Evaluating the global climate change influence on the infrastructure development at the Arctic zone of the Russian Federation

A M Konovalov¹, Z B Namsaraev² and G V Baturova¹

¹ MIREA - Russian Technological University, Moscow, 119454, Russia
² NRC Kurchatov Institute, Moscow, 123182, Russia

Corresponding author: zorigto@gmail.com

Abstract. One of the major problems of the Arctic zone of the Russian Federation (AZRF) is the unpreparedness of all types of infrastructure to the global climate change. The negative effects of climate change deal with impacts on ecosystems, environment, infrastructure, especially for the coastal zones, public health and traditional lifestyle of the local population. The positive effects including the decrease of the heating expenditures increased opportunities for agriculture and forestry, the extension of the navigation along the Northern Sea Route, as well as increased access to the marine living and mineral resources. The implementation of the programs for adaptation to global climate change and the increase in the efficiency of the state investment policy can significantly improve the key performance indicators of the AZRF. The purpose of this article is to evaluate the global climate change influence on the infrastructure development by means of scenario forecasts elaboration (using extrapolation, regression, heuristic methods etc.). The evaluation found the forecast of cargo transportation volume along the Northern sea route could be increased up to 109.7 million tons by the year 2030, according to the target scenario or it can reach 76.5 million tons according to the baseline scenario. The last one extrapolates the existing trends without considering the climate factor.

1. Introduction
Statistically significant positive temperature trend in the Arctic was observed during the last 100 years[1]. The amount of precipitation in the Arctic region increased up to 8%, as well as river flow to the Arctic Ocean[2]. The average thickness of the sea ice in the Arctic also reduced as well, mainly due to the decrease of the area occupied by perennial ice. The summer ice cover of the Arctic Ocean is also decreasing that influences the traffic of the Northern sea route (NSR). The thermal regime of the tundra also changes. It is very important for Russia, where permafrost occupy more than half (63-67%) of the country's territory and more than 90% of the AZRF[1]. The number of hazardous weather and climatic events doubled in the Russian Federation during 21 century[3]. For the Arctic region, the greatest dangers are heavy snowfalls, severe frosts, hurricane winds, as well as a fire danger.

The anthropogenic factors amplify the effects of the global climate change. There are both positive and negative effects. These include chemical pollution, overfishing of aquatic biological resources, land-use changes, population growth, etc. The main goal of the article is to evaluate the global climate change influence on the economic cost and socio-economic infrastructure development (transportation infrastructure, energy infrastructure, social infrastructure including education, public health, culture, fitness, and sports).
2. Materials and methods
A retrospective analysis of cargo transportation volume along the NSR and its extrapolation for the future baseline scenario was done using the regression method. The existing trends were extrapolated on the basis of the statistics data since 1933 published earlier by Konovalov (2015) and the main parameters of the Arctic shipping for the 30-year period (since 1985): the volume of shipped cargo, including bulk vessels and dry cargo ships, the number of vessels involved in transportation and the number of transport passages[3][4].

The target scenario was developed using three major factors. Firstly, we analyzed the parameters included in the federal, sectoral, regional and corporate development strategies. Secondly, we used an assumption that the efficiency of the state investment policy in the Arctic would be increased. Thirdly, we made an assumption that the strategies and programs for adaptation to global climate change would be implemented in the AZRF. The forecast of cargo transportation volume along the Northern sea route was developed on the basis of the estimated level of social and economic development of the AZRF coastal regions, taking into account the data of federal and regional authorities of the Russian Federation and some target indicators of the implementation of strategic planning documents. For the target scenario we analysed the volume of import (dry cargo) and export (bulk cargo from the Yamal Peninsula, raw oil and gas condensate from the Ob River, Yenisei River, Lena River, non-ferrous metals from Dudinka, forest cargo from Tiksi and Igarka, etc.), volume of transit, export from the Arctic to cabotage, in-Arctic cabotage (from rivers), direct delivery from the East and West in cabotage. The indicators of the target scenarios in the existing strategic planning documents[5] were used as a statistical base. The weight coefficients were determined using heuristic methods: brainstorming, expert assessments, situation analysis, etc. These coefficients took into account the expected results of the implementation of adaptation strategies to the possible effects of climate change.

3. Influence on bioresources
Fishing plays an important role in the economy of the AZRF coastal regions. The global warming may lead to large-scale changes in marine ecosystems and radical shifts in species composition, including the biological invasions with unpredictable consequences[6]. However, the majority of research indicates the improvement of the conditions for fishery[7]. These include the growth of the productivity of the feed base for valuable marine species, the increase of the populations, and the revival of the fishing in the Beaufort Sea and the Chukchi Sea, where the commercial fishery was minimized in the past. In addition, fishery in the Bering Sea is predicted to be increased due to ice cover decrease[8]. The international conflicts around the quotas may appear due to the migration of fish from waters under the jurisdiction of one country to another. Many valuable species (opilio crab, pollock, salmon, and halibut) will move from Alaska to Russia due to the ice retreat in the Chukchi Sea and the Bering Sea[2]. For example, pink salmon at present colonize the new rivers in the Far East of Russia. Together, these factors will create a positive background for social and economic dynamics of the AZRF regions, especially those in which industrial fishery has a leading position in the structure of the gross regional product.

4. Influence on marine transport and offshore oil and gas industry
The warming of the Arctic zone will increase the duration of ice-free navigation, opening the possibility of using vessels with lower ice reinforcement (lightweight and inexpensive to operate and to build) or without it at all. First of all, this trend is projected on coastal shipping, including export of forest goods from the Yenisei River, delivery of consumer goods and industrial products to areas with limited delivery periods ("Northern delivery" further in this text ND, "Severnii zavoz" in Russian) of the South-Western part of the Kara Sea and the coast of Northern Chukotka, transportation along the routes of the Laptev Sea and the East Siberian Sea. River–sea shipping will be increased, including the development of export-import cargo flows through the Yakutsk–European Russia line. It is also possible to forecast an increase in the duration of navigation time as well as in the velocity of the vehicle, a reduction in the transportation distance and an involvement of new routes to the NSR system. At the same time, transit traffic by NSR, which has a huge potential, can be revived due to the favorable geographical location of
According to all climate forecasts a global climate change will have a strong impact on the Northern Delivery and waterlogging in the AZRF. The Arctic infrastructure is in the high risk zone. The permafrost thaw will pose a risk of flooding. The growth of seasonally thawed layer will lead to a destruction of roads, buildings and other infrastructure. Oil and gas onshore infrastructure, as well as logging, will be periodically interrupted due to the reduction of the period when the winter roads and the tundra are sufficiently frozen to carry out industrial transportation. The Arctic buildings, roads, pipelines, airports, and other facilities could be destroyed, requiring repair, maintenance, and financial investment. The social and economic development will require new approaches to the adaptation of construction taking into consideration the global climate change influence. The degradation of permafrost will affect ecosystems, leading to soil failures, draining lakes and waterlogging in the AZRF. The Arctic infrastructure is in the high-risk zone. It requires a complex modernization of the basic infrastructure, taking into account global climate change.

5. Influence on onshore infrastructure
The global climate change will have a significant effect not only on marine infrastructure but also on the onshore infrastructure. For example, changes of the sea level and storm activity will increase the erosion of coasts. The permafrost thaw will pose a risk of flooding. The growth of seasonally thawed layer will lead to a destruction of roads, buildings and other infrastructure. Oil and gas onshore infrastructure, as well as logging, will be periodically interrupted due to the reduction of the period when the winter roads and the tundra are sufficiently frozen to carry out industrial transportation. The Arctic buildings, roads, pipelines, airports, and other facilities could be destroyed, requiring repair, maintenance, and financial investment. The social and economic development will require new approaches to the adaptation of construction taking into consideration the global climate change influence. The degradation of permafrost will affect ecosystems, leading to soil failures, draining lakes and waterlogging in the AZRF. The Arctic infrastructure is in the high-risk zone. It requires a complex modernization of the basic infrastructure, taking into account global climate change.

6. Forecast of cargo transportation volume along the Northern sea route
The global climate change will have a strong impact on the Northern Delivery of goods and fuel in the Arctic. It will require a fundamentally different scheme of the ND. It could be implemented on the basis of a new Northern transportation system, including alternative transport networks and modern vehicles. We developed two scenarios for the volume of ND: baseline and target. The baseline scenario extrapolates the available data since 1933, collected by authors. The second scenario takes into account...
the possible global climate change influence. According to these scenarios, the expected cargo transportation volume along the NSR is about from 76.5 million tons (baseline scenario) up to 109.7 million tons (target scenario) (Figure 1).

![Figure 1. Forecast of cargo transportation volume along the NSR.](image)

One of the urgent goals of the development of the AZRF transportation system is to move towards an intensive way of development from the extensive way. It means a transition from the expansion of the infrastructure and fleet capacity to an increase of the economic efficiency of the transportation system including the use of the modern model of transportation and logistics services competitive on the global market. It means implementation of service economy elements including the expansion of the hydrometeorology monitoring stations, ship repair, navigation and hydrographic support of navigation, etc.[7].

7. Conclusion
In order to reduce economic costs and to increase the sustainability of socio-economic infrastructure to the possible negative effect of the global climate change, it is necessary to take appropriate response measures. The adaptation and prevention measures should be integrated into the programs of social and economic infrastructure development of regions and sectors of the economy of the AZRF. Global climate change is not only a scientific or environmental problem but also a significant factor for the economy. The adaptation measures have a direct impact on the development of energy, agriculture, forestry and other sectors of the economy; affect the international trade of the energy resources and technologies. For the AZRF due to its huge size, geographical position, economic structure, demographic problems the appropriate response to the global climate change demands the comprehensive and balanced approach based on multidisciplinary scientific analysis of environmental, economic and social factors.

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