Technological steps towards adaptation and mitigation of the rural economy of Siberia to climate change

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Abstract. The paper presents the results of a scoping study of the possibility of applying various practices of agricultural production adaptation to existing and potential climatic changes to the conditions of the West Siberian economic region. It is assumed that already in the medium term, the agro-industrial complex of the macro-region will face new defining challenges in terms of climate change impact on everyday production processes and the need to respond by developing sustainable strategies to overcome them and adapt to them. The concept of agriculture as a climate-responsible sector is introduced. In this regard, the possibility of developing a unified adaptation mechanism for agriculture in Siberian regions through a combination of economic, research and social practices while maintaining familiar forms and tools of production is considered. In addition, the main barriers to adaptation of the agro-industrial complex of Western Siberia to climate change are presented, and comments are given on possible ways to overcome them while maintaining the growth rate of the industry and the nature of economic activity, including in regions with traditional forms of management.

1 Introduction

Agriculture continues to be one of the most significant anthropogenic sources of climate change worldwide. In this regard, in international practice, agricultural production is increasingly beginning to be under close audit by regulatory authorities and local non-profit environmental organizations. According to estimates by the Food and Agriculture Organization of the United Nations, an increase in the world population by 2050 will lead to the need to increase food production by more than 70%. [1] The key contribution of agriculture to solving the problem of overpopulation of the Earth remains logical, however, on the other hand, it requires a policy of adaptation of agriculture to climate change and a focus on mitigating existing climatic impacts. At the same time, the fixed and actively used term "climate-optimized agriculture" characterizes the approach in which policies aimed at food security and climate change are implemented, while at the same time contributing to mitigating the effects of greenhouse gas emissions.

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The Russian Federation continues to be one of the largest producers and exporters of agricultural products. According to FAOSTAT estimates, Russia holds a leading position in the field of crop production and, as of the end of 2021, held a share of 9.9% of the total volume of wheat produced. [2] The production volume amounted to 76 million tons. In this regard, Russia is one of the key stakeholders in the problem of climate change and the impact of agricultural production on them. A significant increase in production since the early 2000s is directly correlated with an increase in greenhouse gas emissions. Russia is one of the 10 largest countries in terms of greenhouse gas emissions, and since 2006, greenhouse gas emissions from agriculture have increased by 11.93%.

The search for optimal ways to adapt the agricultural industry, taking into account mainly traditional farming practices in certain territories of Greater Siberia and the Far East, is an urgent research and applied task. The researchers note that already in the medium-term time horizon, the problem of the effects of climate change will significantly affect the efficiency of agricultural production and, as a result, the economic efficiency of economic entities, which even today do not differ in stability and stability, while maintaining a certain degree of conservatism regarding technologies and tools with an innovative component.

The initiatives of the world's leading development institutions are known, which are focused on the introduction of practices of strict compliance with emission standards, which leads to crisis situations regarding the need for a sharp reduction in livestock production and the emergence of an unfavorable economic climate for farmers interested in maintaining their own agricultural business. [3] Such practices are unacceptable for the economic foundations of rural Russia, the loss of livestock is in many ways a tragic situation, voluntary slaughter due to the need to comply with the climate agenda is unlikely to be positively perceived in the professional environment. Taking into account the mentality, the traditional nature of farming, the peculiarities of the socio-economic situation of the village, and possible distrust of the next innovations on the part of the state is highly desirable when preparing and developing an adaptation strategy for agriculture. Most likely, the regions that are in the "gray" risk zone regarding both climate change and agriculture will require the most attention. It is customary to refer to such regions as the territory of the Siberian macroregion, mainly focused on the extraction and processing of so-called “minerals”, oil and gas.

2 Materials and methods

The study is based on the analysis of statistical data on the dynamics of agricultural production and its contribution to the formation of the carbon footprint provided by national and international services (Rosstat, FAOSTAT), as well as the study of the possibility of applying certain practices of adaptation of agriculture to climate change, taking into account the specifics of agricultural production in the regions of the West Siberian Economic Region, including solutions, proposed by OECD, FAO. The main methodological technique is the use of a combination of methods such as problem-representative research (in relation to international experience), content analysis (in relation to statistical and analytical data), the Rapid Foresight method (in relation to the development of a point of view on a single mechanism for adapting agriculture in the regions of Siberia through a combination of economic, research and social practices with preserving the usual forms and tools of production). The aim of the study is to form a full-fledged scientifically based picture of the possibility of applying various practices of adapting agricultural production to existing and potential climate changes to the conditions of the Siberian Federal District, including through the development of a single mechanism that takes into account regional and industrial specifics.

3 Results

The climate agenda is becoming one of the leading topics in the global community. Almost every month, more and more new risks are announced, as well as measures to combat them, which do not always find a positive response in the public environment. One of the most discussed economic segments in this regard is agriculture. It is assumed that it was a significant increase in food production as a result of an increase in the world's population that led to a significant increase in greenhouse gas emissions. Climate change, stimulated by emissions of substances into the atmosphere, leads to changes in temperature conditions, degradation of ecosystems, as well as the emergence of risks associated with natural disasters and emergencies. [4]

According to FAO, every support is needed for climate-optimized agriculture, which "aims to provide the means to integrate the characteristics of the adaptation process and mitigate their consequences into sustainable agricultural development policies, programs and investments."

Russia, as an active participant in the international community and UN programs, is actively involved in the implementation of the Sustainable Development Goals and policies to ensure the search and implementation of solutions to combat the acceleration of climate change. At the same time, the country is one of the 5 largest agricultural producers, which makes it obvious that it is urgent and necessary to integrate Russia into international practices to reduce climate risks. Agriculture contributes to the increase in carbon dioxide emissions by increasing land use and reducing the space of CO_2 absorption mechanisms (forests, organic soils).

Direct and indirect agricultural emissions related to land use are accounted for in the agriculture, forestry and other land use (AFOLU) sector. Collectively, emissions from the AFOLU sector include greenhouse gases produced by agriculture (non-CO_2), net CO_2 emissions from soils used in agriculture, and net CO_2 emissions from deforestation and other land uses (FOLU).

Emissions from the AFOLU sector are increasing as a result of the expansion of agricultural land, an increase in livestock numbers and more intensive use of soil and fertilizers. Livestock and especially ruminants are the largest source of direct emissions and the main cause of land-use changes. In addition, synthetic fertilizers also contribute greatly to direct emissions from agriculture. [5]

The agricultural industry contributes to climate change through both direct and indirect greenhouse gas emissions and impacts on soil resources. [6] In terms of the absolute volume of greenhouse gas emissions, agriculture closes the list of the leading sectors of the Russian economy. According to the Federal State Statistics Service, in 2020, enterprises of the agro-industrial complex of Russia emitted greenhouse gases in the amount of 116.6 million tons of CO_2—eq., which is slightly more than the value of 2019 - 114.0 million tons of CO_2-eq. In the time range since 1990, there has been a dynamic decrease in emissions and a reduction in the share of emissions from this sector in the total volume. Both crop and livestock enterprises contribute to greenhouse gas emissions. The most significant source of emissions in the crop sector of the Russian Federation is the cultivation of agricultural land, where emissions in 2020 amounted to 62.9 million tons of CO_2-eq. In animal husbandry, the reason for the emission of more greenhouse gases, namely methane, is internal fermentation in farm animals (39.0 million tons of CO_2-eq. in 2020).

At the same time, the livestock sector itself is one of the largest sources of anthropogenic greenhouse gas emissions — it accounts for 5.8% of total global emissions, of which 95% are methane. Methane, like carbon dioxide, is a gas with high global warming potential, but it, in turn, contributes more to global climate change than other greenhouse gases. Researchers from the Intergovernmental Panel on Climate Change (IPCC) have estimated that since 1990, the production of meat, milk and eggs in the world has increased 1.6 times in less than 30 years. According to scientists' forecasts, production will only increase. If the livestock sector continues to operate without the introduction of low-carbon practices, by 2030, emissions from the agricultural sector will amount to 49% of all greenhouse gas emissions in the world. [7]

Indeed, due to global climate change, the temperature and natural conditions in some regions of Russia are becoming more favorable for agriculture than it was before. In addition to the benefits of increasing agricultural production in Russia due to the expansion of acreage, climate change also carries risks associated with crop losses due to natural disasters caused by climate change. [8] That is why agricultural producers cannot ignore measures to adapt and combat climate change. The increase in average annual temperatures in the country opens up new opportunities for the regions within their agricultural potential. [9]

In Russia, it has warmed by 0.47 degrees Celsius in 10 years, while the global average is 0.18 degrees Celsius. Such temperature changes create favorable conditions for farming in regions where it was not possible before. For example, a new wine—growing region has appeared - the Lower Volga in the Volgograd region, where 20 years ago low temperatures were a deterrent to the development of industrial viticulture. The total area of vineyards in 2021 was 81 hectares, of which almost 68 hectares were fertile. Compared to 2015, the size of grape plantations increased by 21%. [10]

In the 2018 FAO report on the impact of climate change on agricultural production and trade in the world, agricultural production is projected to grow markedly by 2050 in regions with a more temperate climate: in particular, in Russia — by 0.9%. Nevertheless, the effects of climate change are beneficial in Russia only locally. The consequences are extremely negative for a number of regions, with increasing droughts and heavy rainfall.

For example, in Siberia and the Urals, a significant negative trend is observed in the summer period: against the background of a rapid increase in average temperatures, moisture availability decreases, which, in turn, leads to an increase in the risk of drought, which carries serious risks for the entire agro-industrial complex. [11] In 2023, following the results of one of the hottest summer seasons in the history of observations in Siberia, insurance companies tentatively estimated the amount of damage to Siberian farmers from drought at 100 million rubles. The largest amount of this amount is 50 million rubles. — it falls on the Omsk region, where crops on an area of about 50 thousand hectares were lost. The Novosibirsk and Tomsk regions and the Altai Territory also applied for insurance events. In a number of subjects, a 35% decrease in yield is predicted. In the Novosibirsk region, according to the regional Ministry of Agriculture, 240 thousand hectares of acreage died and suffered due to soil drought, which is about 10% of the total (about 2.4 million hectares were sown in 2023). The West Siberian Hydrometeorological Center predicted a decrease in the yield of winter crops in the region by up to 20%. [12]

It can be assumed that the effects of climate change will become more noticeable every year, but already agricultural producers are increasingly losing crops due to unstable weather conditions. The most difficult factor for sustainable agriculture is the low predictability of weather, which complicates the process of adapting to climate change and preserving crops.

As you know, global warming in the Siberian regions, and in particular in the Arctic zone, is faster than the average in Russia. This is clearly seen in Figure 1, which shows the trends in the average annual temperature in Siberia in the period from 1950 to 2020. [13]

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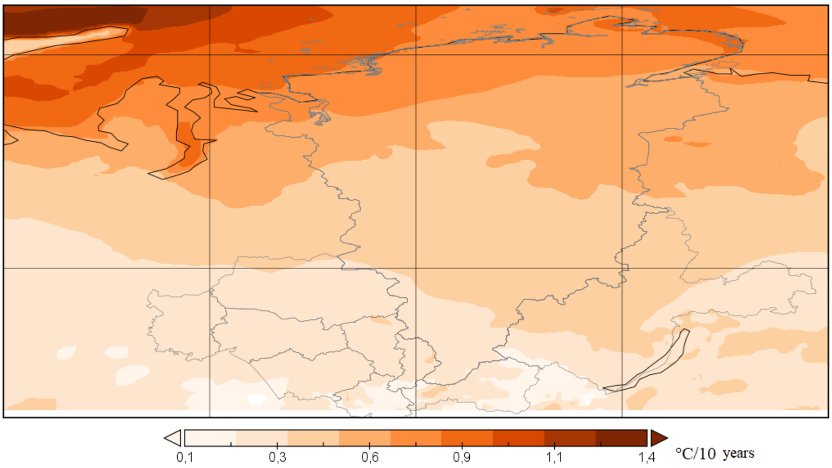

Fig. 1. Trends in changes in the average annual air temperature in the study area for the period 1950-2020

The maximum values of the average annual temperature change (up to +1 °C / 10 years) are observed in the north of the Krasnoyarsk Territory. Minimum (+0.1... +0.2 °C) – in mountainous areas in the south of the territory. It should be noted that all trends are positive and statistically significant.

At the same time, if we look at the temperature change in May, the key month in the agricultural season, when most of the spring field work is carried out, then, on the contrary, the greatest change is observed in the southern part of the Siberian macroregion (Fig. 2). The change in the average annual temperature in Figure 2 is presented as a scatter diagram.

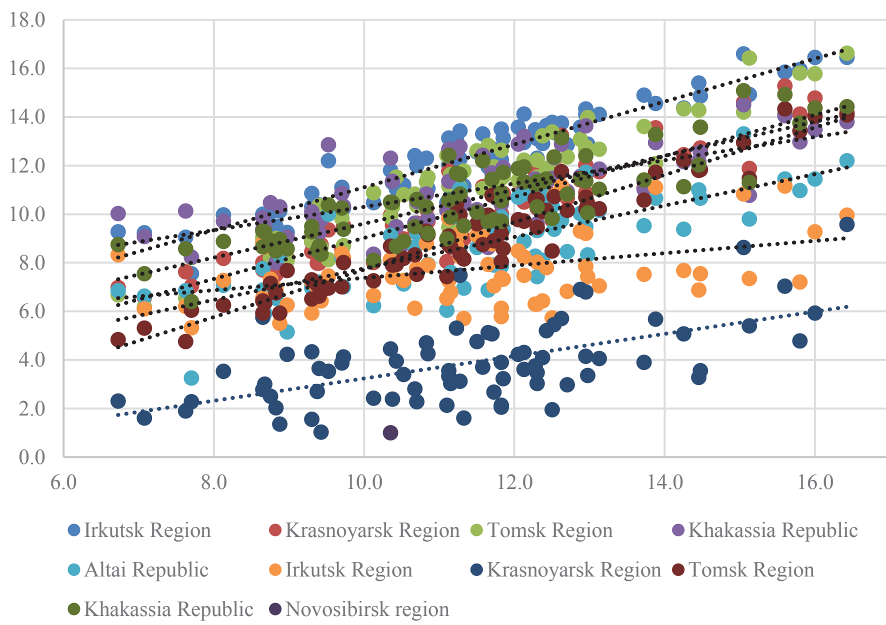

Fig. 2. Scatter diagram of the dynamics of the temperature of the subjects of the Siberian Federal District in May from 1950 to 2023

Figure 2 is based on data on the average temperature in May at four points in each subject of the Siberian Federal District, where the weather stations are located – north, south, east and west. This was done due to the large area of Siberian territories and the possible bias of temperature data in one locality.

The graph shows an increasing trend of the studied indicator in all regions of Siberia. The greatest temperature increase in the period from 1950 to 2023 occurred in Novosibirsk (+12.6%), Tomsk (+14.7%) and Omsk regions (+29.9%), Krasnoyarsk Territory (+15.2%). On average, it is 1-1.3 degrees Celsius in 53 years.

The ongoing and expected future climatic changes cannot but affect the change in the agrometeorological conditions of the territories under consideration. There are a number of models that take into account the dependence of crop yields on agrometeorological indicators. In addition to individual meteorological characteristics, complex indicators can be used as predictors in model calculations – hydrothermal indices characterizing the degree of aridity/moisture content of the territory. Currently, the Selyaninov hydrothermal coefficient (SHC) is widely used in the practice of Roshydromet as the main quantitative indicator of the ratio of heat and moisture. The distribution of SCC is in good agreement with geobotanical zones and, in fact, reflects the differentiation of landscapes.

Figure 3 shows a diagram of the distribution of the average long-term value of the Selyaninov SHC over the territory of Siberia.

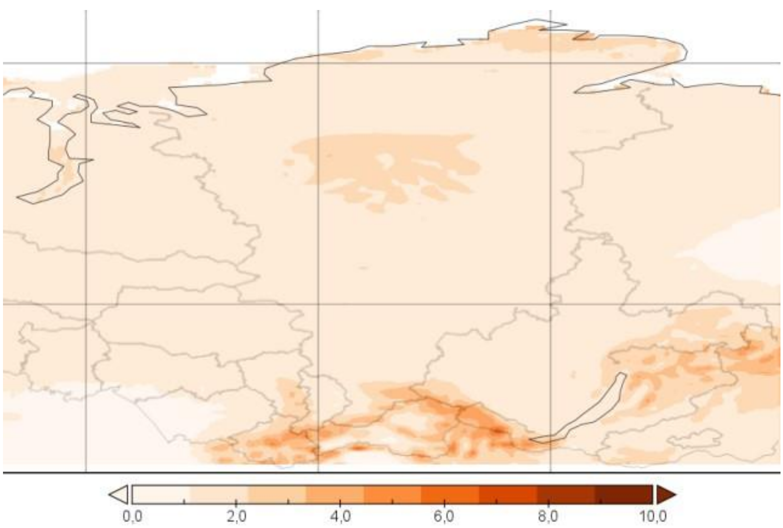

Fig. 3. Distribution diagram of the average long-term value of Selyaninov's GTK over the territory of Siberia

The analysis of the SCC in Siberia showed that over a long period of time statistically significant changes in the indicator occur in most of the territory of the Irkutsk region, in the east of the Krasnoyarsk Territory and in the southern regions of the Altai Republic and the Republic of Tyva. In these areas, there is a decrease in the average GTC value, which indicates an increase in aridity.

The authors also conducted a study on increasing the duration of frost-free and growing seasons.

Trends in the series of temperature transition dates after 0 °C indicate an increase in the period with positive air temperatures mainly due to the shift of the transition dates in spring to earlier dates. Statistically significant trends in transition dates (-1...-1.5 days every 10 years) in spring occupy almost the entire study area. In most cases, the trends of change in autumn are not significant.

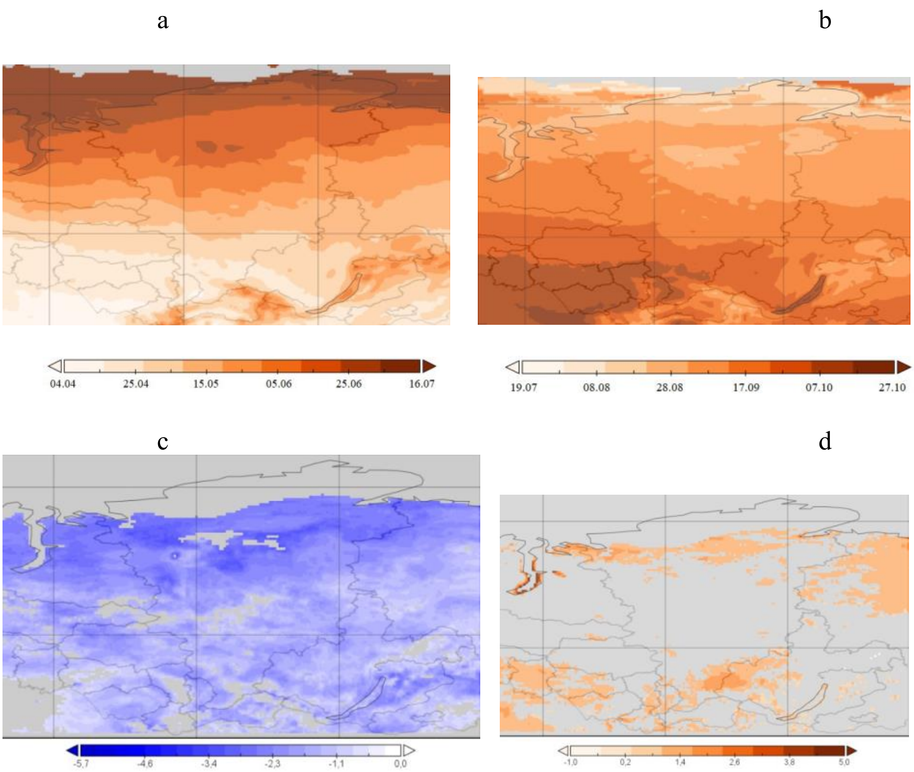

Fig. 4. Dates of air temperature transition through +5°C in spring (a) and autumn (b), these dates change (days/10 years), there are (c, d)

As the analysis of key indicators of climate change has shown, significant transformations of natural and climatic conditions are taking place in the Siberian regions: in the taiga zone, signs favorable for the forest zone appear, in the forest-steppe zone – for the steppe, etc. I.e., in the northern regions of the macroregion, the humidification of the climate decreases, in the southern ones, on the contrary, it increases. The most dynamic changes are observed in the Krasnoyarsk Territory, which in the long term will have the most favorable conditions for agricultural production in Siberia.

The southern regions, such as the republics of Altai, Tyva and Altai Krai, are characterized mainly by the adverse effects of climate change, which are expressed by an increase in the aridity of the climate.

Table 1 provides more detailed information on climate change in the Siberian regions and their impact on the rural economy.

Table 1. Estimated impact of climate change on the rural economy of Siberian regions

The subject of the Siberian Federal District	Projected climate change	Impact on the rural economy
Republic of Altai	The southeast is a semi–desert, the shift of the humidification zone to the north.	Reduction of acreage and pastures. Diversification of the rural economy, moving away from agriculture.

The Republic of Tyva	The predominant zone of excessive waterlogging. The southwest is semi-desert. In the central regions, the displacement of zones is up to 200 km.	The strong negative impact of climate change on the rural economy.
Republic of Khakassia	There are no significant changes	Introduction of new areas into agricultural circulation.
Altai Territory	The expansion of the steppe zone, the reduction of the forest-steppe. The displacement of zones up to 150 km to the northeast.	Cultivation of drought-resistant crops, reduction of grain production.
Krasnoyarsk Territory	Reduction of the area of excess humidification zones, expansion of the zone of provided humidification. In the east, the appearance of forest–steppe landscapes.	Expansion of crops of spring wheat, oilseeds and legumes. Cultivation of winter crops. The possibility of using late-ripening varieties in the south of the region.
Novosibirsk region	The expansion of the northern boundaries of the zones – provided and excessive moisture up to 100 km, the arid zone in the south of the region – up to 75 km.	Expansion of the acreage of grain and leguminous crops by reducing the area of swamps.
Omsk region	A decrease in the moisture content of the territory, with the movement of the zone boundaries in a northerly direction.	Adverse impact on the rural economy.
Tomsk region	The displacement of the excess moisture zone to the north is up to 150 km. The entire territory of the region is an area of excessive moisture.	Possible increase in crop production by reducing the area of swamps.
Irkutsk region	An increase in the area of arid zones by 40-60 km to the south. There is waterlogging in the central areas.	Adverse effects on crop production.
Kemerovo region	Zones of provided and excessive moisture prevail.	Diversification of crop production

Thus, the projected climate changes in the long term will have a significant impact on agricultural production, its structure and development directions. In addition, the rural economy itself will be transformed. In some regions, this is a departure from the predominant share of agricultural production and the emergence of new types of non–agricultural activities. In others, on the contrary, the increase and diversification of agriculture.

The assessment of climate risks and the development and implementation of climate strategies in companies in the agricultural sector is economically feasible. The effects of climate change can play both a positive and a negative role in the conduct of agricultural activities and in the development of the rural economy of the Siberian regions.

As a supporting document in the framework of preventing and reducing climate risks in Russia, the development of sectoral and regional plans for adaptation to climate change was launched. In 2022, such plans were approved for 7 subjects: the Republic of Crimea, Belgorod, Volgograd, Vologda, Kemerovo, Kursk and Penza regions. The documents include measures to introduce environmentally safe and effective methods of adapting production to changing climatic conditions. The list of sectoral adaptation plans contains a plan for the agro-industrial complex and fisheries. The document notes the important role of long-term forecasting as a way to withstand the effects of abnormal weather events.

4 Discussion

Addressing the issue of optimal economic activity in the context of global climate change can have very large economic, social and political consequences. Reducing greenhouse gas emissions will slow down economic growth in many sectors of the economy. Therefore, it is necessary to find such a balanced solution that will be optimal both for the economic activity of the country and for the surrounding ecosystems.

It is extremely important to significantly increase the level of scientific research on all problematic aspects of climate change. This is a wide range of issues, many times exceeding the current level of research on this topic. It is necessary to substantiate the safest and most economically accessible ways of adapting economic activities to global climate change. [14]

Agriculture has the largest share in the structure of demand for investments in the adaptation of economic sectors – 23%. Adaptation technologies in this industry have a high multiplicative effect due to:

1) the strategic importance of agricultural production for ensuring food security and vital activity of the population and its most important role and contribution to the formation of GDP (exports);

2) the most important role and contribution of industries to emissions (agriculture – 31%, loss of food products – up to 6%) and absorption due to agroforestry. [15]

Thus, technologies for adaptation and mitigation of climate change can become a growth driver for the agro-industrial complex, as they are able to provide the greatest efficiency compared to other industries.

The study of international and national experience in developing solutions for the adaptation of agriculture to climate change, combined with an analysis of the regional situation with risk factors for the deterioration of the climatic situation and regional specifics of farming, allows us to form a list of primary tactical steps to adapt agriculture in Siberia to climate change. It should be noted that this list of steps needs to be implemented in close cooperation with the community of agricultural producers, as well as taking into account the complexity of the impact, which will increase the effectiveness of adaptation processes.

The technological directions of adaptation of the rural economy to climate change include the following:

1. Development of new technologies and plant varieties resistant to climate change, adapted to the conditions of areas with a difficult climatic situation.

2. Improving the efficiency of the irrigation and humidification system of crops, including through the rational use of alternative water sources.

3. Intensification of the use of organic methods of raising livestock and poultry, increasing the importance of practices to ensure the welfare of farm animals (better feeding and maintenance conditions).

4. Expansion and improvement of measures for the economical use of natural resources, including measures to preserve highly fertile soils, reduce the amount of degraded land, eliminate inefficient forest management practices.

5. Education and support for rural populations in the field of sustainable agriculture and environmental practices, including consultations, trainings, and public educational events.

At the same time, a prerequisite for the introduction of adaptation technologies should be taking into account the risks of food security of the country, a balance is needed between economic efficiency and the impact on the surrounding ecosystems. [16]

The growing volumes of agricultural production due to both intensification and extensive expansion lead to a corresponding increase in the contribution of industries to atmospheric emissions. In this regard, it is necessary to search for such technologies to mitigate the impact on climate change (mitigation) that will be able to meet the increasing demand for food and at the same time reduce greenhouse gas emissions and ensure resource conservation. [17]

The key technologies for mitigating rural development to climate change include:

1. Management of agricultural lands, which consists in improving agricultural technologies in terms of increasing the resistance of crops to adverse climatic conditions and pests (biotechnology), precise application of fertilizers and plant protection products, organization of optimal crop rotations, agro-reclamation, as well as the introduction of methods of minimal crop treatment (No-Till, Mini-Till). [18]

2. Livestock management, as one of the main sources of methane emissions, is the improvement of the feed base for farm animals and the improvement of their well–being (conditions of maintenance and breeding). Here it is necessary to find a balance between reducing the number of animals and increasing their productivity.

3. Management of organic fertilizers/solid biological waste, which is the basis of closed-cycle agricultural production, when animal husbandry waste is used as organic fertilizer in crop production. [19]

4. Bioenergy – production of solid, liquid and gaseous fuels for energy supply of agricultural production from cultivated biomass. Corn, soybeans, sorghum, harvested leftovers, millet, etc. can be used as raw materials for processing.

5. Organic agriculture is a concept that can make the industry carbon neutral. It is estimated that greenhouse gas emissions from the use of mineral fertilizers amount to about 1,000 million tons annually worldwide. In organic farming, their use is completely excluded. [20]

5 Conclusion

Thus, the aim of the policy on mitigation and adaptation of rural areas in Siberia should be to increase the carbon content in the soil and increase the resilience of ecosystems to various stresses. Rural areas of the Siberian Federal District are highly dependent on natural and climatic conditions, which is due to their "embeddedness" in ecosystems. In this regard, the impact of global climate change determines the further development of these territories.

Adaptation and mitigation measures in agriculture have a positive impact not only on agriculture, but also on rural areas. Agroforestry, reduction of emissions, effective management of water resources – all this improves the quality of life of the rural population.

Climate change policy should be implemented in conjunction with the sustainable development of rural areas in Siberia. It is necessary to synchronize all support measures in order to direct them to simultaneously ensure economic growth, ecological balance and social well-being in rural areas.

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