Assessing the Impact of Global Climate Change on Sustainable Agruculture

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Abstract: - Global climate change significantly affects agriculture through an increase in average temperatures, extreme weather events, and natural disasters. A methodological toolkit for a comprehensive assessment of the impact of climate risks on livestock production along the entire value chain is presented. A quantitative evaluation of the correlation between climate variables and the impact of hazardous weather events on production and economic indicators of livestock was carried out based on data from 75 Russian regions from 1991 to 2019. Food balances made it possible to determine the dependence of livestock indicators on hazardous weather events. Key climate risks were identified, such as extreme temperatures, droughts, floods, and other anomalies that negatively affect animal productivity and livestock production volumes.

Key-Words: - agriculture, agrosystems, climate change, hazardous weather events, agricultural environmental risks, livestock, food resource balances.

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1 Introduction

Global climate change significantly affects agriculture through rising average temperatures and extreme weather events and natural disasters - floods and heavy rainfall, droughts, hurricanes, tsunamis, and potential sea level rise. Agroecosystems may be severely impacted by the effects of global climate change in the future.

Livestock is a key agricultural sector worldwide, generating almost 40% of the world's gross domestic product (GDP) of agriculture, providing 33% of the world's protein and 17% of the world's calories, [1]. In Russia, livestock produces more than 48% of the gross output of the agricultural sector. The consequences of global climate change and moisture supply parameters determine the high relevance of research into their impact on the development of the livestock sector, [2], [3]. In the long term, rising temperatures will cause a geographical shift in agricultural sectors around the world. Moreover, for agricultural production in the Russian Federation, the combined effect of these changes is assessed by experts as rather positive, [4]. The potential growth in the gross harvest of grain and other main crops caused by climate change will have a positive effect on the expansion of the feed base for farm animals.

At the same time, the consequences of global climate change lead to an increase in the number and intensity of natural disasters and abnormal natural phenomena. In the short term, nonlinear changes in the intensity and frequency of natural disasters can neutralize the predicted positive effects, [5], [6].

With regard to short-term weather risks, the scientific literature most often presents studies devoted to their potential impact on the overall productivity of farm animals. To solve the problem of sustainable development of the livestock industry, a comprehensive analysis of the impact of global climate change is needed, which should cover not only the stages of production but also the stages of storage and sale of livestock products. In this case, it is worth considering the regional and structural features of the country's agro-food system.

The uneven climate in the Russian regions that are most effective in terms of livestock farming can negatively affect the physical and economic availability of meat and dairy products for the population. When developing strategies for the development of agriculture, it is necessary to take into account the structural shifts that global climate change factors cause in the livestock sector. This study provides a comprehensive assessment of the impact of climate variables on production and economic indicators of the livestock sector. The results of the study can be used in models for predicting the spatial distribution of livestock and become an empirical basis for developing scientifically based recommendations for adjusting regional systems strategies in the context of adaptation to climate change.

2 Problem Formulation

Given the importance of the problem of ensuring food security, applied research on assessing livestock productivity under changing temperature conditions is actively being conducted in the world literature, [7]. Agriculture and food security are among the key aspects affected by climate change, [8]. The importance of studying this area is confirmed by the fact that from 2019 to 2023, the number of published scientific papers analyzing the impact of climate change on agricultural production increased by 30%, [9].

Bibi et al. paid attention to the adverse effects of climate change and the study of the impact of non-biological stresses on agricultural production: droughts, salinity, and temperature fluctuations, which damage the yield and physiology of crops, [10]. Current studies establish the direct impact of climate change on agrosystems [11], the potential threats of climate change and the impact on crop productivity [12], water resources and agricultural infrastructure [13], soil health, water resources and regional food security [14], and propose strategies for mitigation and adaptation to climate change [15]. In [16] attention is drawn to the importance of developing climate change mitigation strategies and solutions, and note that although the direct impact of climate change on animals is likely to be small (assuming temperature increases do not exceed 3°C), climate change will affect animals indirectly through physiological stress and thermoregulatory control, nutrition, and disease stress. Climate change will have serious implications for livestock production systems that rely heavily on grass and pasture, and will likely have detrimental effects on vulnerable livestock enterprises that engage in extensive livestock production systems in drylands, [17].

In the studies, a causal relationship was found between heat stress and changes in animal reproduction, [18]. Thus, with an increase in average air temperature, a decrease in reproduction is observed, the model describing the dependence of physiological processes on temperature changes was developed, [19]. Another aspect of the research covers the study of infections, livestock diseases, and genetic changes, [20], [21].

Studies of indirect effects are carried out in the context of changes in feed quality, water consumption, and land use, [22], [23]. The influence of seasonal fluctuations and extreme climatic events is considered a factor in changing the amount of feed and grazing management of animals, [24]. Over the past decades, based on projected climate scenarios, the Food and Agriculture Organization [25], the Intergovernmental Panel on Climate Change [26], and other non-governmental international organizations have developed production models and information systems to assess direct climate-induced changes in livestock production. However, despite the abundance of research, further stages of the value chain, including processing, storage, transportation, and marketing of products, are often left outside the scope of the study. Today, there is a lack of economic and statistical studies of the state and provision of food security during periods of unfavourable climate dynamics, "climate-industry-region", [27]. These circumstances determined the goal and objectives of this study to assess the impact of global climate change on livestock production indicators in the Russian Federation.

3 Materials and Methods

In this paper, the study of the impact of climate risks on livestock production was carried out using data from the agricultural sector of the Russian Federation.

For the analysis, official data from the Federal State Statistics Service on agricultural development in the regions of Russia [28] and data on climate change [29] were used. Information sources from the World Agrometeorological Information Service [30] were used to generate information on the number of hazardous weather events in Russia.

The main categories of farm animals were selected for the study: cattle, pigs, sheep, and poultry. All data were structured in a three-dimensional “climate-industry-region” system.

Using the spatiotemporal periodization method, a statistically significant period of time from 1991 to 2019 was identified for the research task, since in subsequent years the COVID-19 pandemic and geopolitical events of 2022 had a statistically significant impact on the studied indicators. The sample included 14,014 observations in 75 regions of the Russian Federation over 29 years.

To process the statistical data, mathematical and statistical analyses were used, which made it possible to study the dynamics of adverse hydrometeorological events in the regions of the Russian Federation and compare them with key indicators of livestock production.

This study was carried out as follows. To select the relevant regions, they were ranked in descending order of the share of livestock products in the region in the total volume in the Russian Federation in all types of agricultural organizations. As part of this analysis, the structural parameters of the development of the agro-food complex for various categories of farms were considered; a list of adverse weather events of a hydrometeorological nature recorded in the territories of the selected group of regions was determined; the direct and indirect influence of these factors on the performance indicators of the livestock industry in the selected regions was studied. Next, the impact of climate risks of dangerous weather events on self-sufficiency in livestock products in the regions of the Russian Federation was analyzed in terms of food balance items using correlation analysis.

4 Problem Solution

The distribution of Russian regions by the indicator of livestock production in all types of agricultural organizations of the Russian Federation in descending order is presented in Figure 1.

28 regions were selected, the volumes of livestock production in which are higher than the average value of the production volumes of these products in the Russian Federation (more than 46,375 million rubles). The leader of this group is the Belgorod Region (products were produced for 214,291.3 million rubles in 2019). A number of other regions produced products worth more than 100 million rubles (the Republic of Tatarstan, the Republic of Bashkortostan, Krasnodar Territory, Voronezh, and Rostov Regions). It is proposed to consider the selected group of regions in the space of production, structural, and climatic characteristics.

Modern Russian researchers note the regional structure of producers and production potential among the most important factors determining the state and level of development of the livestock industry [31]. Table 1 presents the structure of livestock producers. Table 1 shows that in the leading regions, large agricultural organizations account for the main share in the production of livestock products. In only 6 out of 28 (21%) regions, the niche is occupied by small farms.

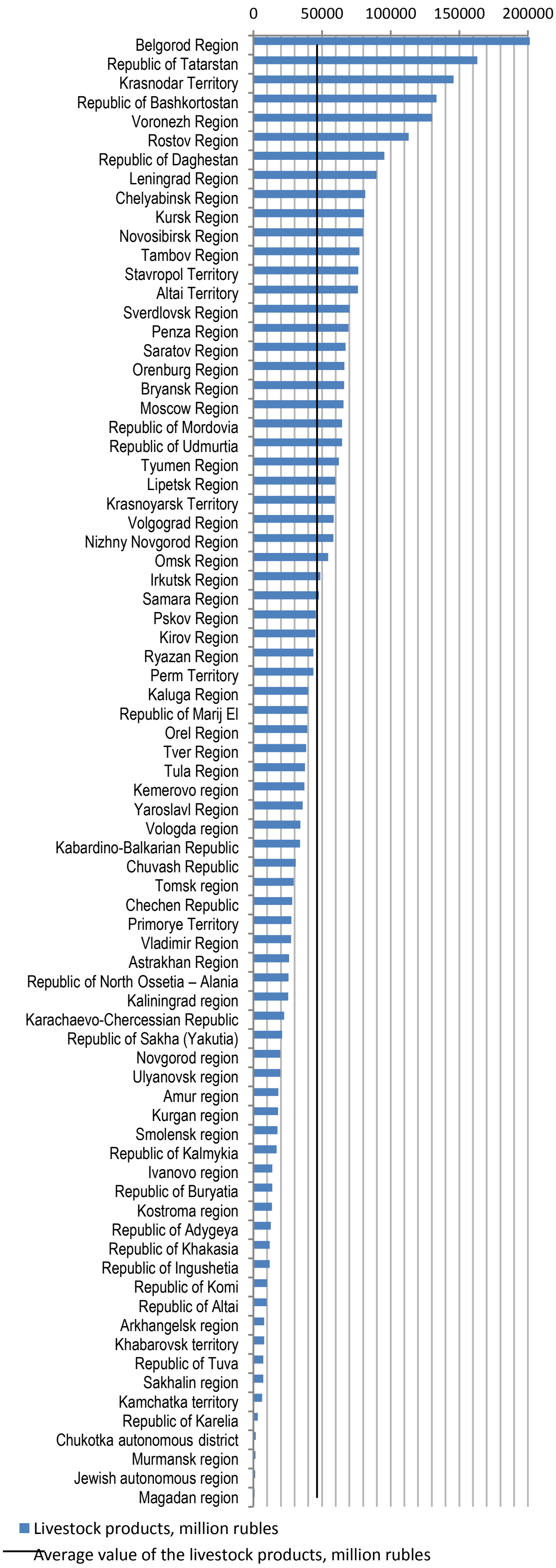

Fig. 1: Livestock production in Russian regions, 2019, million rubles

Source: The Russian Federal Service of State Statistics

Table 1. Average values of livestock production indicators by group of regions (million rubles) and by the structure of producers (%), 2019

Regions	Livestock products	Farms	Agricultural organizations	Households
Belgorod Region	214291	1	96	4
Republic of Tatarstan	163080	9	59	32
Krasnodar Region	145957	5	58	37
Republic of Bashkortostan	133389	8	42	50
Voronezh Region	130199	2	74	23
Rostov Region	113098	11	36	52
Republic of Dagestan	95367	14	15	71
Leningrad Region	89659	2	94	4
Chelyabinsk Region	81592	3	77	20
Kursk Region	80709	1	90	9
Novosibirsk Region	80032	3	71	27
Tambov Region	77362	2	85	13
Stavropol Territory	76505	6	56	38
Altai Territory	76267	5	51	44
Sverdlovsk Region	70084	4	78	18
Penza Region	69351	5	82	13
Saratov Region	67100	6	20	74
Orenburg Region	66308	6	29	65
Bryansk Region	66047	2	85	13
Moscow Region	65671	3	86	11
Republic of Mordovia	64571	2	91	7
Republic of Udmurtia	64546	5	81	15
Tyumen Region	62284	4	71	25
Lipetsk Region	59696	2	80	18
Krasnoyarsk Region	59643	5	59	36
Volgograd Region	58591	7	29	65
Nizhny Novgorod Region	58345	5	77	18
Omsk Region	54592	5	56	38

Source: The Russian Federal Service of State Statistics

The studied group of regions includes regions from different climatic zones: from continental to subtropical. Over the past 30 years, such a vast territory has seen an increase in such abnormal weather events as extreme heat, extreme fire hazard, abnormal cold, ice, heavy rain, hail, hurricane, tornado, flood, high water, and flood.

The greatest changes in livestock numbers were observed in years when such weather anomalies as extreme heat, high fire hazard, abnormal cold, high water, and flood were most pronounced. Table 2 presents a correlation analysis of the impact of climate risks on livestock mortality in relation to the annual turnover of cattle herds in agricultural organizations for 1991-2019.

Table 2. The impact of climate risks on livestock mortality on the turnover of the cattle herd per year, 1991-2019

Regions	Types of climate risks				
Belgorod Region	0,986	0,398	-0,001	-0,251	-0,328
Republic of Tatarstan	0,392	0,395	0	0	0
Krasnodar Region	0,920	0,653	0	0	-0,246
Republic of Bashkortostan	0	0,430	0	-0,373	0,698
Voronezh Region	-0,291	0,493	-0,146	0	0
Rostov Region	-0,421	0,589	0	0,326	0,500
Republic of Dagestan	-0,327	0,106	0	0	0,308
Leningrad Region	0	0,410	0	0	0
Chelyabinsk Region	0	-0,132	0	0	0
Kursk Region	0	0,321	-0,146	0	0
Novosibirsk Region	0,987	0,403	0,026	0,759	0
Tambov Region	0	0,383	-0,114	0	0
Stavropol Region	0,298	-0,432	0	0	-0,225
Altai Region	0,986	0,398	-0,001	-0,251	-0,328
Sverdlovsk Region	0	0,115	0	0,173	-0,148
Penza Region	-0,043	0,484	0	0,614	0
Saratov Region	0,734	0,686	0	-0,190	0
Orenburg Region	0,980	0,831	0,866	0,519	0
Bryansk Region	0	0,458	0,039	0,960	0
Moscow Region	-0,193	0,656	0	0	0
Republic of Mordovia	0,143	-0,056	0,998	0,498	0
Republic of Udmurtia	0	0,026	0,907	0	0
Tyumen Region	0	-0,154	0,127	-0,383	0
Lipetsk Region	0,056	-0,600	0,281	0	0
Krasnoyarsk Region	0	-0,444	0,281	-0,234	0,874
Volgograd Region	0,271	-0,500	0	0,259	0
Nizhny Novgorod Region	0,191	-0,089	0,910	0,695	0
Omsk Region	0	0,925	0,957	0	0

Source: created by the authors

Climate risks such as floods and floods have the most significant impact on livestock production. In regions with a high probability of such events (Novosibirsk, Orenburg, Nizhny Novgorod regions, Krasnoyarsk Territory, etc.), the damage amounted to 30% of the cattle population.

Also, rising temperatures and heat stress hurt livestock production, leading to reduced productivity and the death of livestock. When the ambient temperature rises above 25-26°C, dairy cows experience a decrease in feed intake, [32]. Ruminants experience decreased appetite and intestinal motility. In pigs, when the temperature rises from 20 to 35°C, feed consumption decreases by 10.9%, [33].

Changes in temperature conditions negatively affect weight gain and reproduction. An increase in ambient temperature from 21.1°C to 32.2°C and heat stress in birds lead to a decrease in weight gain and feed intake by 9.5% in birds younger than 6 weeks of age, and a decrease in their reproduction, [34]. Thus, the average daily weight gain of Russian chickens decreased by more than 10 times in 2010 during an abnormal heat wave at many poultry farms in the Russian Federation. In addition, heat stress can cause a decrease in egg production, a deterioration in egg quality, and an increase in poultry mortality, which together lead to significant economic losses for the industry.

The direct consequences of climate change lead to a shift in natural and climatic zones, changes in the growing season, species diversity of cultivated crops, etc. Crop failures in regions specializing in crop cultivation can lead to a decrease in the volume and stocks of agricultural raw materials used for livestock feeding, as well as an increase in prices for feed additives.

The indirect impact on animal husbandry is expressed in a deterioration in the quality of feed and a decrease in their consumption, which can lead to a negative energy balance and a decrease in animal weight. For example, in the Republic of Bashkortostan, about 200 thousand hectares of grain crops died due to the drought caused by the abnormal heat of 2021. Such an important mechanism of climatic adaptation of regional agricultural enterprises, as tools for mutual assistance in providing feed in conditions of shortage, has not been actively applied. Climatic factors in 2021 in Russia led to low-quality hay, feed, and feed grains and, as a result, led to a reduction in the number of cattle by 1.5-2%, [35].

Another negative indirect consequence associated with changes in ecosystem parameters is the impact of microbial communities on farm animals and the emergence of diseases and parasites that are not typical for a given area, [36], [37]. Changes in temperature conditions and relative humidity levels hurt the health of cattle and their reproductive function, [38], [39]. For example, against the background of an increase in the average ambient temperature in the northern regions of the Russian Federation (Arkhangelsk and Vologda regions), an increase in eye and mouth diseases in deer and other ungulates was noted, [40].

Large closed livestock farming systems enable agricultural organizations to reduce the impact of climate risks. This makes them less vulnerable compared to small agricultural enterprises. However, with the combined influence of unfavourable climate changes in regions leading to livestock production, there is a risk of a decrease in the level of food security, [41]. To assess the impact of climate risks on self-sufficiency in livestock products, a correlation analysis was conducted, and estimates were obtained for the impact of specific types of hazardous hydrometeorological events on the territory of the Russian Federation on the indicators of production and consumption of meat and dairy products according to the items of the balance of food resources.

The pattern was identified over the time interval from 1991 to 2019. The Table 3 presents an extended list of hazardous weather events due to the statistical significance of their impact on the process of production, storage, and transportation of meat and dairy products (correlation coefficients> 0.500).

Table 3. Assessment of the impact of hazardous hydrometeorological events on the production and consumption of livestock products, 1991-2019

	Meat and meat products				Milk and dairy products					
	Extreme fire hazard	Wind	A complex of unfavorable	Sudden weather change	Extreme fire hazard	Wind	Rain	A complex of unfavorable	Hail	Sudden weather change
Resources										
at the beginning										
Production					-0,51			-0,63	-0,52	0,72
Import								0,59	0,55	
Import share							0,52	0,71	0,64	
Consumption										
Manufacturing consumption			-0,61	0,81			-0,56	-0,78	-0,59	0,55
Losses	0,53	0,55	0,65	0,75				0,71	0,69	0,72
Export								0,57		-0,56
Personal consumption					-0,54	0,65				0,73

Source: [42]

It is obvious that in the structure of the food balance for meat and dairy products, the most dependent on the influence of weather risks are production losses. The most significant are sudden weather changes (0.750 and 0.722) and the complex impact of adverse weather events (0.549 and 0.718). A dependence is noted between meat product losses and extreme fire hazard (0.533). In the production and sales chain of dairy and meat products, losses occur not only at the stage of raising livestock and poultry but also during the collection of primary raw materials. The greatest damage is incurred by small agricultural producers, which is due to their limited resources for conducting expanded production. Small farms account for 27.4% of the volume of commercial milk production. Small agricultural enterprises and private households use only about 25% of the milk produced in production, the rest goes to domestic consumption or is lost due to unsuitable processing or storage conditions, lack of necessary equipment, etc., [39].

Our results confirm the findings of individual researchers. For example, in [43] points to the negative impact of heat stress on the composition of milk (organic and inorganic components) and describes how these changes are closely related to changes in the properties of cheese making and the commercial value of milk.

In years with the greatest number of climatic anomalies in key dairy-producing regions, there is a risk of a decrease in the level of food self-sufficiency in milk. The share of imported dairy products in the commodity structure increases with the onset of prolonged and heavy rains (0.515), hail (0.643), and a complex of unfavourable weather phenomena (0.712). At the transportation stage, food losses of meat and dairy products and chicken eggs amount to 15% to 35%. In addition, for example, at temperatures above 24°C, the weight of a chicken egg decreases, and their shelf life is reduced with strong temperature fluctuations, [44].

The integral effect of climate risks is reflected in Figure 2, which shows the dynamics of the share of losses in the volume of domestic consumption of livestock products.

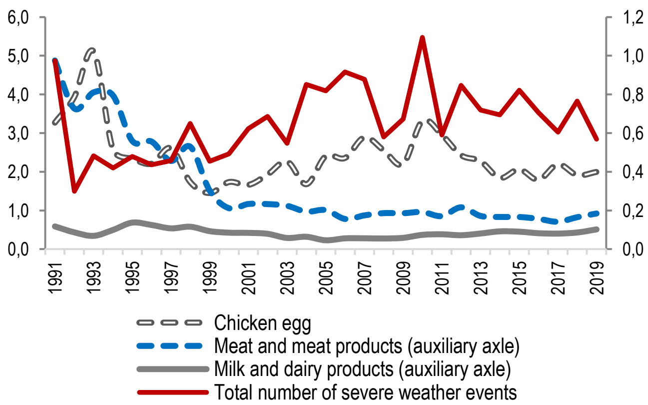

Fig. 2: Total number of hazardous weather events and losses in the volume of domestic consumption of livestock products, 1991-2019, thousands per year
Source: created by the authors

4 Conclusion

The results of the study revealed an important pattern - high connectivity of climate impact indicators on production and economic parameters of livestock development. In years with high amplitude of fluctuations in the dynamics of climate risks in the leading regions in livestock production, the livestock mortality rate increased.

Analysis using the food resource balance tool allowed us to conclude that the consequences of climate risks affect the components of the "food independence" system in the direction of raising farm animals to the stage of storing and processing meat and dairy products. The consequences of climate risks cascade through a series of interconnected processes from direct and indirect influence on changes in the number and productivity of farm animals to a decrease in stocks of meat and dairy raw materials and food.

We believe that global climate change will affect the physical and economic availability of food for the population. Significant fluctuations in the dynamics of climate risks can lead to changes in consumer prices, as well as to a transformation of the structure and volumes of domestic demand for livestock products. The decline in economic accessibility of food creates the preconditions for increasing the risks of poverty for the population, deepening social inequalities, and reducing the quality of life.

Research into the mechanisms of the impact of global climate change on the livestock industry remains relevant and open. On the one hand, due to climate mitigation in the Far Eastern and Northern regions of Russia, the area under grain crops may increase. An increase in the forage base will become an important factor in the development of livestock and poultry farming. On the other hand, climate change may have a serious impact on the development of livestock through indirect links.

Food security depends on the ability of agricultural ecosystems to adapt to climate change. Finding an answer to the climate challenge for livestock requires studying effective institutional mechanisms for adaptation of the industry. Adaptation is an integral part of the sustainable development of agricultural production and should include the development of measures to ensure a balance and redistribution of the forage base, increase the availability of water resources, conduct veterinary measures, and develop appropriate targeted mechanisms of state support.

One of the options for responding to current climate challenges is the comprehensive integration of innovative digital systems into the livestock industry and the introduction of precision livestock farming technologies, selection and genetic innovations to create animal breeds resistant to heat stress and new diseases, optimization of the use of land and water resources, changes in the standards of technological design of livestock buildings, the development of differentiated measures of state support and a system of insurance against agricultural environmental risks, [45], [46], [47].

The scientific results obtained in the article allow us to formulate the following practical recommendations. For farmers, as measures to adapt to climate change, it is possible to propose the introduction of cooling systems for animals to reduce the negative impact of high temperatures on the productivity of livestock and poultry; adjust the diet of animals during periods of extreme temperatures to maintain their productivity and health. The construction of modern livestock complexes with a controlled microclimate is required to minimize the impact of climate risks. It is necessary to form strategic feed reserves in case of crop failure or extreme weather conditions, as well as to develop cooperation between farmers to exchange feed in case of a deficit in certain regions. It is necessary to strengthen measures to prevent diseases, especially in the context of climate change, when new diseases and parasites may appear; to develop animal breeds that are resistant to heat stress and new diseases.

For state agricultural management bodies, the strategic priorities of agricultural policy should be the development and implementation of regional plans for adaptation to climate change, taking into account the specifics of each region. It is advisable to finance programs and grants aimed at introducing innovative technologies on livestock farms, including cooling systems, and improving the conditions for keeping and storing products. To reduce losses of agricultural products, it is necessary to improve the efficiency of logistics and increase investment in the product storage infrastructure, develop financing by microfinance organizations and credit unions, [48]. The most important area of climate-smart agriculture is the development of a system of subsidized insurance for agricultural risks. In conditions of exposure to climate risks, it is important to develop an information and early warning system. Finally, it is necessary to organize educational programs on adaptation to climate change, risk management, and the introduction of modern agricultural technologies for agricultural producers. Given the high degree of inequality in the climatic, economic, and technological development of Russian regions, it is necessary to use an innovative Inclusive approach to enhancing agricultural sustainable development and to form institutions and tools of a full-fledged and effective agro-innovation ecosystem, [49], [50].

The results of the study can be used to develop regional plans for adaptation to climate change with real and scientifically based indicative indicators, which can be relied upon by federal and regional government bodies in strategic planning and the development of program documents in the field of sustainable spatial development of agricultural production.

It should also be noted that climate change requires interdisciplinary approaches to gain deep knowledge and identify potential new risks. In the future, research is needed to develop local mitigation and adaptation strategies, as well as the development of a policy approach to encourage and implement such solutions.

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