of farms in the country. It creates favorable conditions for farmers to purchase fertilizers, machinery and other equipment, as well as access to sufficient credit resources and the possibility of unhindered sale of products so that their farms can survive and function effectively.

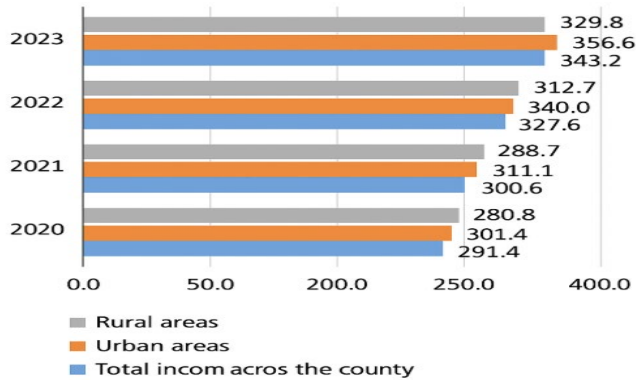
The experience of countries with a developed agricultural sector shows that effective development of farms is possible only with a developed system of institutional relations. In addition, developed infrastructure, the level of social security, healthcare and education are closely related to the development of agricultural production (Cherdanchev, 2021).

Sustainable development of agriculture is the most important condition for the effective development of rural areas. The sustainability of rural settlements is determined by the number of residents living in them, the quality of life of the population, their health, including the development of infrastructure, accessibility of education, medical and information services, as well as the level of sustainability of production in the agricultural sector. One of the most important socio-economic factors for the sustainable development of agriculture is the staffing of the agricultural sector. Studies show that about 36% of the employed population in Azerbaijan is employed in this sector. Currently, due to the diversification process, there is a redistribution of labor resources from agriculture to industry and services.

It should be noted that the income of a significant part of the rural population directly depends on the efficiency of their economic activity. The average monthly nominal wage in agriculture, forestry and fisheries in 2019 was 371.4 manat, and in 2023 - 558.7 manat. In the country as a whole, this figure in 2023 was 933.9 manat, which indicates that in the studied area it is 1.7 times lower. In our opinion, this is due to a number of the following reasons:

- low economic efficiency restrains the rate of wage growth;
- inequality of prices for industrial and agricultural products, reduction of internal sources of reproduction;
- low work motivation, indicating poor adaptation to changing economic conditions.

In rural areas, 17% of the main sources of income of the population in 2023 came from wages, 24.2% from self-employment, 9.9% from old-age pensions and relatively other sources. Employment and social problems of the village against the background of intensive urban development led to an influx of population, primarily of working age, to cities, which exacerbates the problem of a decrease in the reproduction rate of the rural population. Compared to 2019, it increased by 2% - from 4 511.1 thousand people to 4 599.9 thousand people in 2023. In general, rural areas account for 45.4% of the total population, which we assess as a positive situation.



**Fig. 3.** Monthly income per capita in 2019-2023 (in manat).

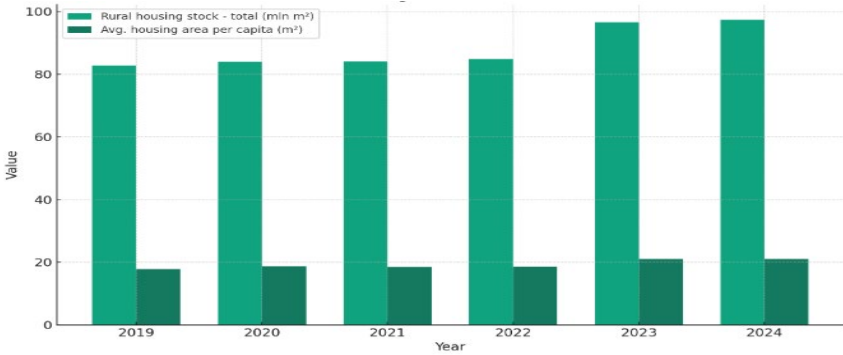
Figure 3 shows the level of average per capita income in urban and rural areas for 2019–2023. As can be seen, although the average per capita income has increased in comparable years, it is lower than both the urban (8.13%) and national average (4%).

An analysis of income by source shows that in 2023, income from hired work accounted for 26.9% of total income, an increase of 2.1 percentage points compared to 2019. Income from self-employment, mainly from agricultural production, decreased by 2.3 percentage points from 24.2% in comparable years to 21.9% in 2023. Current transfers received also increased accordingly.

The level of education also requires a holistic approach that goes beyond the narrow framework of the traditional (agricultural education and vocational education) concept of rural development in the context of a policy dominated by sustainability issues. An analysis of the level of education of the population in rural areas shows that general secondary education predominates - 54.7%, 18.9% have secondary specialized, vocational and technical education and only 15% have higher education. Primary and incomplete primary education accounts for 0.7%. Increasing the level of education will contribute to improving the standard of living of the rural population and preventing urbanization. In short, if the quality of life of the population in rural areas does not improve, there can be no talk of sustainable agricultural development.

Developed countries are currently using digital technologies in agriculture. This is important for the future in order to train highly qualified personnel, create new jobs and increase incomes. In this regard, the education of rural people is a prerequisite for sustainable development. As rapidly changing technologies show, increasing the level of education and specialization is crucial for the sustainability of the rural economy and the competitiveness of the sector. Although this requires significant investment, the socio-economic benefits of this far outweigh the financial consequences, as it can contribute to economic development and inclusion.

One of the priority tasks of sustainable development of the agricultural sector is to improve the standard of living of the population living in rural areas and their living conditions.



**Fig. 4.** Provision of housing to the rural population.

Based on the data in Figure 4, it can be said that the average area of housing per capita has increased over the years under review. Improving the housing and communal conditions of the rural population will help reduce the intensity of migration processes and increase the sustainability of agriculture.

It should be noted that agriculture has a significant impact on the processes occurring in the natural environment and the ecological situation in rural areas. In particular, the main sources of air pollution are wind erosion, livestock waste, harmful substances emitted into the atmosphere when using agricultural machinery, warehouses where seeds are treated with pesticides, etc.

Agriculture is a significant source of carbon dioxide emissions into the atmosphere. Since the mid-20th century, agricultural intensification, industrial development, and the burning of organic matter for energy production have led to a rapid increase in the amount of carbon dioxide and other greenhouse gases in the atmosphere (Mustafayev, Makhmudov, 2019).

Let's examine several indicators of the impact of agriculture on the environment (Table 3). Emissions of pollutants into the country's atmospheric air from stationary sources by ingredients in 2023 compared to the same period in 2019 decreased by 18.4%. There is also a decrease in greenhouse gas emissions in agriculture and when applying mineral fertilizers to crops.

**Table 3.** Impact of agriculture on the environment.

Indicators	2019	2020	2021	2022	2023
Emissions of pollutants into the atmospheric air of the country from stationary sources by ingredients, total thousand tons	177.0	146.7	156.7	158.4	144.4

Per unit of GDP - total, kg/thousand \$	0.9	0.8	0.8	0.7	0.7
Waste generation in agriculture, forestry and fisheries (thousand tons)	1.2	1.0	0.8	0.7	0.6
Greenhouse gas emissions in agriculture, million tons of CO2 equivalent	8.7	8.0	8.0	7.6	8.1
Agricultural land area, million hectares	2.0	1.9	1.9	1.9	1.8
Consumption of mineral fertilizers per unit area of agricultural land, kg/ha	234.5	258.7	152.5	208.8	203.3
The share of areas treated with mineral fertilizers in the total area of agricultural land, %	80.0	79.2	66.3	71.6	71.7
Application of mineral fertilizers under crops in agriculture, kg per hectare of crops	82	81	47	65	65
Funds allocated to fixed capital for environmental protection and efficient use of natural resources (thousand manats)	309855.6	170208.7	71329.4	160542.8	594991.4

Source: Authors' own elaboration based on statistic data.

Among the factors of intensification in increasing agricultural production, the use of mineral fertilizers plays a decisive role. Mineral fertilizers are inorganic substances containing nutrients necessary for plant development. These include nitrogen, phosphorus, potassium and other microelements. The amount of fertilizers applied per 1 ha of arable land for agricultural crops in the country in 2023 decreased by about 17 kg from 82 kg to 65 kg compared to 2019. However, fertilizer rates are calculated based on the reserve of nutrients in the soil and the planned yield. Analyses show that today many farmers apply more mineral fertilizers to arable land than the norm. However, if the required rate of mineral fertilizers is exceeded, a number of agroecological and sanitary-hygienic problems arise. Excessive use of mineral fertilizers pollutes the soil with heavy metals. Mineral fertilizers are considered the main source of soil and water pollution with heavy metals and toxic elements. At the same time, these elements enter the body of humans and animals through the product, causing serious harm to health (Mustafaeva et al., 2024; Alekperov, 2016, p. 51).

It should be noted that the import of mineral fertilizers by type in comparable years also decreased. Fertilizer production in the country began in 2019, which indicates that agriculture is provided with mineral fertilizers from local resources. The analysis shows that in 2023, the import of fertilizers into the country in value terms compared to 2019 decreased by 2.4 times, including in physical weight of nitrogen fertilizers - by 2.3 times, potash - by 1.5 times, mixed (complex) mineral fertilizers - by 2.7 times. The import of phosphorus fertilizers was completely stopped.

It should be noted that in terms of ensuring sustainability in crop production and increasing productivity, the balanced use of nutrients in plant cultivation is of great importance. In recent years, educational work in this area has led to a reduction in the use of mineral fertilizers in the country, as well as the emergence of trends in their correct use. Mineral fertilizers containing nitrogen, phosphorus and potassium contribute to the growth of agricultural crops and increased productivity, but the widespread use of mineral fertilizers is also associated with a number of environmental problems: water pollution, changes in soil composition (excessive accumulation of nitrogen or phosphorus can lead to soil degradation, reduced fertility and water retention capacity), greenhouse gas emissions (nitrous oxide, a powerful greenhouse gas, is released during the production and use of fertilizers) and negative impacts on health.

In agricultural production, complex protection of agricultural plants from pests, diseases and weeds is used. Its main principles are maximum stabilization of ecological balance and preservation of the existing agrobiocenosis, maintaining the number of pests below the economic threshold of harmfulness. This is achieved by complex plant protection, including agrotechnical, physical, biological and chemical methods. The use of chemical methods is allowed only when the number of harmful organisms exceeds the economic threshold of harmfulness. (Markevich, Nemirovich, 2004)

Unfortunately, there is no information on the use of pesticides in Azerbaijan. However, in our opinion, chemical plant protection products are used more intensively in the country's agriculture than in Western European countries. In short, the use of fertilizers and chemical plant protection products in agriculture is one of the most important environmental factors that ensure the sustainability of agricultural development, since, on the one hand, they contribute to increasing soil fertility, reducing the number of insect pests, weeds and diseases, and on the other hand, their use requires scientific justification.

The EU Climate Action Plan aims to reduce the use of pesticides that pollute soil, water and air by 50% and the use of fertilisers by 20% by 2030. Sales of antimicrobials for animals and aquaculture have fallen by 50%. It is planned to use 25% of agricultural land for organic farming. Organic farming plays an important role in the sustainable development strategy. The EU has allocated €86 million for campaigns on organic farming, sustainable agriculture and the role of the agri-food sector in the fight against climate change and pollution.

Investments in environmental protection and efficient use of natural resources are a prerequisite for achieving the target environmental indicators for the development of agriculture and rural areas, as well as reducing the negative impact on the environment

and reducing the vulnerability of the industry (Abbasova, Ibragimov, 2024). The volume of funds allocated to fixed capital for environmental protection and efficient use of natural resources in the country in 2023 compared to 2019 increased by 1.9 times - from 309,855.6 thousand manats to 594,991.4 thousand manats.

Thus, based on the results of a comprehensive analysis of the factors of sustainable development of agriculture in the Republic of Azerbaijan, we tried to identify the problems of ensuring the sustainability of agriculture and would like to highlight the most important of them: in the field of land use - loss of soil properties as a result of soil erosion, salinization, chemical pollution; in the social sphere - the standard of living is lower than in cities, incomplete solution of social problems in rural areas, unattractiveness of rural labor, as well as the departure of young people and the working population from rural areas or outside the country. In the institutional environment - it is possible to note the alignment and improvement of the legislative framework related to the sustainable development of agriculture with international requirements and standards. In a word, the transformation of agriculture into ecological agriculture is a requirement of the time.

In the context of environmental pollution, depletion of natural resources and growing demand, measures to expand the "green" economy to achieve sustainable development are also of great importance for our country. The fifth priority of "Azerbaijan 2030: National Priorities of Socioeconomic Development" is called "Clean Ecology and a Country of Green Development". The document defines specific tasks for the use of environmentally friendly technologies, stimulation of waste recycling and restoration of contaminated areas, as well as expansion of the use of environmentally friendly "green" technologies (NPSED, 2021). The following tasks are envisaged to minimize the burden on the environment: combating water shortages, inefficient use of natural resources, high energy consumption, unsustainable agricultural practices and food security issues, as well as efficient waste management. Therefore, an inclusive "green" economy requires a whole-of-society approach to the development of driving factors of economic development. The main focus is on sustainable means of production, as well as sustainable and responsible consumption of goods and services. This ensures maximum efficiency in the use of resources and reduction of waste throughout the economy. The holding of the Conference of the Parties to the UN Framework Convention on Climate Change (COP-29) in Baku also places great responsibility on our country in this direction.

Of course, the transition to a "green" economy will occur differently in different countries, since it directly depends on the natural, human, institutional, managerial and capital distribution characteristics of each country, its level of development and socio-economic priorities, and the environmental culture of society. Agriculture is one of the areas where the application of green economy methods helps to achieve high results. The green economy combines all structural components of agriculture and is based on the use of environmentally friendly technologies and production methods, sustainable use of land resources, biodiversity and water resources, as well as the development of environmental services and the management of natural resources. In addition, the green economy in agriculture assumes consideration of the socio-economic aspects of development, such as job creation, income growth and reduction of income inequality.

Many countries are successfully implementing the basics of the green economy concept. Countries such as the United States, Japan, and Australia have made significant progress in this direction. For example, in 2021, Australia ranked first in terms of land area allocated to organic agriculture (35.7 million hectares), followed by Argentina (4.1 million hectares) and France (2.8 million hectares) (ECFS, 2020).

In general, despite the problematic aspects noted above, we note positive trends. Such measures as providing subsidies and preferential loans to farmers, activating investment activities, strengthening the material and technical base, carrying out work to improve the living conditions of rural residents, organizing monitoring to reduce the negative impact on the environment, increasing funding for fixed capital for environmental protection and rational use of natural resources, increasing the economic efficiency of agricultural production, making integrated development of rural areas the main direction of the state's socio-economic policy, etc., will contribute to the formation of conditions for the sustainable development of the industry.

### 3 Conclusion

Our research showed the existence of differences between scientific and theoretical views on sustainable agriculture. Scientific and practical analysis of the relationship between economic, social and ecological aspects showed that sustainable development of agriculture can be achieved through an optimal combination of state regulation mechanisms and self-organization processes of agricultural systems.

To achieve sustainable development of the national economy, including agriculture, it is necessary to systematically take into account all three factors, and on this basis it is advisable to develop mechanisms and instruments that ensure quantitative and qualitative transformations.

Achieving efficient, competitive, sustainable and environmentally friendly agricultural production depends on the quality of the scientific basis for the organizational and economic mechanisms that ensure sustainable development of agriculture.

The concept of sustainable development of agriculture is inextricably linked with the growth of food production, the efficient use of economic and intellectual resources, the improvement of the well-being and quality of life of the rural population, and sustainable and balanced use of natural resources. Only with a balance of economic, social and environmental components can sustainable development of this sphere of production be ensured in the long term.

In our opinion, the organization of monitoring of sustainable development of agriculture will allow to substantiate the goals and priority tasks of regional policy of the state, to identify the causes of instability of development of agriculture, to assess the efficiency of agriculture, to substantiate measures of state support for development of the industry.

In order to achieve the goals of sustainable development of the industry, the transition to organic agriculture cannot be carried out without taking into account the specific features of the industry, the availability of “green” technologies, and the relationship between the results of agricultural production and environmental and energy efficiency.

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