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Assessment of the Impacts of Climate Change on the Russian Arctic Economy (including the Energy Industry)

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Abstract: Ongoing climate change most pronounces itself in northern latitudes, including in the Arctic zone of the Russian Federation (AZRF). Climate change is a complex multidirectional process that is characterized by both positive and negative effects on the functioning of territorial economic systems. In this regard, an analysis of the impacts of climate change on economic development is a particularly urgent scientific and practical task that requires comprehensive study. This research was devoted to assessing the probable impacts of climate transformations on the parameters of the economic development of the AZRF regions. The authors created a methodological approach to the assessment of the costs of the effects of climate change for the economy of the AZRF regions, taking into account the average predicted dynamics of surface air temperature and key regional economic specializations, as well as the degree of susceptibility of various industries to the climate change. The energy industry was considered in particular detail since it is the basis for all of the other industries and is the guarantor of life support for the populations that live in the extreme Arctic climate. Calculations have shown that the accumulated economic effects of climate change as a whole for the AZRF economy during the period 2020–2050 will be negative and have been estimated as having a cost of more than RUB 8 trillion (or nearly USD 111 billion in 2020 prices), which would be about 3% of total Russian Arctic GRP in average annual terms.

Keywords: climate change; Russian Arctic; economic effects; climatic costs; climatic dividends

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1. Introduction

At present, climate change is considered as a modern global megatrend and represents one of the most significant challenges to society of the 21st century [1,2]. Taking urgent action to combat climate change and its impacts is one of the 17 Sustainable Development Goals that were developed in 2015 by the UN General Assembly [3,4]. Depending on different scenarios that were formed on the basis of mathematical climate models, the forecasts of the increase in average air temperature during the 21st century range from 0.3–0.7 °C for the minimum scenario of greenhouse gas emissions to 2.6–4.8 °C for the maximum emissions scenario [5]. At the same time, the maximum value and rate of warming is expected in the circumpolar regions [6]; therefore, understanding the consequences of these processes at all levels is of great importance for Russia, as a northern country [7]. Climate change within the territory of the Arctic zone of the Russian Federation (hereinafter denoted as the AZRF) is firstly determined by the average annual air temperature increase, which contributes to the decrease in the area and thickness of perennial sea ice, the rise in sea level, the melting of the permafrost, changes in the structure of precipitation, the transformation of vegetation, natural hazard activation, etc. [8,9].

The complexity of the assessment of the natural processes under consideration was due to the multi-directionality and ambiguity of the possible consequences of climate change and the diversity of the transformations of various components in the natural environment. In this way, the high degree of uncertainty meant that it was only possible to judge certain consequences within a context of probability [10,11]. Society is facing certain global transformations for the first time [12], which makes forecasting even more difficult. Ongoing climate change induces generally negative connotations for the world's scientific community and civil society in terms of its impacts on the environment. However, the consequences of climate change from an economic point of view can vary significantly and could have both positive and negative aspects [13,14]. Finding a balance that creates conditions for obtaining maximum benefits while developing measures for preventing and reducing damage is a necessary condition for climate change adaptation [15]. However, to find this balance, the first step needs to be a scientific understanding of the vector and magnitude of the expected economic effects of climate change.

Some examples of the positive economic effects of climate change include: a reduction in construction costs due to thawed soils; cheaper passenger and cargo transportation, geological exploration and production; an increase in the duration of the navigation period through Arctic rivers and seas (including the Northern Sea Route); a reduction in energy consumption for the life support of those living in the Arctic regions; an expansion of areas for agriculture and forestry, etc. [16,17]. The negative economic effects of climate change are firstly associated with the increased activation of natural hazards and the additional costs for the corresponding prevention and elimination measures [18]. The most typical natural hazards for the Russian Arctic are a combination of dangerous geocryological slope abrasion processes, an increased frequency of extreme heat and cold waves, severe storms and other hydrometeorological hazards, epizootics, etc.

Most of the modern Russian and foreign studies within the framework of climate change analysis have focused on the modeling of climate change or predicting the future states of the natural environment and its components [19]. Modern science has studied the issues of measuring the impacts of climate change on economic dynamics to a much lesser extent. Most of the economic works have been based on analysis at the macro level, which does not allow for the full consideration of the local territory-specific factors. At the same time, the level of generalization within the obtained results has been too high in most cases and it is very difficult to verify them [20]. In addition, economic forecasts have been incomparably shorter than climatic forecasts [21]; however, the high pragmatic need for these estimates and the interest of decision-makers [22] require this limitation to be overcome.

The purpose of this study was to create and test a conceptual and methodological approach to assessing the impacts of climate change on economic development parameters in the Russian Arctic region. At the first stage, the achievement of this goal involved the following tasks:

- Investigate and carry out a comparative analysis on the current scientific approaches to the study issue;
- Identify the key probable positive and negative effects of climate change and their spatial projection on the AZRF territory;
- Provide the information base that would be necessary for the creation of forecast models in subsequent research;
- Create a technique for measuring the impacts of climate change on the dynamics of economic development, test this technique with a first approximation and highlight its strengths and weaknesses, as well as defining further directions for scientific research.

The Arctic, according to the report of the Intergovernmental Panel on Climate Change (IPCC), is one of the four regions in the world for which the effects of climate change are the most pronounced, along with Africa, small island states and the deltas of the largest African and Asian rivers, [23]. Long-term global climate observations have recorded higher rates of the increase in average annual air temperature in the Arctic (higher by up to several times compared to the planet as a whole (Table 1)). In particular, according to estimates from the Russian Federal Service for Hydrometeorology and Environmental Monitoring

(Roshydromet), climate change in Russia is about 2.5 times more intense than the global average and is estimated to have increased by 0.45 °C over the past ten years, while the worldwide average increase for the same period is only 0.18 °C [23–25].

Table 1. The estimates of the increase in average annual air temperature in the AZRF during 21st century (°C).

Source, Year	Western Sector	Central Sector	Eastern Sector	The Whole Planet
IPCC, 2007	4–4.5	4.5–5.5	3.5–4	2
CMIP3, 2007	5.5	5	5	2.8
RCP (CMIP5), 2013	5.5	7	6	2.8
SSP3-7.0, IPCC, 2021	5	6	5.5	3

Source: compiled by the authors based on [1].

In modern Russian science, some particularly noteworthy examples of the studies within the framework of the comprehensive analysis of the influence of probable climatic effects on the state of economic systems include the works of academics B.N. Porfiryev and V.A. Kryukov, as well as economists and economic geographers V.L. Baburin, V.N. Leksin, I.V. Makarov, A.N. Pilyasov, N.Y. Zamyatina, etc. A significant number of estimates regarding the impacts of the climate change on the economy is also contained within the annual analytical reports from Roshydromet, World Wildlife Fund Russia, large industrial companies (for example, "Gazprom", "Norilsk Nickel", etc.), the studies of the Russian Geographical Society and other scientific and public organizations. Recently, more and more attention has been paid to assessing the economic effects of climate change within the work of professional geophysicists, glaciologists, climatologists and meteorologists, including academics Y.S. Osipov and V.P. Melnikov and scholars O.A. Anisimov, A.V. Brushkov, V.M. Kattsov, A.V. Kislov, S.K. Gulev, etc.

The close attention of the Russian scientific community on the problems of the impacts of climate change on the economic development parameters of regions and industries has led to the formation of a strategic interest in this field at the highest level of Russian government. All of the above factors have determined the development of a number of strategic planning documents at the federal level, such as the "Strategy for the Spatial Development of the Russian Federation until 2025", the "Strategy for the Development of the Russian Arctic and Ensuring National Security until 2035" and the "National action plan for the first stage of adaptation to climate change for the period up to 2022". In these documents, separate sections are devoted to the assessment of the impacts of climate change on the parameters of economic development, as well as the development of adaptation measures and the formation of an effective system for the monitoring and analysis of ongoing natural and economic changes. At the highest government level, the development of a draft National Climate Strategy for the period up to 2030 is also being discussed, which is aimed at creating a carbon management system within the context of climate change with a view to switching to more energy efficient technologies.

In foreign science, most of the research has been devoted to identifying and measuring economic opportunities from climate change, which are formed primarily due to the projected increase in the production of oil, natural gas and other minerals and the development of sea and river shipping, tourism, agriculture and forestry [26,27]. Recently, a popular area for foreign research has been the assessment of the negative economic effects and the assessment of the potential damages and risks of climate change [28–32], as well as the modeling of the relationship between natural and economic processes [33]. Some works have summarized the findings of previous research within the framework of the considered problem [34]. At the same time, in foreign science, there are currently relatively few studies that have been devoted to the econometric assessment of the impacts of climate change on economic development processes. This has led to an increased interest in the development of such approaches and tools due to the high significance and relevance of the chosen research issue.

The AZRF is very intra-heterogeneous, both in terms of natural and socioeconomic characteristics. Accordingly, the consequences of climate change could vary greatly between the different parts of it. The experience of developed countries has already shown that early adaptation measures can reduce the damage and increase the benefits of climate change. Therefore, at the first stage, it is very important to understand which industries and territories in the AZRF are the most susceptible to climate change. This important research challenge underlines the significance of this innovative work.

2. Materials and Methods

As noted above, the economic effects of climate change can be either negative or positive, depending on their impact on various economy sectors. As a result, the expected synergistic effects of climate change are currently poorly predictable due to the complexity of connections and the nonlinearity of the dynamics of the studied parameters. The most important pragmatic task in modern conditions is the quantitative assessment of these effects, which can be measured both in absolute values and in relative parameters, e.g., percentage points that are calculated from the resulting macroeconomic indicators, the value added of the regional economy, the volume of investments in fixed assets, economic growth rates, etc.

In order to formalize our methodological approach for measuring the impacts of climate change on the parameters of regional economic development in the AZRF, the positive economic effects of climate change were defined as "climatic dividends" (as an analogy of the concept of "demographic dividend" (demographic dividend—the potential economic growth that can result from changes in the age structure of the population, mainly when the proportion of the working-age population (from 15 to 64 years old) is greater than the non-working age (14 and younger or 65 and older) [35]); in turn, the negative economic effects were termed "climatic costs".

In the modern research that has been devoted to the study of the impacts of climate change on the economy, great attention has been paid to the identification and classification of the possible economic effects of climate change. At the same time, these studies were fragmentary and did not contain a systematic coverage of all climatic effects within the context of measuring their resulting impacts on the development of particular regions and economic sectors and were often carried out on a very small scale. Another equally significant problem is that these studies were mostly theoretical and did not have a pronounced pragmatic orientation.

Within the framework of understanding global civilization processes, such as climate change, a stable position has been formed at the top Russian managerial level. The position lies in the fact that climate change is a long-term and poorly identifiable process in terms of the scale of human life, which is worthy of attention but, at the same time, does not require immediate urgent decisions to be made. This position is fundamentally incorrect since climate change comprises precisely those changes that are occurring here and now, which have a great impact on the economy and social vital activity and require a reasonable economic assessment and an effective adaptation strategy that involves the creation of systems for natural climate-related process monitoring and systems for response, warning and control.

In the first stage of creating a methodological approach for assessing the impacts of climate change on regional economic development, it was advisable to systematize all kinds of possible climatic dividends and costs within the context of the most significant economic sectors in order to estimate them quantitatively. Then, it was necessary to determine the resultant (positive or negative) influences of climate change on each considered economic sector.

According to the Russian presidential decree of 2 May 2014 (number 296: "On the land territories of the AZRF"), with subsequent editions, the administrative entities of nine regions are included in the AZRF. The gross regional product (GRP) of these regions in 2018 amounted to about RUB 8.8 trillion (or nearly USD 122 billion in 2020 prices, based on the average annual data from the Central Bank of Russia exchange rate for 2020 in which 1 USD = RUB 72), which was more than 10.3% of Russia's total GDP. The most significant industries in the AZRF regions are presented in Table 2.

Table 2. The main industries of the AZRF region.

Industry	Value Added, RUB Trillion	Share in Total Arctic GRP
Mining	3.9	44.3%
Manufacturing	1.1	12.5%
Management and social sphere (public administration, healthcare, education)	0.8	9.1%
Construction	0.7	8.0%
Trade	0.5	5.7%
Transportation and logistics	0.5	5.7%
Power	0.2	2.3%
Agriculture and forestry	0.2	2.3%
Other	0.9	10.2%
total	8.8	100.0%

Source: compiled by the authors based on Rosstat (Russian Federal State Statistics Service) data. Collection: "Regions of Russia. Socioeconomic indicators 2020".

Taking into account the listed industries of the economic specializations of the Russian Arctic regions, an analysis of the most probable positive and negative economic effects of climate change was carried out within the framework of this study (Table 3).

Table 3. The probable economic effects of climate change within the context of key industries in the AZRF region (the colors correspond with Table 4).

Industry of Specialization	Key Probable Economic Effects of Climate Change	
	Positive (Dividends)	Negative (Costs)
Mining	Increasing access to mineral deposits, including shelf projects	Deterioration of the ecological situation due to increased production intensity; decreased demand for fossil fuels due to shorter heating season data; possible future tightening of carbon tax
Manufacturing	Intensification of the development of the pulp and paper and chemical industries due to the expansion of and increased access to the raw material base	Deterioration of the ecological situation due to increased production intensity; destruction of fixed assets due to permafrost degradation, including additional costs for thermal stabilization systems
Trade	Intensification of trade due to the acceleration of the transport complex and the expansion of transit functions (e.g., development of the Northern Sea Route, the Northern Latitudinal Railway, etc.)	Failure to comply with delivery times due to the activation of dangerous hydrometeorological processes; destruction of road infrastructure due to the activation of dangerous geocryological processes
Construction	Ability to meet the construction needs of other industries; reduction in the cost of construction on thawed soils and reduction in the cost of building materials due to an increase in year-round transport accessibility; the need to eliminate deformed buildings and structures	Failure to comply with construction deadlines due to the likely need for urgent replacement of a significant share of buildings and structures; increased costs for the development of new technologies in the construction sector; the development of new building regulations and standards

Table 3. *Cont.*

Industry of Specialization	Key Probable Economic Effects of Climate Change	
	Positive (Dividends)	**Negative (Costs)**
Transport and logistics	Extension of the duration of summer navigation without the need for the icebreaker fleet; development of transport routes (e.g., the Northern Sea Route, the Northern Latitudinal Railway, etc.); reduction in the cost of the construction of new roads, railways and main pipelines without taking into account the permafrost; reduction in costs due to shortening the operation period of snow removal equipment	Activation of coastal abrasion and destruction of port infrastructures due to increased storm activity; deformation and destruction of transport infrastructures as a result of permafrost degradation; complication of navigation and work for land transport in certain time periods due to the activation of hazardous hydrometeorological processes
Power	Reduction in the cost of implementing heat supplies (i.e., cheaper fuel, etc.)	Decrease in heating intensity; decrease in utility sector profits
Agriculture and forestry	Increase in the productivity of northern ecosystems; shift of the northern forest border to the north and an increase in its productivity (e.g., the possibility of developing forestry and logging in more northern regions)	The spread of epizootics; plant pests
Other	Development of ecotourism, cruise tourism, etc.; mitigation of living conditions for the population, including the small indigenous populations in the North	Disruption of the natural habitat of animals and plants; the disappearance of permafrost ecosystems; a reduction in the species diversity of the Arctic flora and fauna due to heat waves; the introduction of atypical species and the displacement of endemics from food chains, etc.

Table 4. The classification of the AZRF industries according to the predominant type of economic effects caused by climate change.

Positive (Dividends)	Neutral (Balance of Positive and Negative Effects)	Negative (Costs)
Mining Construction Trade and tourism Agriculture and forestry	Transport and logistics Power	Manufacturing

Therefore, the main risks for almost all industries are associated with permafrost degradation [36]. Taking into account the systematization and differentiation of the economic effects of climate change, the key sectors of economic specialization in the AZRF regions from the first approximation could be classified as follows (see Table 4).

The overall negative consequences of climate change are predicted in terms of their impact on the volume of accumulated fixed assets within all industrial sectors in the AZRF. In this regard, the proposed classification of industries should be used with an adjustment to take into account the negative effects that are associated with permafrost thawing. This point of view has determined the negative vector of ongoing climate change for the Arctic economy as a whole. According to Anisimov, the ongoing processes of permafrost thawing could cause colossal damage to the Russian Arctic economy, which could exceed all predicted positive effects from climate change by several times (Information agency "LenTV24", The scientist told about the threat of climate change to Russia, available online: URL: https://lentv24.ru/ucenyi-rasskazal-cem-grozit-izmenenie-klimata-rossii.htm (accessed on 4 December 2021)). Moreover, the predicted negative effects will undoubtedly arise and manifest themselves in a natural way, while the positive effects of climate change will need to be adapted properly and effectively.

Due to the aforementioned multi-directionality of climate change, as well as the complexity of the processes under consideration, the primary task for economic activity planning in this context is the comprehensive identification of the negative and positive effects of changing climatic conditions and, as a result, the determination of the general vector of projected changes. It is very important to develop the correct strategic vision for further development in terms of the resulting interpretation of the studied processes. First, the following question must be answered: which economic effects of climate change (positive or negative) are most probable at the macro level in general and how much is the AZRF territory internally heterogeneous on this basis?

Achieving a strategic vision for this issue cannot be formed by being based only on the natural, geographical and climatic analysis alone; it is very important to take into account the factors of the macroeconomic situation as well. When all other things are equal, the territorial economic systems that have positive trends in economic development most likely also have conditions for receiving and using the predicted climatic dividends. On the contrary, the stagnant territorial economic systems and those in prolonged economic crises are unlikely to have additional resources to enable effective adaptation to the ongoing changes. For systems with a weakened economy, climatic costs could significantly exceed climatic dividends, which would further increase the pressure on an economy that is already in a crisis state, thereby aggravating the situation. Therefore, the level of regional socioeconomic development that is achieved in this case is the most important basic factor. We highlight that it becomes expedient to develop a methodological approach for assessing the impacts of climate change on the economic development dynamics of the AZRF regions that could take into account and logically combine both natural and economic factors.

In order to create a representative model for assessing the impacts of climate change on the parameters of economic development, it was advisable to identify a list of the most significant sectors within regional economies that would be most affected by climate change. Within the framework of this study, industries with a contribution to the GRP of at least 5% were classified as the most significant sectors of the regional economies (highlighted in bold and colored numbers in Table 5). The most significant industry for all Arctic regions is the mining industry, the contribution of which is the highest for the Nenets Autonomous Okrug (AO) region, which is more than 83% of the GRP, and the lowest for the Arkhangelsk Oblast region, which is more than 5% of the GRP. The locations of the AZRF regions are shown on the map in Figure 1. For most of the studied regions, the transport and trade sectors (seven out of nine regions), manufacturing, public administration and construction (five out of nine regions) are also of great importance (Table 5). It should be noted that a high share of non-market services is mainly characteristic of dependent budget economies in the most depressed regions in which other sectors are poorly developed [37].

Table 5. The industries of economic specialization in the AZRF regions in 2018 (%).

Industry	1 [1]	2	3	4	5	6	7	8	9
Mining	**17.1**	**44.1**	**83.2**	**5.1**	**12**	**67.3**	**25.6**	**51.5**	**40.3**
Manufacturing	**20.8**	**11.5**	0.2	**27.4**	**11.5**	1.6	**31.8**	1.1	0.3
Construction	3.5	**5.7**	3.5	4.9	**7**	**12.4**	4.6	**9.6**	**7.3**
Trade	**5.3**	4.7	0.7	**10**	**9.1**	**6.4**	**6**	**5.7**	**6.3**
Transport and logistics	**11.3**	**6.9**	**5.8**	**11.5**	**10.7**	3.8	**5.9**	**6.3**	4.3
Public administration	**8.7**	**5.3**	1.2	**7.7**	**7.7**	1.3	3.7	4.5	**9.5**
Health service	**7**	4.2	1	**6.6**	**6.7**	1.2	3.5	4.3	**5.8**
Power	2.8	2.5	0.7	2.6	3.6	1.1	3.9	4.3	**13.3**
Agriculture and forestry	**6.1**	1.5	0.7	**6.3**	**14.4**	0.1	2.5	1.6	2.5
Education	4	3	0.7	3.9	3.4	0.7	2.7	4.2	4.6
Real estate	**5.3**	1.7	0.5	**5.8**	3.5	0.9	2.7	1.6	0.6
Other	8.1	8.9	1.8	8.2	10.4	3.2	7.1	5.3	5.2

[1] The following regions are designated by numbers in the table titles: 1, Karelia Republic; 2, Komi Republic; 3, Nenets Autonomous Okrug; 4, Arkhangelskaya Oblast; 5, Murmanskaya Oblast; 6, Yamalo-Nenets Autonomous Okrug; 7, Krasnoyarskiy Krai; 8, Sakha Republic (Yakutia); 9, Chukotka Autonomous Okrug. Source: compiled by the authors based on Rosstat data. Collection: "Regions of Russia. Socioeconomic indicators 2020".

Figure 1. The locations of the AZRF regions. Source: compiled by the authors.

Taking into account the estimates from the previous work of the authors, in particular the estimates of the socioeconomic potential of the AZRF municipalities [10,21], as well as analyzing the economy of the AZRF as a whole and its main mining specialization, it can be noted that climate change could accelerate the development of the mining sector and some manufacturing industries that are built on that basis, such as the woodworking, pulp and paper, chemical and petrochemical industries [38]. The development of these industries could then stimulate the accelerated development of the construction sector, for which high climatic dividends are also most likely. For the Arctic regions that specialize in transport functions, climate dividends could correspond to those regions with a predominance of transit functions. These regions concentrate a large number of transport infrastructures and vehicles, specifically the Murmansk and Arkhangelsk Oblasts and the Karelia Republic [17].

The energy industry is of exceptional importance for the Russian Arctic; on the one hand, it provides the opportunity for 2.4 million people to live in extreme climatic conditions and it allows the operation of other economic sectors and on the other hand, it is a large and independent economic sector, which forms a significant share of the GRP of some territories. The energy system of the Russian Arctic is unique. Most of the Arctic power stations are not connected to the Unified Energy System of Russia. The biggest power stations in the AZRF in terms of installed capacity are the Kola Nuclear Power Station (1760 MW), the group of Norilsk Thermal Power Stations (total capacity of about 1190 MW), the Urengoy State District Power Station (530 MW), etc. (see Figure 1). The Kola Power Station is the largest beyond the Arctic Circle in terms of installed capacity and its total installed capacity is 3640 MW. In general, this energy system is surplus, with some of the generated energy being exported to Norway. The Ust-Khantayskaya (461 MW) and Kureyskaya (600 MW) Hydroelectric Stations also supply electricity to the Norilsk industrial hub (non-ferrous metallurgy is one of the most energy-intensive industries). Among these unique energy industry facilities, the world's northernmost nuclear power station Akademik Lomonosov (a non-self-propelled power barge that operates as the first Russian floating nuclear power station), the experimental Kislaya Guba Tidal Power Station and the Anadyr Wind Power Station (one of the largest in Russia) should be noted. Oil and gas companies own a significant share of the energy facilities in the Nenets and Yamalo-Nenets Autonomous Okrugs. Their distinguishing feature is mobility, as oil and gas companies practice the transfer of diesel generator sets from one field to another in order to offset any emerging power shortages. The cost of electricity generation is highest at mobile diesel power stations. Emergencies in energy systems in the Arctic can always become catastrophic. For instance, in a 45-degree frost in the winter of 1979, a serious accident occurred on a gas pipeline that provides fuel for the Norilsk Power Stations. The situation was so serious that the government was working out plans for the evacuation of a city with a population of 250,000, which only has the option for passenger transport to the rest of Russia by air in the winter.

In this regard, the energy industry requires priority attention within the context of studying the consequences of climate change on the regional Arctic economies. On the one hand, climate change could lead to the easier extraction and transportation of fossil fuel and, accordingly, a reduction in the cost of fossil fuels for the energy industry. Natural gas and oil are currently the predominant types of fuels in Arctic power stations, but there are prospects for switching to liquefied natural gas (LNG). At the same time, existing and prospective LNG plants in the Russian Arctic are located within port industrial complexes. The predicted activation of coastal abrasion and sea level rise may lead to the need to move LNG plants inland, which is also associated with significant costs. In general, the most evident consequences of climate change for the energy industry in the Arctic are associated with a reduction in the duration of the heating season and, accordingly, the demand for electricity. On the other hand, the demand for electricity may contrarily increase in the summer due to the increasing need for air conditioning during heat waves [39]. Another significant factor to consider is the implementation of a carbon tax in an effort to curb climate change. Energy may be one of the most susceptible industries. According to the [40], the earnings in the utilities, materials and energy sectors would be the most impacted and could lose between 40 and 80% of earnings per share by the immediate imposition of a global carbon tax of USD 100 per metric ton. By region, revenue-weighted earnings could fall by about 20% in the Asian Pacific and by 15% in the Americas and Europe. However, the uncertainty of this factor is very high and it was necessary to include this with a longer-term forecast for Russia in our analysis.

As noted above, the main costs of climate change in the Arctic are primarily associated with the destruction of buildings and structures due to permafrost thawing in the permafrost regions. Within the framework of this study, the previously calculated values [41] of projected economic losses were used. For instance, the total value of energy buildings and structures in the Russian Arctic is about RUB 368 billion in 2020 prices. In study [42], it was found that the total damage to the energy infrastructure in the AZRF, in the case of continued warming and permafrost degradation, could be from RUB 128 to 244 billion by 2050. As shown on the map in Figure 2, up to 100% of energy assets could be damaged in some districts according to worst case scenarios. Moreover, the main damage would fall on the main centers of hydrocarbon production, the Yamalo-Nenets and Nenets Autonomous Okrugs and northern Krasnoyarsk Krai, which may also affect the cost of fuel.

Thus, the multi-directionality of the economic effects of climate change that are predicted in different key sectors of the regional Arctic economies has determined the need to create a methodological approach for the resulting quantitative assessment of the probable effects.

This study proposed a new methodological approach for assessing the probable impacts of climate change on the economic development of the AZRF regions. It took into account the following key parameters: the average dynamics of climate change in the western, central and eastern AZRF sectors [1]; the economic specializations of the Arctic regions; the degree of susceptibility of the specialized industries to climate change; the differentiation of the economic effects of climate change through the allocation of climate dividends and climatic costs.

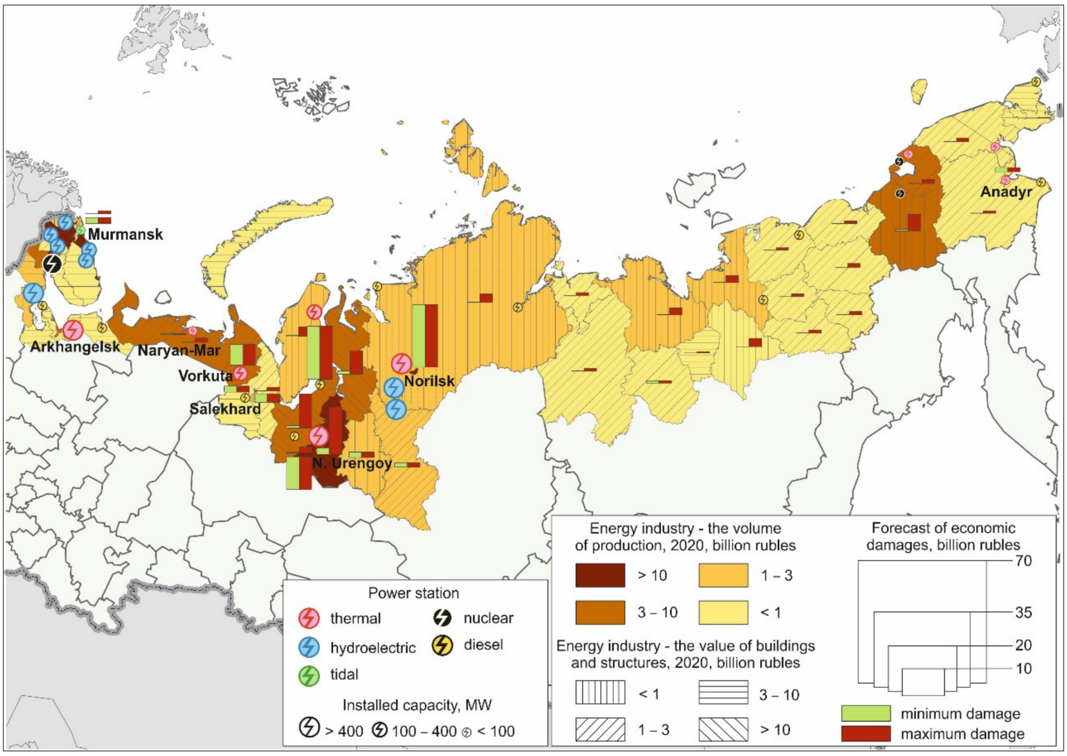

Figure 2. The main characteristics of the energy industry of the AZRF. Source: compiled by the authors based on their own calculations, Rosstat data [42] and the official heat supply schemes for regions and settlements.

The effects of climate change were firstly calculated in absolute values (in RUB), after which they were correlated with the basic macroeconomic indicator of the gross regional product (GRP) of the AZRF regions. In worldwide practice, it is customary to make international comparisons of the economic consequences of the biggest natural disasters in terms of the share in that country's GDP. Thus, the proposed methodological approach would not only allow the quantification of the climatic dividends and costs but would also determine the level of their significance relative to the accumulated economic potential of the regional Arctic economies. It is also necessary to clarify that this study did not make macroeconomic forecasts until 2050, since it was not possible to achieve this for such a distant period. We offer only an assessment of the climate-dependent relative increase in the GRP of the considered regions. In this case, the calculations were based on the current basic situation, which was based on the analysis of the dynamics of the aggregate Arctic GRP for 2000–2018. It was assumed that the average annual growth rate would be 3%. The sum of the accumulated climate dividends and costs until 2050 determined the total value of the economic effects of climate change within this period in 2020 prices.

As a basis for calculating the average annual damage, we used the amount of probable damage caused by the deformation of buildings and structures on thawed soils until 2050 (using the most negative climate change scenario) [41]. Thus, the calculated value of the probable positive effects for the economic sectors was adjusted by the average annual losses. It was assumed that timely measures for the thermal stabilization of soils would not be taken. According to some estimates in [9], the existing funds for the costs of thermal stabilization are practically comparable to the expected damage value and, in some cases, even exceed them.

Within the framework of the estimation of the probable damage that could be caused by climate change, the liquidation value of the destroyed housing stock in the AZRF regions was estimated for the first time. The calculation was based on the cost of dismantling one cubic meter of a house. In Vorkuta, this cost is RUB 1025 (the data were provided upon request to the Komi Republic Government), the cost is RUB 2600 in the Yamalo-Nenets Autonomous Okrug (the data were provided upon request to the Yamalo-Nenets Autonomous Okrug Government) and the cost is RUB 1560 in the Nenets Autonomous Okrug (the data were provided upon request to the Nenets Autonomous Okrug administration). The results are presented in Table 6.

Table 6. The basic calculations for assessing the effects on the construction sector.

Region	1 [1]	2	3	4	5
Yamalo-Nenets AO	279,483	74,936	2997	607,407	24,296
Nenets AO	22,350	3484	139	46,956	1878
Chukotka AO	4696	8996	360	131,162	5246
Komi Republic	10,956	7649	306	92,281	3691
Sakha Republic (Yakutia)	1866	4520	181	35,577	1423
Krasnoyarskiy Krai	40,304	37,701	1508	220,069	8803
Sum	359,655	137,286	5491	1,133,452	45,337

[1] The following parameters are designated by numbers in the table titles: 1, average annual damage for 2025–2050 (RUB million; both housing stock and economic assets); 2, the cost of the liquidation of destroyed housing stock up to 2050 (RUB million); 3, average annual liquidation cost for 2025–2050 (RUB million); 4, the cost of new housing stock construction to replace liquidated stock up to 2050 (RUB million); 5, average annual cost of new housing construction for 2025–2050 (RUB million). Source: the authors' calculations.

Based on this calculated data, the likely effects on the construction industry were estimated. In general, as a result of ongoing climate change, it is expected that construction will be stimulated due to the need to replace deformed assets with new buildings and directly covers work on the demolition of emergency housing, the preparation of construction sites and the building of new construction projects. Thus, the study only considered the economic dividends for the housing construction sector. The fact that the cost of construction on thawed soils could be cheaper than current costs was taken into account; however, by also taking into account the transport factor and the weak development of the building materials industry within the regions of the Russian Arctic cryolithozone, costs would apparently not decrease to the national average values.

Therefore, to calculate the current construction cost of 1 sq. m in the corresponding regions [21], a reduction coefficient of 0.8 was applied because the cost of building foundations for multi-apartment buildings is about 8–18% on average [43]; however, the cost of a pile foundation on permafrost can reach up to 50% of the value of the whole house due to the large number of piles that is required. On average, there are about 150–200 piles per section of a panel multi-apartment house that is built on permafrost, while the average number of piles is about 100 in more southern regions. Thus, the volume of housing stock to be replaced was multiplied by the cost of building 1 sq. m and the corresponding reduction coefficient to calculate the average annual value until 2050.

Thus, the formula for the resulting calculation was as follows:

$$\underset{2020-2050}{\mathrm{EFF}_{climate}} = \sum\left(\frac{T_{{}^\circ\mathrm{C}}}{100}(\pm kx_1 \pm kx_2 \pm kx_n\right) - \sum \mathrm{COST}_{climate}, \quad (1)$$

where:

$\mathrm{EFF}_{climate}$ is the economic effect of climate change;

if $\mathrm{EFF}_{climate} > 0$ is the climatic dividends;

if $\mathrm{EFF}_{climate} < 0$ is the climatic costs;

$T_{{}^\circ\mathrm{C}}$ is the averaged estimates of the mean annual air temperature increase in the western, central and eastern sectors of the AZRF over the 21st century;

x_n is the industry of economic specialization in the AZRF regions with a contribution to the GRP of at least 5%;

k is the coefficient of the susceptibility of the industry of economic specialization to the impacts of climate change. Within the framework of the study, the industries that are most susceptible to the impacts of climate change were mining, construction, trade, agriculture and forestry and manufacturing. For these industries, a coefficient of 0.5 was used. A coefficient of 0.1 was used for the other sectors that are less susceptible to the impacts of climate change. The coefficient weights of climatic susceptibility were estimated using an expert method and took existing assessments [23] of the impacts of climate change on the development of various industries into account;

$COST_{climate}$ is the assessment value of the average annual damage and costs for the AZRF regions.

Formula (1) was based on a combination of natural and economic factors. It formalized the methodological approach for assessing the economic effects of climate change that was proposed in this study. The natural factors were considered using the predicted average increase in average annual air temperature in various AZFR sectors during the 21st century. They were calculated on the basis of the data from Table 1 (variable "T°C"). The economic factors were interpreted using the positive and negative economic effects of climate change. They were estimated based on the differentiation of industries according to the degree of their susceptibility to climate change (see variable *kx* in Tables 2 and 3). Further, the calculated estimates of average annual damage were subtracted from the volume of economic effects (variable COST_*climate*). Thus, the proposed methodological approach reflected one of the most significant and urgent modern scientific issues: the conversion of climate change into measurable macroeconomic parameters.

3. Results

Based on the calculations that were carried out using the developed methodological approach, the climatic dividends and costs for the AZRF regional economies up to 2050 were estimated. In accordance with the results that were obtained, the prevalence of climatic costs over climatic dividends was predicted in general for the Russian Arctic territory, which determined the formation of the general negative effects of climate change for the Russian Arctic economy up to 2050. Thus, the calculations confirmed the initial hypothesis of the study.

In particular, the accumulated value of climate dividends up to 2050 was estimated to be RUB 3149 billion, while the accumulated value of climatic costs for the same period was predicted to exceed RUB 11,233 billion (hereinafter, the data for the macroeconomic indicators are presented in 2020 prices). In accordance with the presented data, the accumulated value of the predicted effects of climate change for the Russian Arctic regions up to 2050 was negative and was estimated to be RUB 8085 billion. The average ratio of climatic costs to climatic dividends as a whole for the period under consideration in the AZRF regions was 1 to 3.6.

Based on the accumulated volumes of climatic effects up to 2050, the average annual volume of climatic dividends for the AZRF economy was estimated to be RUB 105 billion, or 1.2% of the total AZRF GDP in 2018, while the average annual volume of climatic costs was estimated to be RUB 374 billion, or 4.3% of the GDP. Thus, the average annual effect of climate change on the economy of the Russian Arctic regions, as noted above, was predicted to be negative and average 3.1% of the Russian Arctic GDP in 2018.

These initial averaged estimates characterized the predicted state of the regional Russian Arctic economies during the process of climate change, in a much-generalized form. It would not be enough to only use these indicators as averages over a very long time period. A better understanding of the predicted situation could be achieved by analyzing the spatial-temporal picture of the investigated processes.

First, despite a generally negative effect on the Russian Arctic economy as a whole, in the case of individual regions, the ratio of climatic dividends and costs varied considerably. In this respect, two groups of regions could be distinguished: those with positive climatic effects (the Karelia and Sakha (Yakutia) Republics and the Murmansk and Arkhangelsk Oblasts) and those with negative climatic effects (Komi Republic, Nenets, the Yamalo-Nenets and Chukotka Autonomous Okrugs and Krasnoyarsk Krai).

The indicated territorial differences were due to several key factors. First, in the territories of the Karelia Republic and the Murmansk and Arkhangelsk Oblasts, permafrost is practically absent. In this regard, the predicted economic damage from permafrost thawing as the most important negative effect for these regions was not significant. In addition, the European sector of the Russian Arctic as a whole is characterized by milder initial climatic conditions and the more diversified structures of regional economics. Thus, the climate change processes for these regions could mostly be considered as additional opportunities that could contribute to the acceleration of economic development through the stimulation of production and infrastructure activity and the intensification of investments in traditional and new economy sectors.

The institutional factors also generally favor transformation processes in the medium term. For example, the introduction of preferential treatment for new residents of the Russian Arctic (established by Federal Law, number 193-FZ, on 13 July 2020: "On State Support for Entrepreneurial Activity in the Arctic Zone of the Russian Federation") has created favorable conditions for development of the new enterprises.

On the contrary, the Arctic territory of the Sakha Republic (Yakutia) is almost completely occupied by permafrost; however, the level of economic development in this territory is low, including a low level of accumulated socioeconomic potential, such as the volume of fixed assets and the objects in the transport and energy infrastructures. It determined insignificant predicted damages from permafrost thawing, which would not exceed the predicted climatic dividends for the Yakutia economy.

The maximum level of economic damage caused by climate change was predicted for the AZRF regions, which, on the one hand, concentrate a significant accumulated socioeconomic potential, but on the other hand, the territories are vast areas of continuous permafrost distribution. This is why about 80% of the total volume of the predicted negative economic effects of climate change in the Russian Arctic was associated with the most economically and spatially developed region: the Yamalo-Nenets Autonomous Okrug. For this region, climate change could lead to the most catastrophic and destructive consequences, which, in turn, could have extremely negative effects on the dynamics of its economic development and threaten the currently high growth rates of the regional economy.

A significant excess of climatic costs over climatic dividends was also predicted for the Chukotka Autonomous Okrug and Krasnoyarsk Krai. However, due to the lower levels of economic and spatial development in these regions, the predicted climatic costs were not as significant as those for the Yamalo-Nenets Autonomous Okrug. At the same time, the Arctic districts of the Krasnoyarsk Krai also have significant accumulated socioeconomic potential, most of which is associated with "Norilsk Nickel", as well as the Vankor group of oil fields. The key risks of climate change in the Chukotka Autonomous Okrug are associated with the operation of the mining complexes and energy infrastructures, including Bilibino Nuclear Power Plant.

The economic effects of climate change for the Arctic districts of the Komi Republic were also predicted to be negative, but in relative terms, they were much less significant. Their predicted negative impact on the parameters of the regional economic development was not as critical compared to those of the Yamalo-Nenets and Chukotka Autonomous Okrugs, as well as the Krasnoyarsk Krai (Figure 3).

However, the predictions for the average annual share of climatic costs within the total volume of the economy of the AZRF regions also varied significantly depending on the particular time period. Taking into account the forecasts for the increase in average annual air temperature in the AZRF regions [1,5,44], as well as existing estimates for permafrost thawing in different parts of the AZRF [41,45], it was assumed that the level of influence of climate change on the parameters of regional economic development would be described by complex and uneven dynamics.

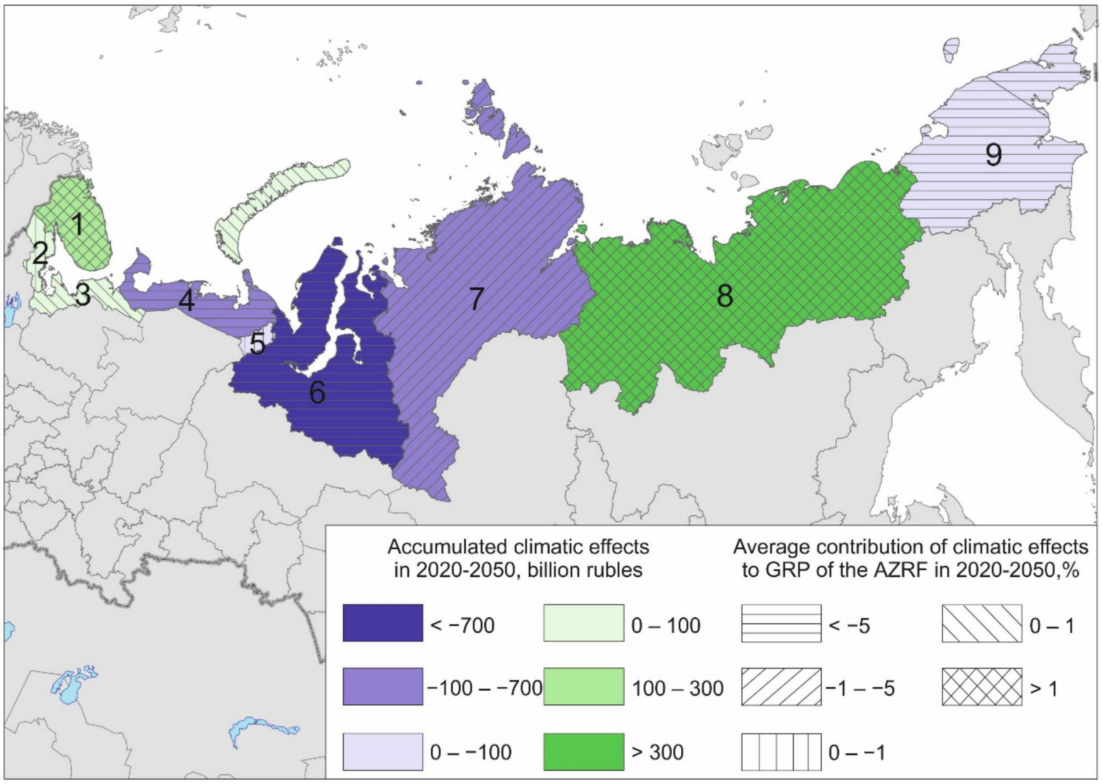

Figure 3. The results of the calculations of the economic effects of climate change on the economic development of the regions of the Russian Arctic for 2020–2050. The following regions are designated by numbers in the figure: 1, Murmanskaya Oblast; 2, Karelia Republic; 3, Arkhangelskaya Oblast; 4, Nenets Autonomous Okrug; 5, Komi Republic; 6, Yamalo-Nenets Autonomous Okrug; 7, Krasnoyarskiy Krai; 8, Sakha Republic (Yakutia); 9, Chukotka Autonomous Okrug.

In particular, during the period 2020–2035, the predicted level of influence of the climatic costs on the parameters of economic development would not be critically significant, with a high degree of probability. However, at the same time, a slow but systemic and growing increase in the degree of influence of climatic factors on the Arctic economy was predicted. This period is strategically significant from the point of view of the need to develop effective adaptive strategies for climate change, the formation of systems for environmental and economic monitoring and analysis and the assessment of ongoing changes.

During the period 2035–2045, in the case of an increase in average annual air temperature in the Russian Arctic by 2.5–3 °C relative to the temperature parameters from the beginning of the 21st century, the cumulative effects that would have accumulated over a more than 30-year period could lead to the intensification of climate change-related processes. During this period, a significant increase in negative climate change-related economic effects was predicted in the Russian Arctic. The predicted level of the impacts of climate change on the parameters of economic development would be determined by the executive decisions that were made at the previous stage in terms of the implementation of adaptation strategies for the ongoing climatic, natural and socioeconomic transformations.

After 2045, taking into account the factor of climate change that would already have occurred as well as the primary economic adaptation of regional economic systems, it was predicted that the level of the impacts of climatic costs on the parameters of economic development will decrease and that the dynamics of the studied processes will reach a plateau (Figure 4).

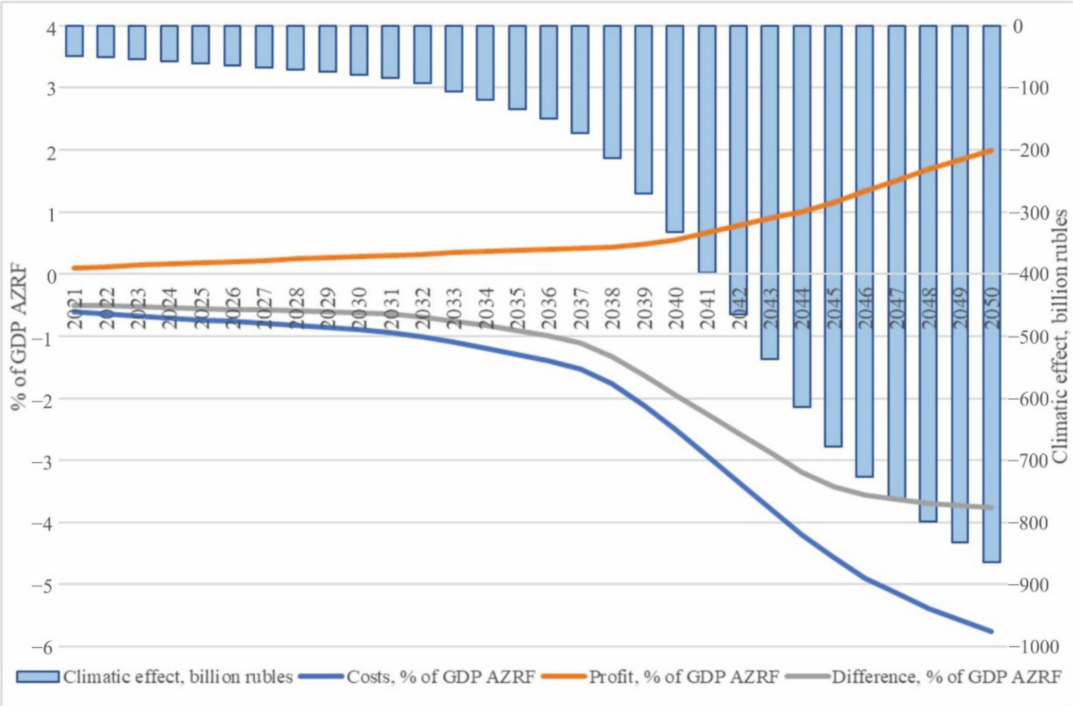

Figure 4. The forecast of the contribution of climatic dividends and costs to the GDP of the Russian Arctic (%) plotted against the total climatic effects for 2021–2050 (RUB billion).

Considering the scenarios for the dynamics of the studied processes beyond 2050, it was be assumed that the process of economic adaptation to climate change in the Russian Arctic would be completed in the second half of the 21st century. it was predicted that the influence of the climate change effects will stabilize, after which their share in the total AZRF GDP will begin to decline, with a high degree of probability, primarily due to an increase in the volume of climatic dividends. The success of this scenario depends on the development of a timely response system to the consequences of climate change, the use of measures that are set to prevent the negative consequences of climate change and the implementation of necessary measures in terms of preventing the manifestation of those consequences in the future. Otherwise, without the implementation of a full-scale comprehensive adaptation strategy for climate change, multiple increases in the number of natural and man-made disasters and, therefore, an aggravation of the ecological situation was predicted in the Russian Arctic. This would ultimately lead to significant damage to economic development, which may be critical for a number of regions in the AZRF.

4. Discussion

This study was dedicated to the assessment of the impacts of climate change on the parameters of economic development in the AZRF regions and can be considered as a pilot and pioneer study. As it was repeatedly noted above, there are currently very few methodological research works that have addressed the issues under consideration, both in Russian and foreign science. At the same time, the continuing acceleration of climate change processes has determined the urgent need to develop such methodological approaches in order to further form and launch effective adaptation strategies for climate change.

Within the context of the problems and development directions of the Russian economy, the issues that were considered in the framework of the study were characterized by particular relevance, since the current climate change in the Arctic is occurring up to several times faster than that across the whole planet, according to various estimates. Another equally significant reason is the strategic importance of the Arctic territories for the economy of the Russian Federation [46]. Taking into account modern economic realities and positioning, the AZRF territories could provide an additional source of economic growth that has not yet been fully implemented, for which it is necessary to develop and implement an effective system of measures that are aimed at maximizing the positive economic effects of climate change and minimizing the predicted risks, costs and damage.

In this study, the probable economic effects of climate change (positive and negative) were quantitatively measured, the ratio of benefits and costs was estimated and, most importantly, the patterns of the spatial heterogeneity of possible effects were revealed for the first time for the Russian Arctic.

The results of this study demonstrate one of the worst case scenarios in terms of the predicted negative impacts of climate change on the economic development of the Russian Arctic up to 2050 and, most of all, the Yamalo-Nenets Autonomous Okrug. However, the probability of the realization of this scenario significantly increases if in the previous stages of the necessary actions are not taken, in terms of preventing the negative impacts of climate change. This study only provided a primary approximation; however, in further studies, the authors plan to clarify and expand the results that were obtained here by using linear programming tools. A description of the target function of regional economy growth, subject to maximizing climate dividends and (or) minimizing climatic costs, is planned.

The direction of subsequent research has to be the clarification and verification of the considered parameters and the expansion of their number. The next step could be the numerical modeling, for example, of the development and testing of a predictive balance model for the benefits and costs of climate change in the AZRF. Finally, a more detailed geographic analysis also needs to be carried out.

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