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INDUSTRIES AND INTERINDUSTRY COMPLEXES

On the Issue of the Impact of Climate Change on the Development of Russian Agriculture in the Long Term

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Abstract—The article analyzes the impact of global climate change on the productivity of domestic agriculture and on the prospects for its long-term development. The conclusion about the moderately negative contribution of the climatic factor to the forecast dynamics of agricultural production and exports is substantiated.

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Introduction. Global climate change is becoming an increasingly important factor determining the dynamics and a wide range of qualitative parameters for the development of the world economy in general and the Russian economy in particular. One of the sectors in which climate characteristics have a significant direct and indirect effect on production volumes and its product and technological structure is agriculture. This influence is transmitted through at least three different channels:

—Through a change in crop yields and livestock productivity.

—Through changes in the global agri-food market due to shifts in the structure of world agricultural production.

—Through a system of restrictions and obligations to reduce greenhouse gas emissions adopted under international agreements (in particular, the 2015 Paris Climate Agreement).

The article attempts to assess the prospects for the long-term development of domestic agriculture, taking into account new opportunities and challenges due to global climate change.

Expected changes in agroclimatic conditions in Russia. A large number of studies have been devoted to the analysis of the impact of climate change on agricultural production in recent years. Evaluation reports of the International Panel on Climate Change (IPCC), the Food and Agriculture Organization of the United Nations (FAO), the Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet) are regularly published.

According to the calculations of climatologists [1, pp. 23–33, 2], in the long run, most of the territory of the Russian Federation, especially Siberia and the subarctic regions, should be in the area of more significant warming compared to the global average. The greatest warming will be observed in the winter (by 2030 by 1–2°C), whereas in the summer it will not exceed 1°C for most regions. An increase in the lowest daily minima of surface air temperature (annual minima) per year is expected to increase by 4–6°C in the south and northwest of the European part of Russia and by 2–4°C in the central regions, in the Urals and in Eastern Siberia. At the same time, the increase in the highest daily maxima of surface air temperature (annual maxima) for the year will be less than the increase in annual minima, no more than 3°C for most regions of Russia. By the middle of the 21st century in Central and Eastern Siberia and the Far East, the number of days with frost will decrease by 10–15, and in the European part of Russia, by 15–30. The amount of precipitation on the territory of the country as a whole will increase, most significantly in the winter and with a maximum in the eastern and northern regions. Summer increase in the amount of precipitation is noticeably less than winter and is expected only in the east and north of Russia. By the middle of the 21st century, precipitation will decrease in the southern regions of the European part of Russia and Siberia. One should also expect an increase in the number of cases with precipitation of high intensity and the frequency of such dangerous events as thunderstorms, hail, and floods. In the southern regions, this will happen against the backdrop of increased arid conditions. With climate warming, in most regions there is a tendency towards an increase in the moisture supply deficit during the growing season. In winter, a noticeable increase in runoff and a slight accumulation of snow mass are expected in the European part of Russia, while in Western and Eastern Siberia a significant accumulation of snow mass and more intense melting in spring are expected. The reduction of the period

Table 1. Expected climate-related changes in the yield of grain crops in Russia for the period of 2011–2030

Federal district	Change in crop yields, % (deviations from the modern level)	
	RCP 4.5 Scenario	RCP 8.5 Scenario
Northwestern	+18.7	+15.9
Central	+9.4	+6.9
Volga	+3.1	+2.0
South	–5.1	5.8
Ural	–2.7	–3.5
Siberian	–0.8	–1.4
Far Eastern	+13.0	+11.7
Russia as a whole	+3.6	+2.2

Source: [4].

with stable snow cover can reach a month, more so in the south of the European part of Russia and Siberia, in the Far East.

In the whole country, the most important expected climate changes for agriculture will be:

—An increase in heat supply for crops (sum of active temperatures[1]) and the duration of the growing season.

—An increase in winter air temperatures that determine the conditions for wintering of crops.

—A change in moisture conditions due to an increase in precipitation in the cold season and a decrease in precipitation in the warm season.

A retrospective analysis shows that the impact of climate change on crop yields in Russia was generally positive. The highest rates of climate-related growth in crop yields were observed in the Volga and Southern Federal Districts (2.2–2.6% over 10 years, 1976–2006). Throughout all regions, the productivity of winter wheat increased (in the Volga and Southern federal districts by 2.8 and 2.0% over 10 years). An increase in yields of sunflower and sugar beets was also recorded. Corn yields increased in the Volga and Central Federal Districts, while in the Southern Federal District they decreased due to increased aridity in the summer. In the Volga, Southern, Ural, Siberian and Far Eastern Federal Districts, the yield of grain crops increased at a rate of 1.6–2.6% over 10 years. In the regions of the Central Federal District, multidirectional changes in productivity were observed, which determined the general trend for the climate-related decrease in the yield of grain crops (–0.3% over 10 years) [3, p. 175].

In the future, until 2030, the marked effect of climate change on the yield of grain and other agricultural crops will continue in most regions of Russia. Calculations based on dynamic climate models for the RCP 4.5 and RCP 8.5 scenarios[2] show that the greatest increase in grain yields can be expected in the Northwest, Central, Volga and Far Eastern Federal Districts, while in the Southern Federal District, negative effects on agricultural production will be observed due to increased aridity of the climate (Table 1).

Increasing heat supply and lengthening of the growing season will significantly expand the development opportunities of high-intensity agriculture of the Western European type in the northwestern and central regions of Russia. Increased productivity of hayfields and pastures is expected due to an increase in the duration of the frost-free period. As a result, the food supply will expand, the stall period of livestock will be reduced, and conditions for livestock raising will improve [1, p. 120]. At the same time, during hot periods, livestock productivity may decline. Moreover, in some years in Russia there have already been cases of mass death of livestock and poultry due to dry weather and malfunctions in microclimate and ventilation systems (see [5]).

An adverse consequence of global warming and increased aridity of the climate will be an increase in the frequency of droughts and other weather anomalies, not only in regions with an expected decrease in precipitation, but also in those where the precipitation is increasing. According to Roshydromet, in the last 6–7 years, dangerous natural phenomena were recorded 2.5–3 times more often than in previous decades [5]. In this regard, there is a tendency to increase the scale of losses in agriculture. In particular, during the years of severe and extensive droughts of the past years, the reduction in gross grain harvests in the main grain-producing regions reached 40–50% compared to years favorable under moistening conditions [2, pp. 53–59].

An important factor will be an increase in the amount of precipitation in the autumn period in most regions. It can lead to a worsening of the conditions for seasonal field work, which will increase the risks of crop losses and a decrease in its quality. At the same time, the onset of winter will extend the harvesting campaign, which will partly reduce the severity of the problem of insufficient supply of agricultural equipment to agricultural producers.

Finally, an increase in the population of heat-loving species of pests (including locusts) and the expansion of their range with advancement to the northern regions will have a significant impact on agricultural development. The negative consequences of warming include distribution of weeds and pathogens of dan-

[1] That is, the sum of the average daily air temperatures is above +10°C (per year).

[2] The RCP 4.5 scenario assumes a reduction in global greenhouse gas emissions after 2040 and a warming to 2°C in 2046–2065 (compared with the level of 1986–2005), and the RCP 8.5 scenario, an increase in greenhouse gas emissions up to 2100 and a warming to 2.6°C in 2046–2065.

gerous diseases of plants and animals [2, pp. 61–62; 6, pp. 929–942].

Impact of climate change on the structure of agricultural production. There are various options for adaptation of agricultural producers to the expected negative changes in climatic conditions [7, pp. 175–205]:

—Expansion of crops of drought-resistant plants, varieties and hybrids.

—Conducting irrigation and drainage and other land reclamation activities.

—Transition to technologies of minimal or zero tillage (no-till farming), which prevent water and wind erosion of the soil and better retain moisture during the growing season.

—Expansion of the use of fertilizers and plant protection products.

At the same time, the possibilities for implementing the corresponding shifts in production and technology are limited and are determined, first of all, by the financial condition of agricultural producers. The transition from estimates of expected climate-related changes in agricultural productivity to scenarios for the development of the agricultural sector in the long term is nontrivial. The main difficulty is that in addition to the climatic factor, there are other, no less significant factors of a socio-economic nature. In particular, the introduction of more "progressive" technologies may be hindered by the fact that the required costs are not covered by additional income (savings on losses) in the current economic conditions. A vivid illustration of this thesis is the development of grain farming in Siberian regions. These regions are traditionally characterized by low crop yields (in 2013–2017, 14.7 centner/ha, compared with an average of 23.9 centner/ha in Russia). A high potential for intensification of grain production and reduction of its dependence on weather conditions remains. But in addition to climatic risks, agricultural producers in this macroregion face risks of a sharp decrease in grain sales prices due to problems with their sale (because of the limited capacity of the local market and the difficulty of exporting large quantities of grain to other Russian regions and for export). In this situation, the model of extensive grain production with minimal investment in agricultural machinery, fertilizers and plant protection products remains more attractive. This model allows farmers to profit in years with favorable weather conditions and minimize losses in the event of crop failure or falling sales prices. In other words, adaptation to negative climatic changes (and, in a broader sense, reduction of dependence on weather conditions) is not a mandatory imperative for domestic agriculture and is largely determined by the state policy of regulating domestic agricultural markets. With this in mind, it should be expected that structural and technological adaptation to climate change will occur only in those regions where agricultural producers will have economic motives and resource opportunities for the implementation of the corresponding shifts.

Our analysis of the retrospective development of domestic agriculture and the prospects for its future growth (see [8, 9]) shows that agricultural production in the south of the European part of Russia is becoming increasingly export-oriented and intensive, while in the regions of Siberia, the Urals and Volga, the level of agricultural intensification and its resistance to weather fluctuations remains low. The high marginality of grain production in southern Russia (up to 50% [10, p. 14]) suggests that the expected adverse climate changes in this macroregion (generally limited in scale) will be damped by expanding reclamation and shifts in the structure of crops and the transition to moisture-saving technologies. In this case, crop yields in the southern regions may even increase due to irrigation and increased heat supply. In other regions (characterized by less favorable economic conditions for agriculture), adaptation to climatic changes will occur primarily due to shifts in the crop structure: increasing the share of heat-loving and drought-resistant crops, expanding the area under winter crops.

Impact of climate change on food security of the Russian Federation. The potential climate-related increase in gross harvests of grain and other crops in the regions of the Central Non-Chernozem Region, the Northwest and the Far East will positively affect the state of their food safety. These macroregions are traditionally characterized by the excess of consumption of crop production over its domestic production (for illustration of the grain market, see Fig. 1). Reducing the dependence of these macroregions on the import of agricultural raw materials and food will increase their resistance to various external shocks.

The regions of the Central Black Earth Region, the south of Russia and the North Caucasus, on the contrary, export large volumes of crop production to other regions as well. A moderate reduction in crop yields due to increased aridity of the climate in these macroregions (if it is not damped due to technological shifts) can create some tension in the food supply sector, but, in our opinion, it should not lead to a critical aggravation situation.

The impact of climate change on the food security of a country can be analyzed by the example of the development of grain farming. Here, in addition to the climatic factor, it is also necessary to take into account other factors, such as an increase in the level of fertilizer application, expansion of the total sown area and shifts in the structure of their distribution between individual crops. As a basic option, which does not take into account the impact of changing agroclimatic conditions, we can consider the scenario of the inertial growth of Russian grain production, which presupposes the preservation of retrospective trends of raising the level of its intensification and increase of sown areas, as well as allowing a linear dependence of grain

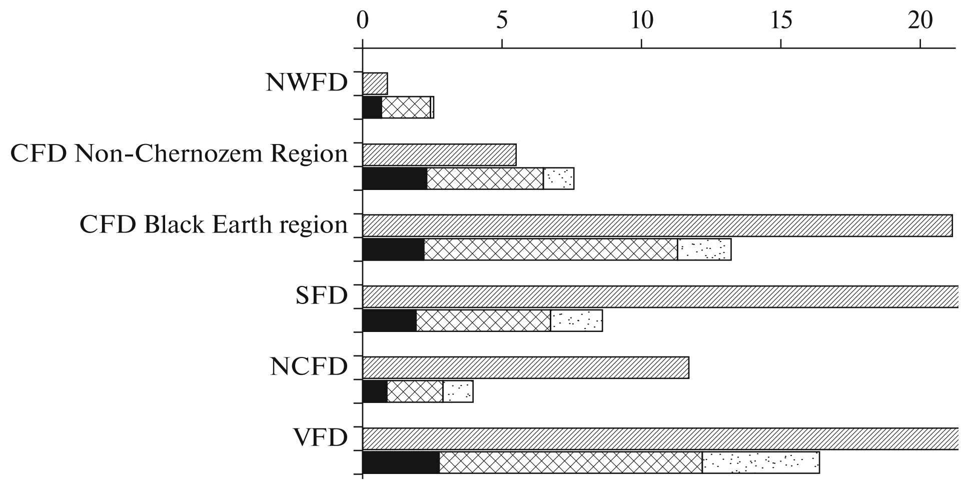

Fig. 1. Domestic production and consumption of grain in 2013–2017: ▨ domestic production; ■ food processing; ⊠ food consumption; ⬚ consumption for other purposes. Source: authors' estimates based on Rosstat data [11].

crops on application doses of mineral fertilizers. In the framework of this scenario, gross grain harvest in 2026–2030 is estimated at 154.4 million tons (in Russia as a whole, on average for the period), whereas in 2013–2017 it amounted to 111.9 million tons[3]. In the case of maintaining retrospective trends in the use of grain, its domestic consumption in 2026–2030, according to our estimates, will increase to 82.4 million tons, that is, in the basic scenario, domestic grain production will greatly exceed domestic needs. In the context of macroregions, the following changes are expected: grain deficit in the Northwestern, Ural, and Far Eastern Federal Districts will decrease, the Central Non-Chernozem Region will turn from a grain-deficient to a grain-surplus macroregion, and surplus of grain will significantly increase in other macroregions (Table 2). This will generally improve the state of food security in the country.

The basic scenario can be adjusted taking into account the expected climate-related changes in the yield of grain crops (see Table 1)[4]. Calculations show that with "hard" arid warming, gross grain harvests may decrease compared to the basic scenario (up to 151.3 million tons, without taking into account adaptation to negative climate changes), but they will still significantly exceed domestic needs. At the same time, the situation with grain supply to macroregions with its deficit (Northwest, Central Non-Chernozem, Urals, Far East) will even improve. Thus, the impact of climate change on the state of food security in the country will soon be positive.

At the same time, a great threat to national food security is the tendency to increase the frequency and amplitude of abnormal natural phenomena. The repetition of several lean years can drastically reduce carry-over stocks of agricultural products and create risks for sustainable provision of domestic consumers. An example of such a crisis development is the situation in the grain market in the early 2010s. Then, due to extensive droughts, gross grain harvests decreased to 61 million tons in 2010 and 71 million tons in 2012 (with average annual collections in 2009–2018 at 100 million tons and domestic consumption at 71 million tons). In this regard, in the central regions of the European part of Russia there was a grain shortage despite the fact that by July 2013 almost all (85%) of the record reserves of the state intervention fund accumulated in 2008–2009[5] had been used up, and in 2010–2011 there was also a ban on the export of wheat and meslin [9].

With this in mind, the formation of strategic stocks of agricultural raw materials and food in a changing climate is becoming an essential element of food security policy. The reserves of the intervention fund should be maintained at a level that allows them to compensate for potential crop losses within one to two years. But, so far, the designated risks are not taken

[3] The methodology and key results of our calculations are presented in [12]. The scenario of inertial growth in grain production should be considered as very optimistic and ambitious – it can be realized in the conditions of a high conjuncture of foreign markets, large-scale expansion of export infrastructure and state support for grain transportation from regions remote from export terminals. Otherwise, the rate of increase in the level of intensification and production volumes will be lower.

[4] To move from the basic to the adjusted scenario, the previously obtained forecast estimates of the yield of grain crops in various macroregions was changed for the average yield of 2013–2017, multiplied by the relative increase in yield in the RCP 8.5 scenario (see Table 1).

[5] The reserves of the intervention fund decreased by 8.2 million tons – from 9.6 million tons on July 1, 2010 to 1.4 million tons on July 1, 2013.

Table 2. Domestic production and consumption of grain in the Russian Federation, million tons

Indicator	2013–2017 (actual values)	2026–2030 (basic scenario)	2026–2030 (adjusted scenario)
Northwestern FD			
domestic production	0.9	1.5	1.7
domestic consumption	2.5	2.9	2.9
surplus (+)/deficit (–)	–1.6	–1.4	–1.2
Central Non-Chernozem Region			
domestic production	5.5	9.6	10.1
domestic consumption	7.6	8.6	8.6
surplus (+)/deficit (–)	–2.1	+1.0	+1.5
Central Black Earth Region			
domestic production	21.1	31.7	30.3
domestic consumption	13.2	15.7	15.7
surplus (+)/deficit (–)	+8.0	+16.0	+14.6
Southern FD			
domestic production	29.7	40.9	39.0
domestic consumption	9.6	10.8	10.8
surplus (+)/deficit (–)	+20.1	+30.1	+28.1
North Caucasian FD			
domestic production	11.8	14.9	14.2
domestic consumption	4.0	4.4	4.4
surplus (+)/deficit (–)	+7.8	+10.5	+9.8
Volga FD			
domestic production	22.4	30.1	30.6
domestic consumption	16.4	18.9	18.9
surplus (+)/deficit (–)	+6.0	+11.2	+11.7
Ural FD			
domestic production	5.3	6.1	5.9
domestic consumption	5.9	6.7	6.7
surplus (+)/deficit (–)	–0.6	–0.6	–0.8
Siberian FD			
domestic production	14.6	18.6	18.4
domestic consumption	12.1	13.4	13.4
surplus (+)/deficit (–)	+2.5	+5.2	+5.0
Far Eastern FD			
domestic production	0.7	1.0	1.0
domestic consumption	0.8	1.0	1.0
surplus (+)/deficit (–)	–0.2	–0.0	+0.0
Russia as a whole			
domestic production	111.9	154.4	151.3
domestic consumption	72.0	82.4	82.4
surplus (+)/deficit (–)	+39.9	+72.0	+68.8

into account in the current program documents. In particular, in the Long-Term Strategy for the Development of the Russian Grain Complex for the Perspective until 2035, adopted in August 2019, it is established that reserves of the intervention fund should be maintained at 2.0–2.5% of domestic consumption [13, p. 58]. In our opinion, these volumes of reserves are clearly not enough to overcome the potential negative consequences of abnormal natural phenomena similar to the 2010 drought.

Additional mechanisms to increase the sustainability of the domestic agri-food system could be measures to stimulate structural and technological changes that allow agricultural producers to reduce their dependence on changes in climatic conditions (primarily land reclamation measures), as well as measures to develop agricultural insurance.

Impact of climate change on the prospects of agricultural exports. At present, Russia is one of the largest exporters of grain, oilseeds, and vegetable oils. The export is primarily focused on the regions of southern Russia (Krasnodar krai, Rostov oblast, Stavropol krai) and, to a lesser extent, the Central Black Earth Region. In the long run, they will be negatively affected by global warming and increased aridity of the climate. The calculation results presented in Table 2 indicate that the potential for grain export from these regions may decrease due to the deterioration of agroclimatic conditions by 4–5 million tons (relative to the basic scenario). At the same time, firstly, there are opportunities for structural and technological adaptation of agricultural producers to negative climate changes[6]. This will require additional costs for farms to modernize production and conduct irrigation and drainage measures, thereby increasing the self-value of agricultural products. But with the prevailing price level on world agricultural markets, the margin of agricultural producers for export supplies is large enough to cover these additional costs without raising sales prices. Secondly, due to the positive impact of climate change, there will be an additional potential for agricultural exports from the Volga and Central Non-Chernozem regions (up to +1 million tons).

In addition, the effects of climate change will be experienced by farmers around the world. It will be distributed unevenly. In the arid regions (in Africa, South, Southeast, and Central Asia), negative climate-related changes in crop yields and gross harvests of crops are expected until 2050. Countries with a temperate climate, including Russia and other large exporters of agri-food products (Canada, the United States, EU countries, Australia, Argentina), on the contrary, can benefit from the increase in heat during the growing season[7]. This will lead to shifts in the structure of global agricultural production and to an increase in world trade in agricultural raw materials and food. Most experts agree that climate change (along with an increase in world population and an increase in average per capita food consumption in developing countries) will predetermine a significant increase in global prices for agricultural products [14, pp. 14–27, 15, pp. 512–513].

Under these conditions, Russian exporters are likely to maintain their position in the world market, even taking into account the growth in production costs. Moreover, rising world prices may create risks for food security in Russia associated with the possibility of excessive expansion of exports and insufficient provision of domestic consumers in a situation where external deliveries are more profitable for manufacturers and traders compared to domestic ones. To minimize these risks, a policy should be developed for flexible regulation of agricultural products export, for example, with the help of floating export duties (see [9]).

Impact of environmental restrictions on the prospects for the development of agriculture. The agricultural sector contributes to climate change both directly through the emission of carbon dioxide, methane and nitrous oxide in the production process, and indirectly, through exposure to soil and forests, as well as the consumption of mineral fertilizers, oil products and other resources, the release of which is associated with greenhouse gas emissions.

Currently, Russian agriculture is characterized by a low overall level of intensification of production: the limited use of fertilizers, plant protection products, equipment, and petroleum products. An increase in the level of intensification in crop production (with stable sown areas) is likely to lead to an increase in greenhouse gas emissions.

In livestock farming, most of the emissions are associated with cattle breeding. In retrospect, its population was declining[8], but in the long run, in scenarios of large-scale production growth in dairy and beef cattle breeding, the number of cattle can noticeably increase (primarily due to the expansion of the meat herd). In other livestock sectors, there may also be an increase in numbers, especially in the scenario of dynamic growth in poultry and pig meat exports. Other things being equal, the increase in livestock pro-

[6] With the expansion of irrigated areas, crop yields in arid territories may exceed projected values in the basic scenario.

[7] According to FAO estimates, for the period of 2011–2050, climate-related yield growth in Canada may be 27%, in the EU countries 16%, in Mexico 8%, in Russia 4%, while in African countries there will be a decrease in productivity by 12%, in South Asia and India by 5% [14, p. 22].

[8] According to Rosstat [11], the number of cattle decreased from 27.5 million units in 2000 to 18.2 million units in 2018, and the number of cows from 12.7 million units to 7.9 million units. The main factor in reducing the number of livestock was the increase in annual milk yield per cow (from 2.5 thousand kg/year to 4.5 thousand kg/year) at stagnation of domestic milk production.

duction in the Russian Federation will lead to an increase in greenhouse gas emissions.

If, in the framework of international climate agreements, Russia assumes obligations to limit or reduce emissions in agriculture, this could affect the prospects for the development of domestic agriculture. But much here depends on the nuances: target levels in terms of emissions, means of stimulating agricultural producers to reduce emissions[9], acceptance or nonacceptance of similar obligations by competing countries of Russia in the global food market[10].

Conclusions. In closing, we briefly state the main conclusions.

The consequences of climate change for Russian agricultural production are ambiguous and vary depending on the regions and the scenarios under consideration. In general, the impact of climate change on agricultural productivity is estimated to be moderately negative (due to the fact that the main negative effects will be observed in the southern regions with the most developed agricultural production). In the densely populated central and northwestern regions of the European part of the Russian Federation, gross harvests of grain and other crops are expected to increase due to an increase in their heat supply. This will improve the state of food security in the country. At the same time, the negative impact of global warming on crop yields in the southern regions will hamper the development of agricultural exports. To overcome these negative consequences, it is necessary to carry out certain structural and technological shifts (increase the area of reclaimed land, change the structure of crops and methods of tillage), including with the support of the state.

Our calculations show that the impact of climate change on the prospects for the development of domestic agriculture is much less significant than the impact of economic factors (which are determined by the characteristics of economic policy and market conditions). In other words, in the context of developing an agricultural policy, the most important are the issues of choosing priorities due to the peculiarities of the socio-economic situation, and the effects caused by the evolution of natural conditions are mostly of a "background" nature. The main risks of climatic changes for Russia are associated with an increase in the frequency and amplitude of anomalous natural phenomena (droughts, floods, hail). The repetition of several lean years can dramatically worsen the situation in the field of food supply. Under these conditions, the formation of strategic stocks of agricultural products should become a key element of food security policy.

The impact of the expected climate change on agriculture in different regions of the world will be uneven. Arid countries will have a negative impact on agricultural production, while temperate countries (including Russia) may benefit from global warming. The shifts in the global structure of agricultural production are likely to lead to an increase in international trade in agricultural products and higher global agricultural prices. This will contribute to the development of Russian agricultural exports. At the same time, it is necessary to provide mechanisms for flexible regulation of exports in a situation where external supplies turn out to be more profitable for manufacturers and traders than domestic supplies. This will reduce the risks to the country's food security associated with the integration of Russia into the global agri-food market.

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[9] They can be repressive ("carbon tax") or supportive (subsidizing capital and operating costs of agricultural producers to the transition to resource-saving technologies).

[10] Additional restrictions may be imposed by external consumers due to the admission to their markets of only "environmentally friendly" agricultural products produced using resource-saving technologies. At the same time, Russian exports are so far focused on deliveries to "poor" countries, for which the main criterion is the price of the product, and not the volume of greenhouse gas emissions from its production.

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