Highlights of Sustainability

ISSN 2696-628X, A Peer-Reviewed Open Access Journal by Highlights of Science

https://www.hos.pub/ho/sustainability

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Cite this Article

ACS Style

Wegren, S.K. The Impact of Climate Change on Russian Agriculture and Implications for Global Food Security. ***Highlights Sustain.*** **2022**, *1*, 188–201. https://doi.org/10.54175/hsustain1030014

APA Style

Wegren, S. K. (2022). The Impact of Climate Change on Russian Agriculture and Implications for Global Food Security. ***Highlights of Sustainability***, *1*(3), 188–201. https://doi.org/10.54175/hsustain1030014

Highlights of Science

Publisher of Peer-Reviewed Open Access Journals

https://www.hos.pub

Barcelona, Spain

Highlights of Sustainability

Article

The Impact of Climate Change on Russian Agriculture and Implications for Global Food Security

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Abstract Although Russia's grain growing regions have experienced episodic droughts, the financial impact of climate change has to date been modest when measured in terms of value of production lost. As industrial agriculture continues to emit greenhouse gases, the impact of climate change will intensify, making Russia's southern regions drier and hotter, and potentially forcing a structural shift in production northward, an event that will lead to lower yields and grain output. The sustainable sector in Russia's agricultural system is not able to compensate for lower grain output in the south, nor is it able to feed the nation or ensure food security across the full spectrum of commodities that consumers expect. The prospect of Russia as a declining grain power impacts the dozens of nations that import Russian grain, most notably authoritarian regimes in the Middle East.

Keywords Russia; climate change; agriculture; sustainable development; food security

1. Introduction

The 2022 report by Intergovernmental Panel on Climate Change (IPCC) on climate change warned that, "climate change including increases in frequency and intensity of extremes have reduced food and water security…Increasing weather and climate extreme events have exposed millions of people to acute food insecurity…with the largest impacts observed in many locations and/or communities in Africa, Asia, Central and South America, Small Islands and the Arctic" [1]. Global agriculture is being impacted by the effects of climate just as it has for thousands of years, but scientists today conclude that human activity is warming the earth's atmosphere in ways that are unprecedented [2]. No region is immune or can escape the effects. Greenhouse gas emissions reached a new high in 2019 before receding a bit in 2020 due to COVID-related economic slowdowns and lockdowns that closed businesses and kept people at home. Despite the slowdown in economic activity in 2020, the year 2020 was one of the three warmest on record and the years 2015–2020 were the six warmest years on record [3]. Ocean temperatures reached an all-time high, affecting Arctic melting and sea levels. Ocean warming influences regional rainfall. The year 2020 witnessed extensive flooding in large parts of Africa, with Sudan and Kenya among the worst affected in Africa. Energy consumption in 2021 returned emissions to pre-pandemic levels. In 2022, severe drought affected the Horn of Africa, with Ethiopia, South Sudan, and Somalia experiencing a significant decline in food output at the same time that Ukrainian grain was blocked from reaching those and other destinations due to the war with Russia. The Food and Agriculture Organization (FAO) predicts that climate-related disasters will impact agricultural production more severely and frequently as the twenty-first century progresses [4].

The impact of climate change on agriculture is among the most urgent threats to emerge from climate change [5]. Aside from access to fresh water, nothing is as fundamental to human existence as food. The vicissitudes of climate change affect politics because food price spikes that may result from drought or flooding are often associated with political instability [6]. During 2003–2013 natural disasters affected more than 1.9 billion people in developing countries, with crop damage accounting for 42% of the damage from natural disasters [7]. The threat from climate change reduces crop production and lowers yields, while warmer temperatures lead to a higher incidence of plant, livestock, and fish diseases [8]. Heat also produces stress in many crops and increases their vulnerability to pests, which multiply as average temperatures rise. Climate change affects the quality of forage and feed for livestock and water availability for farm animals. Rising temperatures directly threaten livestock by increasing animals' vulnerability to disease.

Received: 24 July 2022
Accepted: 25 August 2022
Published: 26 August 2022

Academic Editor
Carlos Parra-López, Institute of Agricultural and Fisheries Research and Training (IFAPA), Spain

Higher temperatures also lower milk yields in dairy cattle as their capacity to tolerate elevated temperature decreases [8]. Likewise, heat stress leads to leanness in pigs and poultry. Acidification of the oceans and change in water flows impact fisheries and aquaculture. The availability of food is, therefore, directly impacted by climate change and that impact will intensify as a larger global population requires more food in the years ahead.

This paper is interested in the effects of climate change on agriculture in Russia. The Russian case is important to global food security because it has become the leading wheat exporter in the world, and its surpluses are purchased by dozens of countries annually, with its biggest customers in the volatile Middle East. The paper is also interested in whether sustainable agricultural practices are able to offset the damage caused by industrial agriculture at the same time ensuring food security for the national population.

Russia is both a contributor to and a "victim" of climate change. Russia is a major contributor to greenhouse gas emissions that exacerbate the global warming problem. Prior to the 2022 invasion of Ukraine and subsequent Western sanctions, Russia's economy was the seventh largest in the world by Purchasing Power Parity (PPP) but ranked fourth in terms of volume of carbon emissions annually [9]. As a result, northern areas of Russia, including the Arctic, are warming 2.5 times faster than the world at large. Further, climate change is already affecting Russian agriculture, which is discussed in more detail in Section 4, an impact that will intensity in coming decades [10]. Analysts conclude that all regions of Russia will become significantly warmer in the second half of the twenty-first century, with Russia's southern regions becoming the warmest by far [11]. As a consequence, Russia's grain production, which has increased significantly since 2010, will be affected [12–14].

The paper addresses the three main questions: (1) How is climate change affecting Russian agriculture? (2) What are the prospects for sustainable agriculture to play a more prominent role in Russia's agricultural output, thereby reducing the environmental impact of industrial agriculture? (3) How does the impact of climate change on Russian agriculture affect global food security?

1.1. Arguments

My analysis of climate change and Russian agriculture makes three broad arguments. The first argument is that the financial effects of climate change to date have been modest when measured in lost value of crops. Although climate change has had only a modest impact on Russian food production to date, that situation is likely to change as early as the 2030s and 2040s. The second argument is that Russia's sustainable agricultural sector is weak and is steadily becoming weaker, and that is important because it means that there is no viable alternative to industrial agriculture that can feed the nation and ensure food security across the spectrum of commodities that consumers expect. The third argument is that although Russia is more economically and politically isolated after its invasion of Ukraine, the fate of global food security remains tied to Russian agricultural production, particularly wheat. To the extent that climate change forces change within the system and its structure of output, global food security will be impacted.

2. Materials and Methods

The article uses interdisciplinary methods. The article is based upon open-source material from international non-governmental organizations and their data; secondary sources in English; and Russian language journals, online websites, and statistical sources.

3. Russia's Climate Change Policy

During the Soviet period, the modus operandi was systematic disregard for the environment in favor of meeting the goals of the economic plan [15]. This disregard for nature carried over into the first post-Soviet decade [16]. Russia's climate policy has been ambivalent, reflected in the way that the Russian media covers climate change. Coverage varies according to the economic situation, with less attention during downturns and more attention when the economy is recovering or strong [17]. Russia's ambivalence is due to the fact that Russia is a winner and loser from climate change. On the one hand, Russia stands to benefit from melting ice caps in the Arctic because new shipping routes are opening for which Russia can charge transit fees. Another source of ambivalence arises from the fact that between one-quarter and one-half of

government revenue is generated from the export of oil and gas, so any curtailment in production and export would have dramatic effects on government finances. Melting ice caps are opening new opportunities to tap into enormous gas and other mineral wealth. On the other hand, melting permafrost threatens the infrastructure in the northern and eastern regions of Russia as roads and housing developments sink into the soil. In addition, climate change leads to increased frequency of drought and floods that endangered crop production in southern and eastern regions of Russia. In 2000, for example, Russia registered 141 severe weather events; in 2018 there were 580 severe weather occurrences [18].

Russia's first policy steps toward climate change mitigation were modest. In 2009, Russia adopted a Climate Doctrine, but it was not effective because it lacked enforcement mechanisms. This Doctrine was the first document that presented a road map for national climate adaptation and mitigation [19]. Implementation of its ideas were complicated, however, by skepticism over climate change from the business community, policymakers, and the general public [20]. Shortly before he left office, in April 2012 former President Dmitry Medvedev approved a document on the "Bases of state policy for ecological development to 2030", which defined state goals in ecology policy. The Bases did not deal specifically with decarbonization and although the document was wide-ranging it was criticized for failing to allocate financial resources, for not assigning ministerial responsibility for implementation, and for lacking enforcement or specification of penalties [21]. In 2013, a presidential decree on the reduction of greenhouse emissions was signed, but it did not require any actual reductions to stay within 75% of 1990 emission levels [22]. In 2018, a national project called "Ecology" was adopted that will run through 2024. The project includes nine subprojects that encompass initiatives such as clean water, waste management, protection of nature, protection of Lake Baikal, protection of biodiversity, and protection of forests, but decarbonization was not directly addressed [23].

Despite President Putin's questioning of the origins of climate change in 2018 [24], and his cavalier dismissal of green energy (windmills) in July 2019 [17], Russia's climate change policy advanced considerably in the years leading up to the war in Ukraine. In September 2019, Russia ratified the 2015 Paris Agreement, although meeting those obligations did not require any significant decarbonization because the 1990 base line was a time that the Soviet economy was already in decline [17]. In late 2019 Russia adopted a national action plan that recognized the myriad threats that climate change posed. It set a deadline of September 2021 for the federal government to adopt mitigation measures and May 2022 for regional governments to do the same [25], but apparently those deadlines were ignored following the outbreak of war with Ukraine. In November 2020, a presidential decree proposed a 30% decrease in greenhouse gas emissions from Russia's 1990 level. Another decree from February 2021 expressed support for climate-related research. In summer 2021, a federal law on restricting greenhouse gas emissions was adopted that requires mandatory disclosure for companies that emit 150,000 tons or more of carbon dioxide per year starting 1 January 2023, and disclosure starting 1 January 2025 for companies that emit 50,000 tons or more of carbon dioxide annually [22]. Following the February 2022 invasion of Ukraine, Russia's federal government relaxed several previous policies regarding obligatory digital coding of dairy products and imports of needed machinery parts, so it remains to be seen if mandatory disclosure of carbon dioxide will be enforced.

At the October 2021 United Nations Climate Change conference in Glasgow (COP26), Russia pledged carbon neutrality by 2060, a decision driven by the warming of Russia's Arctic regions and the prospect of the EU Carbon Border Adjustment Mechanism which puts a carbon price on imports for selected goods. According to the policy, during 2023–2025 importers will be asked to declare their emissions and from 2026 onward they will need to pay a carbon tax [22]. President Putin did not personally attend the Glasgow COP26 conference, but the Russian delegation included representatives from the presidential administration, ministries, the Moscow city government, leading banks, and major corporations. At the conference, Russia claimed that most of its energy usage is from low-carbon or no-carbon producing sources: 40% from nuclear and hydroelectric, and another 40% from natural gas. Russia has 20% of the world's forests (more than 800 million hectares) and plans extensive green projects in Siberia and its Far East as carbon sinks.

In November 2021, Russia's government announced a climate strategy to 2050 that is to reduce greenhouse gas emissions to 80% of Russia's 1990 level and 60% of the 2019 level, which Prime Minister Mishustin claimed would put Russia on track for carbon neutrality by 2060 [26]. In addition, Russia plans to initiate energy saving modernizations, to introduce new regulation

of and taxation on greenhouse emissions, and to expand of hydrogen energy. Those projects are for the future, however. Currently, despite Russia's claims of low carbon energy use, the reality is that Russia has a very weak renewable energy sector. Gustafson indicates that most of Russia's renewable efforts have gone into solar power. In 2019, solar and wind power in Russia produced 1.6 billion kilowatt hours, or 0.15% of total kilowatt hours generated [27]. Further, he notes that most of the opportunities for renewable energy are in remote areas and not connected to the central transmission system [27]. The areas where renewables may be developed are often poor and generate power locally using state-subsidized diesel fuel which is trucked in from the south [27]. These areas are not attractive to private investors and government support for renewables is weak, similar to the situation in the U.S. that pits wind and solar power companies against the established oil and gas sectors that receive huge annual government tax breaks and subsidies.

Despite the shift in Russia's climate policy, reservations remain. In December 2021, Russia vetoed a draft resolution in the UN Security Council that stated that climate change is a threat to international security, justifying its veto on the pretext that the resolution could be used by Western powers to interfere in the domestic affairs of other nations [28]. Of course, as we now know, by December 2021 Russia was already planning to invade Ukraine.

The February 2022 invasion had several ramifications for climate change policy in Russia. First, Russia's governmental guidelines and goals for reducing emissions were discarded in favor of pursuing the goals of war. Second, an enormous volume of particles is released into the atmosphere from artillery shelling and bombing of Ukrainian cities and towns; and carbon dioxide emissions from tanks and other military vehicles increased. Third, the rebuilding of military equipment stocks will require an increase in carbon-producing industrial activity, thus adding to Russia's high levels of greenhouse gas emissions. Fourth, an estimated 200,000 Russians who were opposed to the war, departed Russia forever [29]. Many who comprised the brain drain were young people. It is likely that these "liberals" were also supporters of pro-environment policies who favored efforts to mitigate the effects of climate change. Going forward, Russia's already weak environmental movement will be even weaker. Finally, the rebuilding of Ukraine will require an enormous increase in the production of steel, concrete, plastics, and other construction materials, all of which come from carbon-emitting processes.

4. Discussion. Climate Change and Russian Agriculture

The industrialization of agriculture was a key component of Stalin's collectivization in the 1930s. Although the Stalinist agricultural model had many shortcomings, the mechanization of agriculture allowed the mass of rural migrants to cities to be fed. Subsequently, industrial agricultural brought a basic level of food security, which means that although local supplies could be spotty and quality was often poor, during normal times very few people were chronically hungry. Today, Russia's government remains committed to an industrial agricultural model. The industrial model feeds the Russian population, provides surplus food for export, and brings prestige to the country as Russia has become a major grain exporter. Each year, Russia's government spends hundreds of billions of rubles in support of industrial agriculture, spanning the complete production cycle. The entire agricultural system is based upon the widespread use of carbon-producing machinery, equipment, and processes to produce food. In fact, virtually all processes along the food chain are based on the burning of fossil fuels, from the production of animal feed to the production of chemical fertilizers to sowing and harvesting by diesel burning equipment to food processing and manufacturing. The transportation of food for retail distribution also depends upon carbon-producing vehicles. In this respect, Russia is not different from other developed states. While Russia's industrial sector is the country's main contributor to greenhouse gas emissions, the agricultural sector accounts for 15–18% of greenhouse gas emissions and as much as 28% of emissions if food processing is included [30]. For context, the agricultural sector contributed less than 3% of Russia's GDP in 2018 [31]. Thus, greenhouse gas emissions far outstrip the contribution to economic activity, spurred by an agrarian policy that has yet to turn "green", although there are pockets of "greenness" represented by ecovillages which use fully sustainable practices [32], but these ecovillages are outside of official state policy and do not make a significant contribution to national food supplies.

State commitment to industrial agriculture is embedded in the state program for the development of agriculture, which in its updated December 2021 version indicated a goal to modernize the stock of agricultural machinery to increase the effectiveness of agricultural production. Toward that end, the number of tractors should increase by 3.9% and grain combines by 5.7%

by 2030 [33]. Thus, rather than de-carbonizing agriculture, Russia's federal government wants large corporate farms and private farms to use more carbon-producing equipment and machinery to increase agricultural production and yields. State agricultural policy implies that the desire for higher food output is greater than concerns about carbon emissions.

To help farms re-mechanize after the collapse in the 1990s, federal and regional governments offer subsidized credit to purchase machinery and a leasing program for agricultural equipment. For example, in Stavropol krai, one of Russia's most productive agricultural regions located in the south, farms acquired nearly 10,500 pieces of agricultural equipment during 2018–2021 at a value of RUB 25 billion—with half being obtained with state subsidies [34]. In Lipetsk oblast, the regional governmental allocated RUB 11 billion in subsidies in 2022 for leasing agricultural machinery, up to 45% of the cost [35]. In 2020, more than 59,000 pieces of agricultural machinery were acquired by farms throughout the country. During 2021, the Ministry of Agriculture estimated that the agricultural sector would increase its acquisition of machinery by least 20% [36]. High-tech and digital technologies are being introduced on Russian farms which will reduce the volume of pesticides, herbicides, and chemical fertilizers, which obviously is good for the environment [37]. But other technologies, such as driverless tractors, continue to operate with gasoline or diesel fuel. Western sanctions on Russia due to its invasion of Ukraine may slow the rate of farm mechanization by banning the sale of agricultural equipment to Russia or withholding computer chips and other components used to produce equipment, but the basic motivation to increase the use of carbon-producing equipment will continue.

4.1. Effects on Agriculture

During the twentieth century, Russia experienced at least 27 droughts in its southern regions [38]. In the first post-Soviet decade, weather related anomalies led to poor grain harvests in 1995, 1996, and 1998, and 1999. Drought occurred in 1995 and 1998, which combined with farm de-mechanization, the collapse of state financial support for agriculture, and a decline in fertilizer application, produced poor harvests. In 1995, the harvest dropped to 63.4 million metric tons from 81.3 million metric tons in 1994; and in 1998 the harvest fell to a post-Soviet low of 47.8 million metric tons, down from 88.5 million metric tons in 1997 [39]. The reoccurrence of droughts, however, did not bring famine or widespread hunger because Russia's interregional system of grain exchange worked well, and because Russia was able to import grain. After the 1998 harvest, Russia received food aid from the United States and European Union into 2000.

In the post-2000 period, it is expected that the area affected by frequent severe droughts will increase, encompassing a large portion of Russia's European south [40]. A very severe drought occurred in 2010 that affected about one-half of Russia's regions and destroyed one-third of the harvest, resulting in the lowest grain output since the 1950s, and that in turn led Russia to ban wheat exports from August 2010 through July 2011 [41,42]. The 2010 harvest not only was lower than the disastrous 1995 harvest, but wildfires displaced thousands of people and severe air pollution led to an estimated 11,000 excess deaths [43]. Another severe drought occurred in 2012 which cost Russia one-quarter of its harvest [44]. Less severe droughts occurred in 2013, 2015, 2017, 2018, 2019, 2020, and 2021. Overall, according to Russia's Ministry of Agriculture, direct losses due to droughts during 2010–2019 affected about 40 million hectares of agricultural land [45]. Deputy Prime Minister Viktoriia Abramchenko warned that if Russia does not change its climate change policies, the country could lose up to 30% of its harvest annually by 2040 [46].

To date, however, even though drought has affected a large number of regions and agricultural land, aside from the two severe droughts in 2010 and 2012 monetary losses to agriculture have been modest when compared to the annual ruble value of output, as shown in Table 1.

Monetary losses due to climate change exceeded 1% of the annual ruble value of Russia's agricultural output only in 2010. In other years, climate-related monetary losses were less than 1% of the ruble value of annual output. Climate-related events that cause monetary losses to agriculture include drought in Russia's South, Central, and Siberian Federal Districts where the majority of food is produced; and flooding in the Far East Federal District where soybeans are grown. Overall, financial losses from climate-related events were moderate and episodic, and thus did not motivate systemic change in the agricultural sector toward sustainability.

The moderate impact of climate change during 2000–2020 had two ramifications. The first ramification was that Russian agriculture was able to become profitable and globally competitive. State financial support for agriculture facilitated the transformation of Russian agriculture from a "black hole" into a productive, profitable sector. In total, from 2005 to 2020 the federal

government allocated more than RUB 2.6 trillion to agriculture, most of which was directed to large corporate farms [47]. During 2005–2020, average annual grain harvests increased from an average of 79 million metric tons during 2000–2005 to nearly 125 million metric tons during 2016–2020 [48]. During 2005–2020, the value of agricultural output grew fourfold in nominal rubles [47]. Farm profitability for large and medium agricultural enterprises rose from 7% in 2000 to 23% in 2021 [49,50]. The increase in production meant that higher volumes of food were sold. For example, the volume of meat sold by agricultural enterprises rose from three million tons in 2000 to over 12 million tons in 2020; the volume of milk sold increased from 12.5 million tons in 2000 to 17.1 million tons; and the volume of grain sold by agricultural enterprises rose from 32 million metric tons in 2000 to 70 million metric tons in 2020 [51,52]. As a result, the dollar value of food exports increased from $1.6 billion in 2000 to over $37 billion in 2021, with grain accounting for about 30% of the value of Russia's exports [53]. Overall, Russian agriculture was transformed from an unprofitable, de-mechanizing and de-modernizing sector in the 1990s into something quite different after 2010.

The second ramification of the moderate climatic impact during 2000–2020 was that domestic food security improved. During these two decades, Russia underwent a food revolution, which reflected not only to a rebound in levels of food consumption, but also unprecedented consumer choice about where to buy food, selection and quality, and options for eating outside the household [54]. In September 2020, Minister of Agriculture Dmitry Patrushev maintained that food deficits were something from the past and the concept of food shortages should be forgotten [55]. Prior to the war in Ukraine, experts within Russia considered the country more food secure than at any time in the post-Soviet period [56].

Table 1. Financial losses to Russian agriculture from climate-related events, 2010–2021.

Years of Drought and Floods	*Value of Monetary Loss to Agriculture (Rubles)*	*Value of Agricultural Output (Trillion Rubles)*	*Monetary Losses from Climate Events as % of Annual Value of Agricultural Output*
2010	41 billion	2.4	1.7%
2012	21 billion	3.3	0.6%
2013	20.2 billion	3.6	0.5%
2015	7 billion	4.7	0.1%
2017	3.6 billion	5.1	0.07%
2018	7.3 billion	5.3	0.1%
2019	13 billion	5.8	0.2%
2020	8 billion	6.4	0.1%
2021	20 billion	6.7	0.3%

Sources: Rosstat. *Regiony Rossii*. Moscow: Rosstat, various years and pages; author's calculations.

4.2. Current Impacts

Today, climate change affects Russian agriculture in several ways. First, Russia's hydrometeorological agency that monitors environmental conditions has found that main agricultural producing regions in the south are already experiencing warmer summers with less rainfall and fewer cloudy days [57]. It is expected that southern regions will continue to warm and will be 3–4 °C hotter by 2070 with precipitation staying the same or decreasing [40]. As a consequence, the frequency of droughts is likely to increase in Russia's main grain growing regions as the century progresses. Furthermore, grain production and yields will decline in several of Russia's most important grain-producing regions as the twenty-first century progresses [58]. These two events are important because the top five grain producing regions have higher yields and account for a large share of total grain production, as shown in Table 2.

Russia's weather patterns for grain growing regions were modeled to project the future impact of climate change. Stavropol krai, consistently in the top five regions for grain production, had an average frequency of 28 dry years per century in 2010, but according to the model by the 2070s the frequency will increase to 89 dry years per century. In Krasnodar krai, the number one region for grain production in Russia, the frequency of dry years will increase from an average of 21 times per century in 2010 to 67 times per century by 2070 [40]. If the model is correct, this portends of more volatility in grain production. In contrast, northern regions of European Russia did not experience an increase in the number of dry summers according to the model.

Second, as northern regions of Russia become warmer, some crop production may shift to the north, even though production levels and yields in the north are lower than in the south. Theoretically, intensive commercial agriculture could shift 600 kilometers to the north, with some authors predicting a rise in output [59]. Dronin and Kirilenko disagree that shifting grain

production to the north will lead to higher output. They point to limited land availability and poor soil fertility to argue that production in the north cannot compensate for the loss of production in the drought-stricken south where agricultural production is more intensive [59]. It is also noted that rural depopulation and land abandonment in the non-black earth zone in Russia's north during the past 30+ years makes agricultural revival unlikely [40]. In addition, such a shift would contravene the historical pattern whereby commercial agricultural production is concentrated in the south, so the movement of agricultural production northward would entail enormous investment costs as necessary infrastructure such as grain storage and processing would need to be constructed. In short, grain production could shift from surplus producing regions to consuming regions that historically import their food and fodder, but that shift comes with consequences.

The potential shift in grain production to the north has immense implications. Russia's top five grain producing regions, located mostly in the south, produced 31 percent of the total grain harvest in 2020, and this result is typical. Those same five regions had an average yield of nearly 41 centners per hectare in 2020 [60]. In contrast, the other 69 grain producing regions had a yield of about 28 centners per hectare. This difference is important because it is the increase in yield per hectare that has driven the rise in Russian grain production more so than the modest expansion in cultivated land. With a shift of production to the north where yields and the overall level of production are lower, domestic food security may be affected. If in the future, under a scenario of lower production due to climate change, grain producing regions adopt protectionist measures, and grain consuming regions may experience heightened food stress. Lower yields and production will also impact the volume of grain that Russia is able to export, a topic discussed in Section 6.

A second implication is that northern, non-black earth areas of Russia are forested, with large amounts of carbon and methane stored in vegetation and the soil, which means that the conversion of forests to cropland will release greenhouse gas emissions. Further, Russia's 800 million hectares of forests serve important ecological purposes, one of which is as a carbon sink. As forests are disturbed by the increasing frequency and scope of wildfires attributable to climate change, the absorption capacity as a carbon sink is diminished [61].

A third implication is that weather variations in Russia bring large fluctuations in output and yield from year to year in grain production in the south. As weather extremes increase in frequency and severity, farms' monetary losses will mount, potentially setting off a localized financial crisis. Russia has a crop insurance system, but in general the system has been plagued with problems and does not work very well. In 2021 for example, about RUB 5.2 billion of insurance payments were paid out [62], but weather-related losses in mid-year were estimated at more than RUB 19 billion and total agricultural output for the year was valued at more than RUB 6.7 trillion. Thus, only a small percentage of cropland is insured. If a weather-related catastrophe occurs, most of the financial impact will be felt by the farm, the local community, the district government, and the regional government.

Table 2. Agricultural performance by top five regions, 2010–2020.

	Rank in Total Grain Production 2010–2020 [a]	***Total Grain Production 2010–2020*** [a,b]	***Average Annual Grain Production, 2010–2020*** [a,b]	***Average Grain Yield, 2010–2020*** [c]	***Growth in Ruble Value of Output, 2010–2020*** [d]
Russian Federation	-	1152	104.7	24.0	+166%
Krasnodar krai	1	93.26	8.45	52.0	+135%
Rostov obl.	2	79.64	7.24	30.0	+205%
Stavropol' krai	3	61.04	5.54	34.8	+127%
Saratov obl.	4	36.28	3.29	16.2	+183%
Voronezh obl.	5	35.27	3.20	30.3	+286%

[a.] After cleaning; [b.] Million metric tons; [c.] Centners per hectare; [d.] Nominal rubles.
Sources: Rosstat. *Regiony Rossii 2021*. Moscow: Rosstat, various pages; author's calculations.

5. Prospects for Sustainable Agriculture in Russia

So far, we have seen that the Russian government is committed to its industrial agricultural system, a system that contributes to climate change through greenhouse gas emissions. Climate change is making Russia's main grain growing regions in the south drier and hotter. In coming

decades, grain production may have to shift north as drought in the south becomes more frequent, but such a shift will be very expensive and will result in lower yields and total output. Grain production in northern regions is plagued by poor soil and fertility, depopulation of rural areas, and critical deficiencies in infrastructure. This section considers the prospects for Russia's agricultural system to move away from an industrial model to a sustainable model. The general conclusion is that a wholesale conversion to a sustainable agricultural system is unlikely.

Sustainable agriculture entails myriad social, political, economic, and environmental aspects. An enormous literature on sustainable agriculture exists, with many variations on its definition and assumptions about sustainability [63]. Thus, here we can mention only some the basics. At its core, sustainability means the capacity to endure. As Kleppel argues, "sustainability is a set of behaviors, a way of thinking about how the present affects the future that leads simultaneously to environmentally, economically, and socially desirable outcomes" [64]. Sustainable agriculture de-mechanizes and de-carbonizes by replacing machines with animals; replaces chemical fertilizers with organic fertilizers; reduces if not eliminates the use of chemical pesticides and herbicides; emphasizes localized food and reduces the transportation distances that food travels to retail markets; encourages biodiversity and movement away from monocultural cropping; and substitutes fresh food for processed and manufactured products [65]. Further, sustainable agriculture combats the concentration of control by multinational corporations over food production, processing, and distribution that has occurred during the past twenty years [65–67], and instead returns control to local owners. When local food production and control over land is combined with broader political and social goals, it falls under the rubric of food sovereignty which arose in the 1990s in response to multinational corporate control over food production and alienation of agricultural land from those who till it [68]. In sum, sustainable farms are smaller, less capital intensive, and less dependent on financial conglomerates.

Two broad models exist for the introduction of sustainable agricultural practices. One model is from above, found in the European Union which has adopted explicit policies for sustainability. The EU supports those policies with a range of subsidies and types of financial assistance through Green Direct Payments which are included in the Common Agricultural Policy (CAP) since 2015 [69]. A second model is from below and originates with local initiatives outside of government policy. In the United States, the community supported agricultural model (CSA) links small-scale organic farmers with local consumers. Globally, the FAO is promoting CSA in developing countries to increase agricultural productivity, build resilience to climate change, and reduce greenhouse gas emissions [70]. Russia only partially shares in those models. There is no coherent government policy for sustainability. Although sustainability is not discouraged, strong government influence to facilitate sustainable practices is absent. And local initiatives are weak and unorganized and found only in a few of Russia's regions.

Although Russia is different from the European Union and the U.S., different forms of sustainable agriculture are found in Russia. One form of sustainable agriculture is an ecovillage, mentioned above, which is a community that lives off the grid and is self-sustaining. Ecovillages are formed for a variety of reasons but have in common counter-urbanism and are environmentally sustainable [32]. A second form of sustainable agriculture consists of dacha plots, which refer to small plots of land (on average about 0.11 hectares in size) surrounding a dacha, which is a weekend cottage for urbanites located outside a city. These popular weekend getaways are intended primarily for relaxation and owners spend their free days tending growing berries and vegetables. Moscow oblast has more land registered to dacha plots than any other region in Russia, and each Friday the highways out of the city of Moscow are jammed with cars heading to their country dachas. On Sundays, the flow is back into the city. In Russia's 2016 agricultural census, dacha plot land was equal to about 5% of total agricultural land [71]. Production from dacha plots may have importance for the family that grows the berries and vegetables, but nationally their contribution to food supply is insignificant.

The most economically significant form of sustainable agriculture in Russia is the household garden, lichnoe podsobnoe khoziaistvo, which has a long history in Russia and served as a substantial source of food that supplemented the household diet during the Soviet period [72]. Today, household gardens remain ubiquitous in the countryside, with more than 17 million registered plots that averaged 0.69 hectares at the time of Russia's 2016 agricultural census [71]. According to this agricultural census, which provides the most detailed data at the household level, one-third of households had land plots 0.10 hectares or less in size, and 53% of households had plots equal to or smaller than 0.15 hectares [71]. Thus, Russian household production

represents a form of smallholding agriculture that share many of the limitations that smallholders have in other countries including insecure property rights, low technological knowledge, a shortage of skilled labor, poor product tracing and quality control, low levels of finance and capital, and tenuous links to commodity markets [73].

The view of household producers as sustainable agriculture requires further nuance. To borrow from Lenin's scheme, there are poor, middle, and rich household gardeners. The poor and middle households have very small plots of land, are unmechanized and depend upon manual labor, and are non-commercial which means that they grow for food for self-consumption. These types of households use animal manure for fertilizer and other sustainable practices to grow their food. The small producer who is sustainable represents the majority of household gardeners. In contrast, richer households have larger plots of land, and some are private farms that register as household gardens (non-entrepreneurial activity) but are in fact commercial enterprises. These operations may be partially or fully mechanized, use chemical fertilizers, and produce food for sale. These larger gardens, therefore, have distinct characteristics and may or may not use sustainable practices.

In 2020, household production accounted for less than 30% of the ruble value of food production, most of which came from raw, unprocessed animal husbandry products, vegetables, and potatoes. Households consume most of their production, although a small percentage is sold for processing, some is sold in local markets, and some is bartered or exchanged with other households in a social network [74]. The degree to which food is commodified depends on the household's level of income: lower income households consume more of their production and higher income households sell more [75]. Because households' land holdings are small, they are not significant producers of grain or industrial-use crops such as sugar beets or sunflower seeds. Households' contribution to total food output since 2000 is shown in Table 3.

Table 3. Household food production as percentage of total output.

Year	*Household Production as % of Total Output* [a,b,c]	*Corporate Farm Production as % of Total Output* [a,b,c]
2000	52%	45%
2005	49%	45%
2010	48%	45%
2015	37%	54%
2017	32%	55%
2018	31%	57%
2019	29%	58%
2020	27%	58%

[a.] Output is based on nominal ruble value of production.
[b.] Numbers have been rounded.
[c.] The remaining percentage comes from private farm production.
Sources: Rosstat. *Rossiia v tsifrakh*. Moscow: Rosstat, various years and pages.

As a category, household food production is in decline due to the transformation of Russian society and changes in the role that households play in the food system. Household food production continues to play useful social roles in contemporary rural Russia in terms of social interaction and economic exchange in villages, a situation that is unlikely to change anytime soon. That said, from a food system perspective, households' economic role has changed due to the emergence of super-large, mechanized and modern farms called agroholdings that now dominate food production [76–78]. These large farms, some of which are introducing robotics, artificial intelligence, and digitalization, are much more efficient than households and can easily out-produce smallholders.

A second reason for the decline of household production is that Russia's food retail environment has also changed, with grungy state food stores and their mostly empty shelves replaced by modern, clean, well-supplied retail chain stores and supermarkets, both Russian and foreign (at least prior to the war in Ukraine). Russian consumers are more sophisticated and appreciate the convenience of prepared, ready to eat, and frozen foods that have become popular. No longer do urban consumers need to venture to local farmers' markets to search for food as during the 1980s and 1990s. Instead, urban consumers have grown accustomed to shopping in supermarkets. Household food production remains popular in rural areas, but this food is mostly for self-consumption that never makes it to market; and households have become less willing to raise large animals such as cows and pigs. Thus, changes on the demand and supply sides mean that household food production has become less important to Russia's food security, although

certainly for low-income households the supplementary production serves as a crucial source of food.

A third factor in the decline of household food production concerns demographic decline in the rural population, which is getting smaller and older. Forecasts by the Russian government envision a decline in the rural population from 37.7 million in 2018 to 32.9 million by 2036 (medium variant), while the most optimistic variant foresees a decline to 34.1 million [79]. A smaller rural population means that there will be fewer people to engage in household gardening, although one survey indicates that post-pandemic urbanites are rethinking urban life and may be open to relocating to the countryside in pursuit of cleaner air and environment [80]. Whether they do or not is an open question, but if they do, 75% of respondents were interested in having a household garden. The aging of the rural population, paradoxically, is not necessarily bad for household production since persons 50 years old and above are more likely to engage in household gardening than persons under 25. According to the same survey, half the people who are open to relocating to the countryside would like to obtain land, and two-thirds of those people are aged 51 to 64 [80].

High inflation globally and in Russia during 2021–2022 may lead to a short-term uptick in household food production in an attempt to substitute home grown food for store bought. That said, the long-term decline in household food production—the primary sustainable sector in Russian agriculture—is unlikely to abate. The upshot for sustainable agriculture, therefore, is that the household sector will steadily be marginalized. The household sector is not able to feed the nation or ensure food security across the full spectrum of commodities that consumers expect. Household production will not disappear, but it is a relic of the past and does not hold a viable economic pathway to future food security. State policy does not seem particularly interested in stimulating household production. Consequently, Russia's food system will remain dependent on industrial agriculture, with all of the attendant ramifications for climate change.

6. Conclusion. Russia's Climate Change and Global Food Security

Because Russia is a significant emitter of greenhouse gas emissions, the global challenge posed by climate change cannot be met without Russia's cooperation. Russia's positive contribution is complicated by tepid and inconsistent government policy toward climate change; by a war with Ukraine that has thrown pro-environmental policies off course; and by a mismatch between Russia's contribution to global food security and its sustainable agricultural sector.

We have seen that climate change is bringing hotter, drier conditions to Russia's south where most of its grain is grown. As average temperatures continue to climb in Russia's south, it will be harder to grow wheat and other heat-sensitive crops, and thus the structure of Russia's grain production will have to shift, a change that is important because Russia is the world's leading wheat exporter. Russia has ranked first or second every year since 2014 in volume of wheat exports and in the 2022/23 agricultural year is poised to sell more wheat abroad than ever, perhaps in excess of 40 million metric tons. In 2021, Russia's food exports reached a record $37.7 billion, with grain the primary commodity sold abroad that brought in more than $11 billion [81].

The changes that climate change will bring to Russia's agriculture most likely mean that its era as a "food superpower" will be relatively short. Grain surpluses that exist today and used for various foreign policy goals, for example to support the Assad regime in Syria or the authoritarian regime in Egypt, may diminish. In Syria, the civil war that has extended for more than a decade has led to the death of many young men who used to work the fields, and Russian military support for the Assad regime destroyed critical agricultural infrastructure. As a result, more than nine million Syrians, 60 percent of the population, suffers from acute food insecurity [82]. Syria receives humanitarian grain and other aid from Russia. Egypt is among largest importers of wheat in the world and is an important customer of Russian wheat. The banning of wheat exports by Russia after its 2010 disastrous harvest contributed to food riots in Egypt and further undermined the legitimacy of the Mubarak regime. Thus, if the use of food exports as an instrument of Russian foreign policy is constrained by lower harvests, Russia's global influence may be affected. Russia's main form of sustainable agriculture, household gardens, are small plots of land that are unsuitable for grain production. Thus, there is a mismatch between Russia's contribution to global food security and its sustainable agricultural segment. Industrial agriculture in Russia, therefore, is its future just as it was its past.

With lower volumes of grain available, the incentives for Russia's government to use export controls will increase. We have already seen Russia's use of export controls on grain in response to market conditions even without supply problems during 2020–2022. Russia used grain export controls in 2020 in the form of export quotas, even though the grain harvest was at that time the second highest on record in the post-Soviet period. In 2021, export quotas and export tariffs were applied to wheat, barley, corn, soybeans, and industrial crops such as sunflowers, the purpose being to discourage exports and keep these commodities at home. Export tariffs are a cost borne directly by exporters. Russia uses a floating export tariff that adjusts according to world prices. The higher the market price, the higher the tariff, which means that exporters cannot take full advantage of favorable global prices, and not being able to do so is a key driver in the decision to expand sowing and production. The response by exporters was predictable and exactly what the government wanted: less grain was exported. During the first half of the 2021/22 agricultural year, from 1 July to 23 December 2021, Russia exported 23% less wheat than during the analogous period in 2020 [81]. For the entire 2021/22 season, Russia's wheat exports declined 16%, due in large part to the export tariff [83].

In December 2021 Russia's Ministry of Agriculture indicated that export quotas would again be used during February–June 2022 [84]. On 15 February 2022, an export quota on grain sold outside the Eurasian Economic Union—11 million tons—took effect, including eight million tons of wheat, and three million tons each on barley, rye, and corn [85]. The government also announced that it intended to continue export tariffs, despite the strong 2022 harvest and opposition from both grain producers and exporting companies. Importantly, export tariffs have not been given an expiration date similar to export quotas, and therefore exert more enduring damage on grain trade.

It is worth emphasizing that Russia's grain exports were restricted despite good harvests. If Deputy Prime Minister Viktoriia Abramchenko is correct that climate change will reduce Russia's grain harvests by 30% by the 2040s [46], the impact on global food security will be profound. A 30% drop in the grain harvest equates to 24 million metric tons, using the annual production average of 125 million metric tons. For context, the global food crisis of 2006–2007 was precipitated by a drop of 24 million metric tons of grain from 2005–2006 to 2006–2007. In a situation of lower supply, Russia's government is likely to restrict grain exports even more, perhaps by raising the export tariff or lengthening the term of an export quota. Access to Russian grain is currently complicated by the fact that Russia was kicked out of the SWIFT system after it invaded Ukraine, a system that facilitates global financial exchanges. Although the purchase of Russian grain became more complicated, there are work-arounds as Russia and other countries attempt to replace SWIFT with an alternative financial transfer system. But there is no work-around for the effects of climate change. There is no alternative grain production system that can be substituted. If the supply of Russian grain declines on the global market due directly to climate change or a restructuring of production within Russia, grain prices will not just spike but remain high. With the likelihood that climate change will bring lower yields and lower volumes of grain production to Russia, global food security will be impacted. A perfect storm of lower global grain supply, more demand from importing countries, a higher number of food insecure people, a growing need for humanitarian aid, and the increasing severity of climate-related events could bring chronic food crises that extend for several years at a time.

Funding

No special funding was obtained for this article.

Author Contributions

I am the sole author and was responsible for all aspects for completion of this article.

Conflicts of Interest

The author declares no conflicts of interest.

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