

**KAPITEL 8 / CHAPTER 8⁸****THE IMPORTANCE OF AUTOMATION AND ELECTRIFICATION FOR SUSTAINABLE AGRICULTURAL DEVELOPMENT****DOI: 10.30890/2709-2313.2024-32-00-003****Introduction**

Efficient use of water and energy resources in agriculture today is impossible without automation and electrification of basic processes. The introduction of modern technologies for managing water and energy resources based on automated systems and alternative energy sources makes it possible to significantly optimize the work of farms. This is especially important in the context of global climate change and scarcity of natural resources, which requires new approaches to maintain sustainable agricultural production. Agriculture traditionally consumes significant amounts of water and energy, especially for irrigation, tillage and transportation of products. However, in the context of increasing resource scarcity and climate change, the task of transition to sustainable agriculture, focused on minimizing costs and reducing negative environmental impacts, is becoming increasingly urgent. Automation and electrification are key aspects of this approach, making it possible to modernize agricultural production, increase its efficiency and reduce dependence on external factors. Automation of agricultural processes allows you to control every stage of cultivation, watering and processing of products, which leads to increased productivity and reduced losses. For example, automated irrigation systems with sensors of soil moisture and ambient temperature help to precisely regulate the volume of water supply, which prevents excessive consumption of resources and improves conditions for plant growth. Such systems not only save water, but also significantly reduce labor costs, allowing farmers to manage their farms remotely and with a high degree of accuracy.

In addition, automation reduces dependence on climatic conditions, ensuring stable production even in adverse weather conditions. The introduction of smart control systems using artificial intelligence and predictive models allows processes to be

⁸**Authors:** Yusibov Faxraddin Murad, Orucova Nabat Qiyas, Imanova Natavan Mobil, Abbasov Camal Agaali, Mehdiyeva Camila Ismayil



adapted to weather changes and plant needs. This is especially important in regions with unstable climatic conditions, where farmers face risks of drought, floods and other natural disasters that can reduce yields [11,96-101].

In addition, automation allows you to manage resources more efficiently and increase productivity. For example, precision farming technologies make it possible to take into account the characteristics of each section of the field and adapt watering, fertilization and other agrotechnical measures to specific conditions. This contributes to a more rational use of resources and reduces the environmental burden, making agricultural production more environmentally sustainable. The use of electrification, in particular, renewable energy sources, reduces energy costs and makes farms less vulnerable to fluctuations in oil and gas prices. In recent years, farms have increasingly introduced solar panels and wind turbines to provide energy for irrigation systems, greenhouses and other agricultural machinery. In the context of rising fuel prices and increasing requirements for environmental friendliness of production, renewable energy sources have become an important component of sustainable agricultural production. Solar energy, due to its accessibility and relatively low installation cost, makes it possible to provide farms with a stable and environmentally friendly energy source. Installation of solar panels on greenhouse roofs, for example, can cover a significant part of the electricity needs to maintain an optimal microclimate. This not only reduces energy costs, but also makes production more environmentally friendly by reducing carbon dioxide emissions. Wind energy has also found its application in the agricultural sector, especially in regions with constant winds. Wind turbines help to provide energy to irrigation pumps and other equipment necessary for the efficient functioning of farms. The use of such technologies makes it possible to reduce dependence on traditional energy sources, which is especially important for remote regions where access to power grids may be limited or unavailable. Despite the obvious advantages, the introduction of automation and electrification in the agricultural industry is associated with a number of challenges. First of all, these are high initial costs for the installation and configuration of automated systems. For many farms, especially small and medium-sized ones, such investments can prove to be a serious



barrier. However, the availability of government support and subsidy programs makes technological innovations more accessible, helping to accelerate their implementation. Another challenge is the need for technical support and qualified maintenance of automated systems. Integrated management based on the Internet of Things, artificial intelligence and other technologies requires specific knowledge and skills that not all farmers possess. This creates a need for training and attracting specialists to work with the equipment, which may also require additional costs [3.15].

8.1. The history of the emergence and development of automation in agriculture

Automation of agriculture has a long and complex history, dating back to the 19th century. The evolution of this field has gone through several stages, each of which has brought new technologies and approaches aimed at increasing productivity and reducing manual labor costs. The changes that have taken place over the last century have radically changed the face of agriculture and prepared it for modern challenges related to sustainable development. In the 19th century, the mechanization of agriculture became possible due to the industrial revolution, which led to the development and mass production of the first mechanical devices for cultivating the land and harvesting crops. Before that, agriculture remained mainly a manual and labor-intensive process, limited by production capabilities. One of the first mechanisms were plows, harrows and seeders, which greatly facilitated the work of farmers. It is noteworthy that at this time steam tractors appeared, which were able to replace horses on farms. These machines made it possible to process large areas with less labor and time. An example of a significant invention of that time was the appearance of a threshing machine in 1834, which greatly simplified the process of threshing grain and became an important step towards the mechanization of agriculture. By the middle of the 20th century, agriculture had experienced another stage of technological breakthrough, when the first automated devices designed to perform tasks mechanically were developed. At that time, tractors with motor engines, combines, as



well as specialized machines for sowing, processing and harvesting appeared. Mass production of cars became possible thanks to the development of such industrial giants as John Deere and Ford. These companies began to produce tractors and other agricultural machinery, which began to be used by farmers around the world. The availability of technology has made it possible to significantly increase labor productivity and reduce dependence on human power, which is especially important in the conditions of large farms [5,34-39]. In addition to mechanization, the first systems for automatic control of work processes were also actively developed during this period. For example, mechanical irrigation control systems began to be introduced, which made it possible to automate the water supply, ensuring uniform soil moisture.

In the 1980s and 1990s, there was another leap in the development of agricultural technologies, which was associated with the advent of precision farming. The basis for its implementation were geographic information systems (GIS) and the global positioning system (GPS), which allowed farmers to more accurately monitor the condition of their fields and optimize resource allocation. The principles of precision farming involve the use of data on soil conditions, moisture levels, nutrient concentrations and climatic conditions to optimize work in the field. For example, with the help of GPS systems, farmers could automatically control the routes of machinery, ensuring even rows of crops and reducing crop losses due to improper seed distribution.

Precision farming has also led to the emergence of managed systems for fertilization and pesticide application, which has reduced the amount of chemicals used and increased the environmental sustainability of agriculture[6,53-56]. In the 1990s, companies began to develop special software solutions for processing data on the state of fields, which made farm management more centralized and efficient. The programs made it possible to monitor various parameters in real time, which became the basis for the subsequent implementation of automated control systems. In the 21st century, agriculture has entered a new stage of development, where information technologies such as the Internet of Things (IoT), artificial intelligence (AI) and big data analysis have begun to play a key role. These technologies have made it possible to create fully automated systems that are able to control and regulate every aspect of the production



process.

The Internet of Things (IoT) is a system that allows you to combine physical devices and sensors into a single network that can collect, analyze and transmit data in real time. In agriculture, IoT has opened up new opportunities to improve process management, increase productivity and rational use of resources. With it, farmers can control and optimize a variety of processes, from irrigation and lighting to monitoring plant and animal health. IoT provides accurate and up-to-date data, which is especially important for improving the efficiency and sustainability of agricultural production [9,78-80].

The use of IoT on farms and in greenhouses In agriculture, IoT sensors are installed throughout the production complex: in fields, greenhouses, storages and on equipment. Here are some common types of sensors and their functions: Temperature and light sensors allow you to maintain the necessary conditions for plant growth. For example, in greenhouses, temperature sensors help regulate heating, ventilation and lighting, ensuring a stable microclimate. Sensors for monitoring plant health record parameters such as chlorophyll levels and nitrogen content in leaves. This makes it possible to identify possible plant diseases in the early stages and take measures to preserve the harvest [12,30]. Weather stations with sensors for air humidity, wind speed, precipitation and other indicators allow you to predict weather changes and adjust plans for irrigation and other activities. Automated irrigation systems integrated with IoT are one of the most sought-after applications in agriculture. IoT systems allow you to start watering automatically based on data on soil moisture, weather conditions and plant needs. This is especially useful for crops that require precise moisture levels, such as vegetables and fruits. Thanks to IoT, farmers can optimize water use, reduce water losses and improve soil conditions. For example, if insufficient humidity is detected, the system automatically activates watering of the desired areas, preventing drought and improving conditions for plant growth. As a result, farmers can save up to 30-40% of water compared to traditional irrigation methods, which is especially important in conditions of water scarcity.

In addition to crop production, IoT is also widely used in animal husbandry.



Sensors mounted on animals can track their location, body temperature, activity level, and even behavior. This data helps farmers monitor the health and well-being of animals, detect signs of disease in a timely manner and prevent the spread of infections. For example, motion sensors can show how active animals are and help identify abnormalities that may indicate health problems. If the cow does not show normal activity or often lies down, this may indicate a disease, and the farmer can promptly call a veterinarian.

In addition, IoT allows you to optimize feeding processes, providing animals with food in the right amount and at the right time. In greenhouse complexes, maintaining a stable microclimate is critically important for plant growth. IoT systems allow you to control temperature, humidity, light level and carbon dioxide concentration. For example, on hot days, sensors can activate ventilation to lower the temperature in the greenhouse, or turn on heaters on cold days to protect plants from freezing. IoT systems also help to regulate the level of illumination, including additional lamps in conditions of insufficient sunlight. In this way, farmers can minimize energy costs by maintaining optimal conditions for crops. Some smart greenhouses are equipped with fully automated systems that control all parameters, including watering, heating, ventilation and lighting, which greatly simplifies plant care and allows you to increase yields [10.76-82].

One of the most significant IoT capabilities in agriculture is analysis and forecasting based on the collected data. The large amount of information coming from various sensors helps farmers make informed decisions, increasing the accuracy of resource management. Data on weather, soil, plants and animals can be processed using specialized software to identify patterns and predict the needs of the farm. For example, based on temperature and humidity data, it is possible to predict when plants will need additional watering or fertilizer. This helps to prevent overdrying or oversaturation of the soil, which has a positive effect on the condition of crops. The analysis of data on the condition of plants and soil also helps to determine the optimal timing for planting and harvesting, which is especially important for regions with a short growing season. IoT actively interacts with technologies such as artificial intelligence (AI), big data



analysis and unmanned aerial vehicles (drones). These technologies significantly expand the capabilities of IoT, making agricultural production even more accurate and economical.

8.2. Artificial Intelligence (AI) in agriculture

Artificial intelligence (AI) is becoming one of the key tools for improving the efficiency and sustainability of agriculture. Modern IoT-based systems generate huge amounts of data that can be analyzed using AI to obtain valuable information for managing resources and processes on farms. AI helps farmers make more informed and accurate decisions, allowing them to improve yields, reduce losses and minimize environmental impacts. Thanks to AI, farmers receive not just data, but a whole range of recommendations and forecasts that make their farms more profitable and sustainable. IoT systems collect data on humidity, temperature, illumination, soil composition, plant condition, weather conditions and many other parameters. AI processes this data set to reveal hidden patterns and dependencies. For example, AI systems can analyze long-term climate data to help farmers understand which types of crops are most resistant to local conditions and when it is best to plant. The analysis of patterns allows you to optimize the entire process of growing plants, from planting to harvesting, taking into account the specific conditions and needs of plants. One of the important applications of AI in agriculture is the prediction of plant water and nutrient needs. Based on data on weather, soil moisture, and plant health, AI can determine how much water plants will need in the coming days and weeks. This helps to avoid both excessive watering, which can leach nutrients from the soil and lead to their deficiency, and lack of moisture, which can negatively affect yields. AI can also help the farmer determine when and to what extent fertilizers should be applied. For example, based on data on soil conditions and plant growth rates, AI can predict when plants will begin to experience a deficiency of nutrients such as nitrogen, potassium and phosphorus.

This allows timely fertilization, improving crop quality and reducing fertilizer



costs due to their optimal use. AI is able to predict yields based on data on the current state of plants, climate and agrotechnical measures. Such forecasts help farmers plan the season and prepare for harvest, estimating how much produce they will be able to get. Yield forecasts also help farmers make decisions about the sale or storage of products, which is especially important for large market-oriented farms. In addition, AI helps farmers optimally allocate resources, including water, fertilizers and pesticides. For example, the AI can analyze data on the condition of plants and recommend which areas of the field need additional watering or fertilizer treatment and which do not. This reduces resource costs and improves the environmental performance of the farm. Artificial intelligence also plays an important role in monitoring plant health and detecting diseases and pests in the early stages. AI can analyze images of plants taken from drones or cameras and identify signs of disease, such as changes in leaf color or texture. Some systems use machine vision to detect small spots or damage that may be invisible to the human eye, but indicate the presence of infection or pest attacks.

Thanks to AI, farmers can quickly take measures to prevent the spread of diseases and pests, which reduces crop losses and minimizes the use of chemical pesticides. For example, if the AI detects signs of disease in one area of the field, the farmer can limit the processing of only this area, avoiding unnecessary consumption of chemicals and reducing harm to the environment. AI also allows you to automate many tasks on farms, which makes agriculture less labor-intensive and more productive. For example, AI systems can control robots for planting, watering, harvesting and even pruning plants. Such robots can work autonomously, using data from AI to make decisions about when and how to complete tasks. On vegetable and fruit farms, AI robots can harvest ripe fruits, determining their maturity by color and size. Unlike manual harvesting, such systems work faster and more efficiently, which reduces labor costs and improves product quality, since fruits and vegetables are harvested in an optimal state of maturity. AI robots can also carry out sowing and thinning of crops, ensuring a more even distribution of plants and improving conditions for their growth. In Australia, companies use AI to analyze soil and predict wheat yields, which helps farmers plan



planting and use resources efficiently. In the USA, farmers are actively using drones with cameras equipped with AI systems to monitor the condition of fields. Drones transmit images that the AI analyzes, determining the condition of plants and identifying potential problems. Robotic systems for picking strawberries and tomatoes have been introduced in Japan, which use AI to recognize the ripeness of fruits and their careful harvesting. This allows you to maintain high product quality and reduce the cost of manual labor. AI can use big data and climate models to analyze the impact of climate change on agriculture. For example, AI can process data on long-term changes in temperature and precipitation levels to predict how climatic conditions will affect yields in the future. This helps farmers adapt to changing conditions and choose sustainable crop varieties that better cope with extreme weather conditions. Big data also helps AI analyze seasonal fluctuations and predict periods of drought or frost, which allows farmers to prepare for extreme climatic conditions and minimize crop losses. This is especially relevant for regions prone to droughts and floods, where risk management is becoming an important part of agricultural strategy. Through precise management and monitoring of plant health, AI helps to increase agricultural productivity and improve product quality. AI allows you to optimize the consumption of water, fertilizers and pesticides, as well as reduce labor costs by automating tasks. AI also helps to reduce the use of chemicals, optimize irrigation and improve the environmental performance of the farm. Climate data analysis and forecasts help farmers adapt their strategies to changing conditions, which is especially important in the context of global warming. The use of AI in agriculture opens up new prospects for resource management, increasing productivity and sustainability of production. The integration of AI with IoT systems and big data analysis allows you to create comprehensive solutions that facilitate process management and reduce risks. In the future, AI will play an increasingly important role in agriculture, helping farmers adapt to climate change, minimize costs and improve environmental performance.



8.3. World experience in the implementation of automation and electrification in the agricultural industry

Agriculture around the world is facing a number of similar challenges, such as climate change, water scarcity, population growth and the need to improve food security. However, approaches to solving these problems vary depending on the conditions and technologies available in a particular country. Let's look at how different countries are implementing automation and electrification in agriculture, based on their unique needs and capabilities.

Israel: the use of drip irrigation systems for efficient water use Israel is one of the world leaders in the use of drip irrigation systems, which has allowed this country to significantly improve agricultural productivity even in conditions of severe water scarcity. The development of precision irrigation in Israel began in the middle of the 20th century, when the country faced an acute shortage of water resources. Drip irrigation, developed by Israeli engineers, allowed water to be supplied directly to the roots of plants, which minimized losses due to evaporation and seepage into the soil [2,45-57]. In addition, thanks to automatic control systems, drip irrigation can be adjusted to optimal volumes of water depending on the condition of the soil and the needs of plants. Today, Israeli farmers widely use IoT technologies to monitor and manage the irrigation system, which further reduces water consumption and increases crop productivity. Technologies developed in Israel are also actively exported to other drought-stricken countries such as India and South Africa, which contributes to improving water use on a global level.

USA: the use of drones and big data for crop management and forecasting The United States, one of the leading agricultural powers, is actively implementing automation, robotics and data analysis technologies to improve the efficiency of the agricultural industry. American farmers use drones to monitor the condition of fields and plants. Drones are equipped with cameras and sensors that record the condition of plants, soil moisture, the presence of weeds and pests. The data collected by drones allows farmers to make decisions quickly and minimize crop losses. Data collection



and analysis are also an important component of American agriculture. Farmers use big data and artificial intelligence to predict yields, plan crops, and monitor weather conditions. Such systems make it possible to estimate future harvest volumes and better manage resources. Sustainable agriculture support programs at the U.S. government level promote the introduction of energy-saving technologies, renewable energy sources and automated resource management systems, which help strengthen the resilience of agriculture to climate change. European Union: support for farmers through subsidizing automated systems and renewable energy sources The European Union actively supports the introduction of automation and renewable energy sources in agriculture.

Through programmes such as the Common Agricultural Policy (CAP), the EU provides subsidies to farmers who invest in automated management systems such as smart irrigation, precision farming and robotic assembly systems. These programs are aimed at reducing costs, improving environmental performance and increasing the sustainability of the agricultural sector [14]. The European Union also has strict environmental standards that encourage farmers to use environmentally friendly technologies and reduce carbon emissions. Farmers receive subsidies for the installation of solar panels, wind turbines and biogas plants, which helps them reduce energy costs and reduce the carbon footprint of farms. As a result, farmers can use energy for automated irrigation systems, greenhouse climate control, and other production-related tasks, making agriculture more environmentally sustainable and economically profitable. Japan: the use of robotic systems in crop production and greenhouses Japan, known for its high level of technological development, actively uses robotic systems in agriculture. Due to limited land resources and high population density, Japanese farmers are forced to look for ways to increase yields in limited areas, which has led to the massive introduction of automation and robotization.

In particular, Japan is actively using robotic systems in greenhouses, which makes it possible to create highly productive conditions for growing vegetables and fruits. Automatic harvesters equipped with artificial intelligence systems are used to harvest crops such as strawberries and tomatoes. These robots analyze the maturity of



fruits by color and size, which allows you to collect products in an ideal state of maturity. In addition, automatic microclimate control systems are used in greenhouses in Japan: temperature, humidity and lighting. These systems are integrated with sensors and analyze the condition of plants, which allows you to create optimal conditions for their growth. Technologies developed in Japan are also being actively implemented in other countries, as they help significantly reduce labor costs and ensure stable production of high-quality agricultural products. Japanese companies are investing in the development of smart greenhouses and robotic farms that can operate almost without human intervention, which creates opportunities to increase the sustainability of agriculture and expand its capabilities against the background of growing demand for food. World experience shows that automation and electrification of agriculture can significantly increase its efficiency and sustainability. Each country chooses the approaches that best suit its climatic conditions, available resources and economic priorities. The general trend is the desire to use technologies to optimize water and energy resources, improve environmental performance and reduce labor costs. Automation and electrification are the basis for the transition to sustainable agricultural production, capable of responding to the challenges of the modern world, including climate change and population growth.

Conclusion

The Internet of Things (IoT) has become an integral part of the modern agricultural industry, providing farmers with access to new opportunities to improve efficiency, manage resources and improve product quality. IoT technologies combine sensors, controllers, control systems and analytical software, which allows you to create complex automated systems that greatly facilitate the management of processes on farms. Thanks to these systems, agriculture becomes more sustainable, economical and productive. Let's take a closer look at the main advantages that the introduction of IoT brings to the agricultural industry. One of the key advantages of IoT is the ability



to accurately manage water and energy resources. In agriculture, irrigation and lighting are processes that require a large amount of resources, especially in arid regions or on farms located in places with limited access to water and electricity. IoT systems help to use these resources efficiently, minimizing costs.

Precise irrigation control: Moisture sensors installed in the soil collect information about the current moisture level and transmit it to the central control system, which analyzes the data and decides when and to which areas water needs to be supplied. Thus, IoT systems can prevent both insufficient and excessive watering by maintaining optimal conditions for plant growth. Optimization of energy consumption: In greenhouses, where significant costs are required to maintain a microclimate, IoT helps to control the lighting and ventilation system depending on weather conditions and the condition of plants. For example, the system can turn off the lighting during periods of high solar activity, which saves electricity. At night, the lighting is turned on at the minimum necessary level to maintain the vital activity of plants without wasting excessive resources. Saving water and energy not only reduces costs, but also reduces the impact of the farm on the environment, which is important for environmental sustainability. IoT systems play an important role in maintaining optimal conditions for crop growth, which helps to increase yields. Thanks to monitoring and analysis of data on soil, climate and plant condition, farmers can quickly make changes to growing conditions, providing plants with everything necessary for their healthy development [7,23-32].

Nutrient monitoring: IoT systems monitor the content of nutrients in the soil, such as nitrogen, phosphorus and potassium, and automatically transmit the data to the management system. This allows the farmer to apply fertilizers in a timely manner and maintain a balanced nutrition of plants, which contributes to their active growth and improvement of product quality [9,45-59] Minimizing the risk of diseases: In conditions where conditions for plant growth are maintained at an optimal level, the likelihood of diseases and damage from pests is reduced. IoT systems can also quickly detect signs of diseases or adverse conditions, which allows you to take action before the problem spreads and leads to crop loss. Increasing yields is especially important in



the context of population growth and increased demand for food. IoT helps to meet this demand without the need to increase the area for agricultural land. Automation of processes based on IoT technologies can significantly reduce the need for manual labor, which is a great advantage, especially for large farms and farms with a limited number of employees. IoT helps automate processes such as watering, fertilizing, monitoring plant health and even harvesting, which greatly simplifies the care of crops and animals. Automated irrigation and fertilizer systems: Thanks to IoT, farmers can configure irrigation and fertilizer systems so that they turn on automatically depending on soil condition and weather conditions. This reduces the need for manual management of these processes and frees up workers to perform other tasks. Animal monitoring and feeding management: IoT also plays an important role in animal husbandry. Sensors mounted on animals can monitor their condition and monitor feed intake, which makes it possible to automate and simplify the feeding and care processes. If the system detects a change in the behavior or appetite of an animal, this may indicate a disease, and farmers can take prompt action. Reducing labor costs makes it possible to save money on labor costs and makes the farm less dependent on the human factor, which is especially important in conditions of personnel shortages in the agricultural sector. One of the main advantages of IoT is the possibility of detailed monitoring and control of all processes taking place on the farm in real time. Sensors installed in soil, plants and animals collect data that is instantly processed and analyzed by the control system. This gives farmers accurate information about the condition of plants and animals, which allows them to make informed decisions [4,65-69]. Emergency prevention: IoT helps farmers to respond quickly to any changes in conditions, whether it is a sharp drop in temperature, a decrease in humidity or problems with the condition of plants. The system can automatically alert the farmer or even take necessary actions, such as turning on the heating in the greenhouse when it gets cold or activating irrigation when soil moisture decreases. Long-term planning: Data collected over long periods helps farmers better plan their work and adapt strategies. For example, data on plant water and nutrient requirements can be analyzed to optimize them for future seasons and to anticipate possible changes in conditions.



Improved monitoring and control allows farmers to manage resources more accurately and minimize risks associated with changing weather conditions and other factors. Agriculture is highly dependent on weather conditions, and climate change is creating new challenges for farmers around the world. IoT helps to increase resilience to these changes by providing accurate data and forecasts that enable farmers to adapt to conditions.

Adaptation to extreme conditions:

IoT systems provide farmers with data on current climatic conditions, which allows them to respond in a timely manner to phenomena such as droughts, frosts or heavy rains. For example, a farmer can adjust irrigation and fertilization based on drought forecasts to minimize crop losses. Forecasting and data analysis: The accumulated data allows you to create models and forecasts that help farmers better prepare for climate change. AI systems integrated with IoT can analyze this data and recommend actions to adapt to the expected conditions. Such adaptability helps to reduce losses caused by climate change and maintain a stable level of production, which is especially important in conditions of increasing food demand. IoT allows farmers not only to optimize the use of resources, but also to reduce the impact on the environment. The use of IoT in agriculture contributes to the development of more sustainable and environmentally friendly production methods, which is important for the conservation of ecosystems and the maintenance of biodiversity.

Reducing the use of chemicals: IoT systems help to minimize the consumption of fertilizers and pesticides, as they are used only where and when it is really necessary. This reduces the likelihood of chemicals entering groundwater and minimizes their negative impact on the environment. Reducing carbon emissions: The use of renewable energy sources and energy-saving technologies in combination with IoT helps to reduce greenhouse gas emissions, which helps to reduce the carbon footprint of the farm. IoT systems also help to control energy consumption, which makes agricultural production more environmentally friendly. Environmental sustainability is important for the long-term development of agriculture and the conservation of natural resources for future generations. IoT contributes to the transition to sustainable agricultural



production, which is becoming an important priority in the context of climate change and population growth [5,45-59]. These six benefits show how IoT is transforming agriculture, making it more efficient, sustainable and environmentally friendly. In the future, the role of IoT in the agricultural industry will only increase, providing farmers with more and more advanced tools for managing and adapting to new challenges. Despite the significant advantages that IoT technology has brought to agriculture, its implementation is associated with a number of serious challenges. These obstacles may limit the use of IoT, especially for small and medium-sized enterprises. The key challenges faced by farmers and agro-industrial enterprises when implementing IoT systems in their processes are discussed below. One of the most significant barriers to the introduction of IoT in agriculture is the high initial costs.

Installation and configuration of IoT systems require significant financial investments, including the purchase of equipment, installation of sensors, implementation of data processing software and employee training. These costs can be significant, especially for small farms that do not always have access to the necessary financing. The cost of equipment and installation: Sensors, controllers, communication devices and analytical software for IoT are not cheap, and installation costs can vary significantly depending on the size and specifics of the farm. The larger the area to cover, the higher the cost of purchasing and installing equipment.

1.Support and modernization: In addition to the initial costs, farmers must also consider the costs of maintenance and modernization of equipment. IoT technologies are developing rapidly and equipment is becoming obsolete, which creates the need for regular replacement of outdated components. These costs can become an insurmountable obstacle for small farmers, who often cannot afford large investments. In some countries, there are support programs for farmers offering subsidies for the introduction of technologies, but access to them is limited and they are not available everywhere.

2. The need for reliable Internet

For IoT systems to work successfully, a stable network connection is required, since IoT sensors and devices exchange data with the central system in real time.



However, in rural areas, especially in remote and hard-to-reach areas, it can be difficult to provide a high-quality Internet connection. This creates serious obstacles to the use of IoT technologies. Lack of network infrastructure: In some rural areas, there is no access to high-speed Internet, which makes the implementation of IoT systems impossible or severely limited. Without a stable connection, sensors can operate intermittently, and data can be transmitted non-operatively, which reduces the efficiency and reliability of the system. Connection and connectivity costs: In regions with low Internet coverage, installing equipment to ensure a reliable connection can become a significant cost item. In some cases, the installation of own communication stations or the use of satellite technologies is required, which further increases the cost of implementation. To solve these problems, there may be prospects for the development of data transmission technologies, such as satellite Internet, or the use of low-power local area networks, but these solutions are not yet available to most farms due to their high cost.

3. The complexity of maintenance and the need for technical support

IoT devices and sensors require regular maintenance and technical support, which may require additional costs and time. Agriculture has its own characteristics, and IoT equipment must withstand difficult operating conditions such as temperature fluctuations, high humidity and dustiness. Regular maintenance: Sensors installed in fields and greenhouses are prone to wear, especially in extreme climatic conditions. To keep the systems in working order, it is necessary to regularly inspect and maintain them, as well as replace worn or damaged parts. This requires time and additional costs, which can be burdensome for farmers, especially during peak season. The need for qualified personnel: The maintenance and management of IoT systems require certain skills and technical knowledge that may not be available to farm staff. In some cases, farmers are forced to hire specialists or contact companies providing technical support services, which increases costs and creates dependence on external contractors. Solving the problem of maintenance complexity requires efforts on the part of equipment manufacturers who can offer more reliable and easy-to-use systems capable of operating in aggressive conditions. Additional opportunities include farmer training



programs and the development of self-service technologies that minimize the need for human intervention.

4. Cybersecurity

The collection and storage of data from fields and farms require reliable means of protection against hacking and information leaks, since vulnerabilities in the system can lead to data loss or even the possibility of third-party control of equipment. The introduction of IoT in agriculture makes farms more vulnerable to cyber attacks, which can not only disrupt the operation of equipment, but also lead to financial losses. Data protection: The data that IoT devices collect contains important information about soil conditions, plants, weather conditions, and resource management. A security breach can lead to data leaks and damage to the farm, as the lost information can be used to the detriment of the farm or even by competitors. Remote control risks: If the system is hacked, attackers can gain access to control equipment such as irrigation, lighting and ventilation systems. This can lead to unintended malfunctions, such as excessive watering or equipment shutdown, which will affect the condition of plants and animals [15]. To protect farm IoT systems from cyber threats, regular software updates, the use of data encryption and strong passwords are necessary. However, this requires certain knowledge and skills from employees, which can be an additional challenge. In addition, in most cases, farmers do not have sufficient experience in cybersecurity issues, which makes protecting IoT systems on farms one of the most difficult tasks.

5. Compatibility and standardization issues

Agriculture involves many different processes, and IoT systems must ensure compatibility between different devices and platforms. However, the agricultural industry does not yet have uniform standards for IoT devices, which makes it difficult to integrate various systems. Hardware incompatibility: Different manufacturers of IoT equipment may use unique communication and data transfer protocols, which makes them incompatible with other companies' devices. This makes it difficult to create complex IoT systems where devices from different manufacturers must work together. Difficulties in updating and upgrading: Farmers may encounter a problem when updating or replacing one component requires replacing the entire system due to



incompatibility of the new equipment with existing devices. This complicates the modernization and increases the maintenance costs of IoT systems. To solve these problems, it is necessary to implement standards and protocols that will ensure compatibility between devices from different manufacturers. International organizations such as ISO and IEEE are already working on creating standards for IoT in agriculture, but the standardization process takes time. The introduction of IoT in agriculture is accompanied by a number of significant challenges that may limit the possibilities of using this technology, especially for small and medium-sized farms. High initial costs, problems with Internet connection, the need for maintenance, cybersecurity and lack of standards create barriers to the implementation of IoT, requiring an integrated approach to overcome them. Solving these problems will require the participation of various parties, including governments, equipment manufacturers and farmers' organizations, which can develop support programs and provide affordable technologies for all. In the long term, overcoming these challenges will significantly expand the capabilities of IoT in the agricultural industry, making agriculture more sustainable, cost-effective and environmentally friendly.

Automation and robotization of electrical systems in agriculture: prospects and technologies

Modern agricultural enterprises require highly efficient power management to perform tasks such as lighting, ventilation, heating, cooling, and climate control in greenhouses and storage facilities. Effective automation of these processes can significantly reduce energy consumption through the use of intelligent control systems that optimize the operation of equipment depending on current conditions. For example, automated lighting systems equipped with light and motion sensors provide optimal light levels only when necessary, which reduces energy consumption. Climate control systems with integrated temperature and humidity sensors regulate the operation of heaters, fans and air conditioners, maintaining the necessary microclimate and preventing energy overruns. Remote monitoring of electrical systems using Internet of Things (IoT) technologies provides farmers with access to real-time equipment status data. This is especially important for large farms, where the control



of many facilities can be difficult without automation. IoT devices not only signal system failures, but also allow for preventive maintenance, preventing breakdowns. For example, automatic monitoring of the load level on electrical networks helps to prevent overheating of equipment and emergency situations. In addition, the use of intelligent power systems with peak load management function allows you to redistribute electricity depending on its availability and cost. Such systems may include backup power sources, such as batteries or generators, which ensures uninterrupted operation in conditions of unstable power supply. Modern agricultural enterprises require highly efficient power management for tasks such as lighting, ventilation, heating, cooling and maintaining a microclimate in greenhouses and storages. The integration of automated electrical systems makes it possible to significantly improve energy resource management, minimize losses and ensure optimal conditions for agricultural production. For example, automated lighting systems equipped with intelligent light, time of day and motion sensors adapt the light intensity depending on the need. This is especially important for greenhouses, where year-round production requires strict control over lighting levels. At the same time, circuit breakers prevent unnecessary power consumption in empty areas. Ventilation and air conditioning systems with artificial intelligence elements analyze the current environmental parameters and adjust their work to achieve a balance between energy efficiency and maintaining the required conditions. For example, on hot days, such systems can control the distribution of air flows to avoid overheating of equipment and products, and in cold periods, activate economical heating. Remote control of electrical systems via the Internet of Things (IoT) provides farmers with the opportunity not only to monitor the state of the infrastructure, but also to make changes in real time. This is especially useful for preventing emergencies. For example, if deviations in energy consumption are detected, the system can automatically reduce the load on overloaded sections of the network or switch to alternative energy sources. In addition, intelligent energy management systems allow you to redistribute the load between different parts of the farm, reducing peak energy consumption. This is achieved through a programmable schedule of energy-consuming equipment, which is especially



important in the context of rising electricity tariffs. The use of electrical systems is evident in robotic milking machines and feeding systems that operate with a high degree of precision and automation. Such systems play a key role in optimizing livestock production processes, reducing labor costs and increasing productivity. Robotic milking machines are equipped with intelligent sensors that identify each cow, analyze its physiological state and automatically regulate the milking process. This allows you to maintain high milk quality, avoiding damage to the udder, and ensures the comfort of the animals. Thanks to automatic monitoring of the condition of cows, farmers receive real-time data on animal health, which helps to identify possible problems in a timely manner and take preventive measures. Automatic feeding systems are also based on electrical technologies and integrated control algorithms. These systems calculate individual feed rates for each animal based on its weight, age and productivity. The electrical components ensure accurate dosing of feed and its uniform distribution, which minimizes waste and improves the diet of animals. Some systems are equipped with a feed composition analysis function, which helps to adapt nutrition to the current needs of the herd. Integration of artificial intelligence into electrical systems Artificial intelligence has become an integral part of modern agricultural electrical systems. With the help of AI, automated systems can analyze data on soil conditions, plants, weather and animal needs in order to predict energy consumption in advance. For example, AI can regulate the operation of solar panels or wind turbines, ensuring an uninterrupted supply of energy in changeable weather conditions. In addition, AI systems are able to automatically detect the need for equipment repairs, which reduces the risks of downtime and emergencies. The use of renewable energy sources, such as solar panels and wind turbines, is becoming an important element of the robotization of electrical systems. The introduction of autonomous power supply systems makes it possible to ensure the smooth operation of robots and automated installations even in remote areas. For example, on sunny days, electric irrigation systems can be fully powered by solar panels, which significantly reduces energy costs. Despite the obvious advantages, the introduction of automated and robotic systems is associated with a number of challenges. The main obstacle remains the high initial



costs of equipment installation and maintenance. In addition, agricultural enterprises often face a shortage of qualified specialists capable of managing and maintaining such systems. Another challenge is to provide a reliable Internet connection for IoT devices, especially in remote areas. Without a stable connection, the systems lose their efficiency, which requires additional infrastructure costs. Automation and robotization of electrical systems in agriculture open up new opportunities to increase productivity, minimize costs and improve environmental sustainability. The integration of innovative technologies with traditional methods makes it possible to adapt the agricultural industry to modern challenges such as climate change and lack of resources. Support for the implementation of such systems at the state level and the development of infrastructure will help accelerate this process, making agriculture more efficient and sustainable.

Prospects and challenges of sustainable agricultural development

Sustainable agricultural development is becoming an increasingly urgent task at the global level, as climate change, population growth and limited natural resources create unprecedented challenges for the agricultural industry. In this regard, automation, the use of renewable energy sources, precision farming technologies and IoT are becoming key elements that can transform agriculture, making it more efficient and environmentally sustainable. Agriculture around the world faces different challenges depending on climatic conditions, economic situation and the level of technology development in each country. However, despite the differences, the prospects for the introduction of advanced technologies in the agricultural industry are obvious for all regions. Countries with highly developed infrastructure, such as the United States, Japan and the European Union, are actively developing automation, robotics and IoT integration on farms. These technologies help to improve resource management, minimize costs and increase productivity. In developing countries such as India, Brazil and African countries, there is also a growing interest in sustainable technologies. Here, the introduction of automation and renewable energy sources helps farmers solve problems related to water scarcity and energy dependence. For example, the use of solar panels for autonomous power supply of agricultural devices allows you to save on electricity and reduces the impact on the environment. Technologies are of



particular importance in regions prone to frequent droughts and extreme weather conditions. Here, precision farming based on monitoring soil moisture, microclimate and plant needs becomes an important tool for ensuring food security and adaptation to climate change. Key challenges: investments, qualified services, climate change and access to natural resources. Despite significant prospects, sustainable agricultural development faces a number of challenges that limit the pace of technology adoption. One of the most serious obstacles is the high investment costs. The installation of automated irrigation systems, robotic assembly devices and IoT sensors requires significant financial investments that may not be available for small and medium-sized farms. The need for qualified service is also difficult, as modern management systems require specialized knowledge and skills that are not always available to farmers, especially in rural areas. In addition, agriculture remains vulnerable to climate change. Extreme weather conditions such as droughts, floods and temperature anomalies negatively affect agricultural productivity and increase the need for adaptive technologies. However, the introduction of such technologies also requires financial investments and organizational support. Another challenge is access to natural resources, especially water. With the growing demand for food and increasing pressures on water resources, the issue of effective water use is becoming critically important. Precision irrigation technologies and IoT-based water management can help solve this problem, but access to such technologies remains limited for many farmers, especially in low-income regions. Support from Governments and international organizations as an incentive for sustainable development. Support from Governments, international organizations and the private sector is needed to accelerate the introduction of sustainable technologies in agriculture. Government subsidy programs and grant support can help reduce financial barriers and increase access to technology for farmers. Programs offering financial assistance for the purchase of equipment or tax incentives can be an important incentive for the transition to more sustainable agricultural production methods. International organizations such as the Food and Agriculture Organization of the United Nations (FAO), the World Bank and the International Fund for Agricultural Development (IFAD) also play an important role in supporting sustainable agriculture. These organizations offer grants and loans to developing countries, finance educational programs and research, and facilitate the



exchange of knowledge and technology between countries. In addition, an important factor in the development of sustainable agriculture is the exchange of experience and knowledge. International platforms and conferences, where farmers, scientists and representatives of the private sector share their achievements and best practices, accelerate the spread of innovations and help develop new solutions for agriculture. The prospects for sustainable agricultural development largely depend on the integration of advanced technologies capable of adapting the agricultural industry to new challenges. However, successful technology adoption requires a comprehensive approach that includes financial support, access to educational programs and international cooperation. In the context of population growth and climate change, advanced agriculture should be based on the principles of sustainability, efficiency and environmental friendliness. Automation, robotics, the use of IoT and renewable energy sources open up new opportunities to increase productivity and reduce the impact on nature. Support from Governments and international organizations plays a key role in this process, helping to accelerate the transition to sustainable production methods and ensure food security at the global level.