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УСТОЙЧИВОЕ РАЗВИТИЕ АРКТИЧЕСКОГО РЕГИОНА РОССИИ: ЭКОЛОГИЧЕСКИЕ ПРОБЛЕМЫ И ПУТИ ИХ РЕШЕНИЯ

Н. В. Ромашева[1], **М. А. Бабенко**[2], **Л. А. Николайчук**[1]

[1] Экономический факультет, Санкт-Петербургский горный университет, Санкт-Петербург, Россия;
[2] Нефтегазовый факультет, Санкт-Петербургский горный университет, Санкт-Петербург, Россия

Аннотация: Арктический регион России имеет стратегическое значение для страны из-за наличия важных морских путей, военных баз и широкого спектра полезных ископаемых. В то же время, несмотря на стратегическое значение региона, его развитие идет медленно из-за различных факторов внешней среды. Кроме того, существуют различные экологические проблемы, препятствующие полноценному развитию севера России (глобальное потепление, загрязнение воздуха, воды и почвы). Угроза экологической нестабильности в значительной степени связана с деятельностью промышленных предприятий в регионе, вследствие чего производственный процесс должен быть модернизирован таким образом, чтобы исключить или свести к минимуму возможные риски для окружающей среды. В статье определены основные проблемы развития горнопромышленного комплекса Арктического региона России. Рассмотрены направления и пути решения выявленных проблем, способы достижения экологически ответственного природопользования и создания циркулярной экономики в регионе. Основными результатами исследования являются представление взаимосвязи между выявленными экологическими проблемами и путями их решения, анализ негативного воздействия ряда горнодобывающих компаний на окружающую среду Арктики, а также расчет экономического эффекта от внедрения водоочистных сооружений на предприятии ПАО «ГМК «Норильский никель».

Ключевые слова: Арктический регион, горнопромышленный комплекс, окружающая среда, устойчивое развитие, загрязнение и очистка воды.

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Sustainable development of the Russian Arctic region: environmental problems and ways to solve them

N. V. Romasheva[1], **M. A. Babenko**[2], **L.A. Nikolaichuk**[1]

[1] Faculty of Economics, St. Petersburg Mining University, St. Petersburg, Russia;
[2] Oil and Gas Faculty, St. Petersburg Mining University, St. Petersburg, Russia

Abstract: the Arctic region of Russia is of strategic importance to the country due to the presence of important sea routes, military bases and a wide variety of minerals. At the same time, despite the strategic importance of the region, its development is slow due to various environmental

problems. In addition, there are various environmental problems that hinder the full development of the North of Russia (global warming, air, water and soil pollution). The threat of environmental instability is largely due to the activities of industrial enterprises in the region; as a result, the production process must be modernized in such a way as to eliminate or minimize possible risks to the environment. The article identifies the main problems of development of the mining and industrial complex of the Arctic region of Russia. The directions and ways of solving the identified problems, ways of achieving environmentally responsible nature management and establishment of circular economy in the region are considered. The main results of the study are the presentation of the relationship between the identified environmental problems and ways to solve them, the analysis of the negative impact of a number of mining companies on the Arctic environment, and the calculation of the economic effect of the introduction of water treatment facilities at the company of PAO MMC Norilsk Nickel.

Key words: Arctic region, mining complex, environment, sustainable development, water pollution and purification.

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Introduction

The Arctic is a strategically important region for a number of countries, including the Russian Federation. It has acquired such importance due to the significant reserves of minerals, especially oil, gas, tantalum, niobium and others, for which there is a "battle" between many countries [1, 2]. In addition to geological riches, major sea routes pass through the Arctic, which contributes to the development of trade and international relations [3, 4].

Despite the importance of the Arctic region for Russia, it has been not sufficiently developed to contribute to the growth of the economy of the region and the state through the use of its resources. At the same time, the sustainable development of the region is associated with a number of problems, the main of which are: problems of attracting human capital; lack of infrastructure; severe climatic conditions; high energy intensity of mining production; lack of investment in the region; lack of necessary technology, and environmental problems (emissions, wastewater discharge, solid waste generation in large areas, etc.) [5, 6]. According to many studies [7–9], the Arctic is the region most affected by global warming, and the activities of the mining industry only degrade this situation, and the entire ecosystem of the Arctic may suffer from this [10–12].

In connection with the above, the purpose of the work is to identify the negative impact of mining companies on the environment, identify ways to reduce this impact, as well as the economic justification for the construction of wastewater treatment facilities.

Materials and methods

The analysis is based on the materials of conferences (official documents, texts of reports, presentations and summaries of participants' speeches) held in Russia in the last ten years, as well as an array of Russian and English-language scientific publications published since 2015 (periodicals devoted to the Arctic, including separate specialized issues of journals, collections of articles), materials of the *Journal of Mining Institute*.

The methods of calculation and evaluation of economic efficiency indicators, desk studies, statistical methods, methods of comparative analysis, synthesis and deduction, principles of systematic approach, as well as tabular and graphical methods were used in the work.

Research results

Russia is the leading "Arctic" state from a geographical point of view, since quite large territories, in comparison with other countries, are located beyond the Arctic circle, and the Russian Arctic includes not only the continental part of the state, but also the shelf areas. Russia's Arctic includes more than 20 territories [13], but the development of the North is significantly inferior to the western and southern regions of the country. At the same time, the Arctic is rich in mineral resources, and therefore its exploration and sustainable development are the priority objectives of Russia's strategic planning for the period up to 2035 [14—15].

The Russian Arctic large hydrocarbon resources (85.1 trillion cubic meters of natural gas, 17.3 billion tons of oil) [16—18], amounts of solid minerals (SMs): gold, tin, titanium, iron ore, apatite, coal, nickel, various rare earth metals, construction materials (sand, clay, gravel) and others. The total value of SMs reserves in the region is $1.5—2 trillion [19]. However, as a result of the activities of mining and concentrating plants and mining and metallurgical plants (MCPs and MMPs), toxic substances are released into the water and atmosphere, and solid wastes accumulate in the form of overburden at dumps. For example, copper and nickel processing produces such harmful substances as sulfur dioxide, heavy metal oxides, aerosols, hydrogen sulfide, etc [20]. At the same time, in the Kola Peninsula alone, waste disposal (overburden and host rocks, waste in tailings ponds, poor ores) does not exceed 3—4% of the total extracted rock mass [21]. Various types of pollutants are present at almost all mining enterprises, of which there are many in the Arctic region: Olenegorsk MPP, Norilsk MTPP, Lovozero MMP, ANOF-3, Gorevsk MMC, Deputatsk MMP and others [22]. However, the environmental pollution associated with the mining and industrial complex (MIC) can occur not only in the production process. An example of colossal damage to the environment is the oil spill at the Norilsk Thermal Power Plant in 2020. The cause of the accident is called subsidence of foundation piles due to melting of permafrost [23], which indicates two other problems of the Arctic region at once: the undeveloped old infrastructure and global warming.

At present, many enterprises owned by large companies of the mineral resource complex are trying to minimize the environmental damage from the results of their activities [24], but these methods do not fully contribute to the elimination of their negative impact. The environmental damage caused by the activities of mining enterprises can be described as follows [25—27]:

• The production process at the enterprises of the MIC entails the formation of solid waste, from which overburden dumps are formed, occupying significant territories. Dumps like these contribute to soil corrosion, the formation of empty spaces in the subsurface (which later leads to subsidence of the soil) [28], land contamination with various substances and a decrease in biodiversity.

• The production process require large quantities t of water. Used water that contains toxic substances, is discharged into water bodies, which causes their pollution. Toxic substances can spread In the water and poison it or be deposited in the soil, reaching groundwater. This process also reduces biodiversity, making the water unfit for drinking.

• During the production process many toxic substances and greenhouse gases with various impurities are released into the atmosphere, resulting in excessive concentrations of harmful substances in the air and intensifying the greenhouse effect. Also, air emissions of harmful substances contribute to precipitation

in the form of acid rain, which pollutes water. Air pollution accelerates global warming processes, breathing problems.

The statistics of the environmental impact of some enterprises of the Arctic region MIC presented in Tab. 1.

Based on the data in Tab. 1, it can be concluded that the amount of environmental damage in the region is quite large, especially since the data were collected only for some PAOs, excluding small and medium-sized companies.

The protection of the Arctic environment is not only part of the Russia's Strategy, but also part of the international Paris Agreement, ratified by Russia, which states that the growth of the global average temperature should be kept below 2°C [33].

Tab. 2 presents the main environmental problems of the development of the Arctic region and identifies possible solutions to these problems.

Compliance with these measures will make it possible to reduce the negative impact on the environment by enterprises associated with the extraction and processing of ores of various metals. That will be of a great importance for large enterprises (MMP Norilsk Nickel, Deputatsk MPP, etc.) [34].

It is known that one of the most important is the legislation on the extraction and use of water [35]. One of the perspective ways to comprehensively solve the problem of the negative impact of mining companies on the environment is the construction of wastewater treatment facilities. These facilities will minimize harm to aquatic ecosystems from the discharge of substances into water bodies. An example of using this technology is the Southwest Treatment Facility (hereinafter — SWTF) in St. Petersburg. The first stage of treatment is the mechanical purification of water,

Table 1

Environmental impact of MIC companies in the Arctic Region of Russia in 2019 [29–32]

	Company			
	PAO PhosAgro	**PAO MMP Norilsk nickel**	**PAO Sevestal**	**PAO Akron**
Atmosphere				
Evissions of pollutants into the atmosphere (thousand tons), incl.:	9.221	1 914.567	213.131	4.60
Sulfur dioxide	3.458	1 898.139	69.860	0.126
Nitric oxide	1.535	3.120	5.068	0.912
Carbon monoxide	0.478	n/d	4.090	2.160
Solids	3.734	13.308	9.329	n/d
Others	0.000084	n/d	124.523	1.402
Greenhouse gases (CO_2 equivalent), thousand tons	1 447.853	9 869.905	23, 400	617.63
Water bodies				
Total water intake, mln m^3	145.404	319	116.571	7.267
Total wastewater discharge, mln m^3	137.386	67.79	60.694	3.843
Discharge of pollutants in wastewater, thousand tons	12.42	209.49	20.89	0.00
Waste management				
Waste generation (mln tons), incl.:	101.313	36.420	202.557	36.405
Wastes I-IV Hazard Class	0.007	1.120	5.287	0.005

End of Table 1

	Company			
	PAO PhosAgro	**PAO MMP Norilsk nickel**	**PAO Sevestal**	**PAO Akron**
Wastes V Hazard Class	101.306	35.300	197.270	36.4
Waste from other organizations, mln tons	n/d	0.633	n/d	n/d
Waste disposal at own enterprise, mln tons	19.657	22.769	13.894	n/d
Neutralization of waste at own enterprises, mln tons	n/d	0.003	1.186	n/d
Transfer of waste to other organizations for utilization or neutralization, mln tons	n/d	0.502	0.308	n/d
Transfer of waste for disposaz to other organizations, mln tons	n/d	0.640	n/d	n/d
Waste disposal at own facilities, mln tons	81.635	6.025	189.040	n/d

Table 2
Environmental problems and ways to solve them

Problem	Decision	Clarification
High level of pollution of local water bodies	Water treatment facilities	With wastewater treatment plants, the concentration of harmful pollutants in wastewater will be reduced, which will have a positive impact on the environment. The activated sludge used in water treatment and accumulated garbage can be sent for recycling, obtaining from it building materials, electricity, or even the main products produced by the company. Building materials can be used for the development of the region's infrastructure.
High level of air pollution, large volumes of greenhouse gas emissions	Gas cleaning systems and disposal of carbon dioxide	Gas purification systems will capture harmful substances from the gases emitted during the production process, leaving only carbon dioxide at the outlet, which will be captured by specialized units. This will minimize the amount of hazardous substances and greenhouse gases in the atmosphere and improve air quality in the region.
Generation of large volumes of solid waste at dumps and tailings	Complex processing	processing of rock in the dumps and tailings using special technologies will make it possible to increase the volume of extraction of the mineral.
Degradation of the bioproductive capacity of lands and soils	Land reclamation	Reclamation technologies after the damage caused by the mining enterprise will enable to continue to conduct other activities on these territories
Incomplete development of mineral deposits	Admission to the industry of technically advanced small and medium-sized businesses	Based on foreign experience, the admission of small and medium-sized companies to the industry may allow for a more complete extraction of minerals from the subsurface, since big companies may not take on small deposits or not fully develop large ones, due to lack of equipment or low profitability.

which removes large pollutants and debris. The next phase is biological treatment with the help of activated sludge (special microorganism scavengers). To ensure the breathing of the activated sludge, it is necessary to pump air into it. To remove the various biogenic elements, special reagents are used at the SWTF, through the use of which insoluble compounds are formed and removed from the system along with the sediment. At the final phase, the water is completely disinfected by ultraviolet light [36]. Such water treatment minimizes the risks associated with the release of pollutants into water bodies. In addition, it is possible to reuse water in production process (industrial water).

The sediment obtained in the course of water treatment can be re-enriched if it contains metals, and the remaining part can be sent for disposal or for recycling into building materials. These materials can be used in the future to develop the infrastructure of the region. Production of building materials is also possible in the main block of the metallurgical process used in the production of non-ferrous metals. The raw material is a mixture of solid industrial and municipal waste. The essence of the process of obtaining materials is the melting and burning of organic components from the waste. A special feature of this technology is the joint processing of all types of waste [37].

During thermal processes, gases containing harmful substances are produced. They can be eliminated by means of gas purification systems, where the gas must be supplied immediately after the thermal processes, in order to obtain clean carbon dioxide at the output. The scheme of gas purification may look as follows: hot gas in combination with pollutants enters electric filters, where the particles of the pollutants adhere to the electrodes, after which wet irrigation begins, in which all these substances adhere to drops of water or special reagents, and the purified gas is released into the atmosphere or enters the next stage — sequestration. There are many other gas purification systems, such as a centrifugal filter, which does not require water to operate.

After gas purification it is rational for environmental protection to use technologies for the capture or utilization of carbon dioxide, as well as the use of carbon dioxide in industry. In the world there are already projects using technology to capture and utilize carbon dioxide in the oil field, coal industry, metallurgy, mining, chemical and other industries, but at the moment there are no such projects being implemented in Russia. The use of such technologies allows to achieve the following results: improving the environmental situation in the region; increasing life expectancy of people; development of infrastructure and oil and gas complex and so on [38].

More clearly the stages of cleaning of industrial emissions are shown in Fig. 1.

Nowadays, the technology of gas capture technologies is quite expensive and not widespread in Russian companies, so the economic effect of the introduction of water treatment facilities will be considered further on the example of a company whose emissions are the highest among the companies considered, i.e., — PAO MMP Norilsk Nickel.

The discharge of pollutants included in wastewater from the activities of enterprises of this company is more than 200 thousand tons. The integration of water treatment technologies is planned based on the example of the SWTF. Wastewater discharge of MMP Norilsk Nickel is almost half the volume of water filtered at the SWTF, so calculations will be made based on this information. Additional costs for the construction of wastewater sludge processing plants are

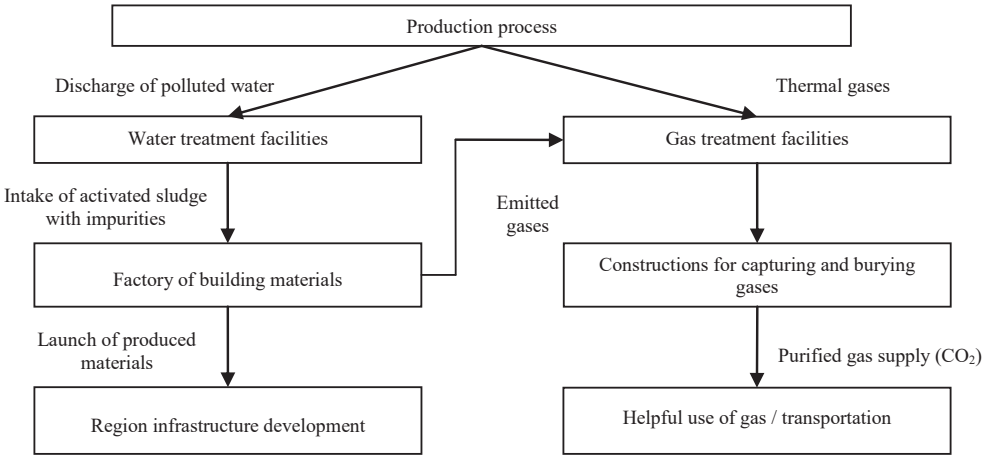

Fig. 1. Stages of cleaning industrial emissions

Table 2

Calculations of the economic effect of water treatment facilities introduction at Norilsk Nickel's enterprises

Index, mln rub.	Year					
	2021	2022	2023	...	2029	2030
Capital investments	400 000	0	0	...	0	0
Depreciation	40 000	40 000	40 000	...	40 000	40 000
Increase in cost due to depreciation	40 000	40 000	40 000	...	40 000	40 000
Increase of taxable profit due to decrease of electricity costs	9 130	9 130	9 130	...	9 130	9 130
Increase of taxable profit due to increase of produced building materials	51 000	51 000	51 000	...	51 000	51 000
Increase of taxable profit due to increase of produced mail products due to processing of pollutants from wastewater	10 370	10 370	10 370	...	10 370	10 370
Income tax	6 100	6 100	6 100	...	6 100	6 100
Net profit	24 400	24 400	24 400	...	24 400	24 400
Cash Flow	–335 600	64 400	64 400	...	64 400	64 400
Discount coefficient	1,00	0,91	0,83	...	0,47	0,42
NPV	–335 600	58 545	53 223	...	30 043	27 312
Cumulative NPV	–335 600	–277 055	–223 831	...	7 969	35 281

not envisaged, since the company already has plants in the regions where the ore mining enterprises are.

In addition to the processing of pollutants in the discharged wastewater (metals, petroleum products, nitrogen, phosphorus, etc.), the activated sludge is the also subject to processing. The mass of dry sludge, is usually about 1% of the total volume of wastewater [39].

If 68 million m³ of water is filtered (this is the volume of untreated wastewater discharged by Norilsk Nickel's enterprises), 6.8 million m³ (or 10.2 mln tons) of dry mass is produced per year, from which 2.55 mln tons of building materials and 1.826 million kW of energy per year are produced by pyrolysis. The construction cost of the SWTF and the cost of the necessary pyrolysis facilities were taken as capital investments. Depreciation is calculated using the linear basis. A discount rate of 10% was chosen for the calculations. Calculations of the economic effect are presented in Tab. 2.

In this case, the company's profit increases due to an increase in the volume of things produced and a reduction in energy costs. According to calculations, the project of introducing water treatment facilities at the enterprises of MMP Norilsk Nickel will pay off in 9 years, with a NPV of over 35 billion rubles. The profitability index will be 1.09, and the internal rate of return — 12.4%.

Thus, with the right approach to recycling and reuse of industrial waste in the complex processing of SM in the Arctic region of Russia, it is possible to achieve maximum benefits from the environmental point of view and from the social point of view.

Conclusion

The Arctic region is strategically important for Russia due to the presence of many minerals and sea routes there.

The management of the mining complex in the Arctic region of Russia is an important tool for maintaining a favorable environmental situation. It is also a guarantee of national security of the state and the development of the economy. By analyzing the activities of the MIC companies, a number of different problems related to the negative impact of companies on the environment were identified.

Based on this, the paper proposed ways to minimize the environmental consequences of of mining companies' activities; as an example, the economic efficiency of the project for the introduction of water treatment facilities at the enterprises of PAO MMP Norilsk Nickel was assessed.

Solving environmental problems unlock the potential of the Russian Arctic in terms of socio-economic and environmental progress. The described methods of minimizing harm from mining activities in the Arctic will help achieve economic benefits for the enterprises themselves and environmental stability for the region.

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ИНФОРМАЦИЯ ОБ АВТОРАХ

Ромашева Наталья Владимировна[1] — канд. экон. наук, доцент,
e-mail: smirnova_nv@pers.spmi.ru, ORCID ID: 0000-0003-3074-5137;
Бабенко Михаил Андреевич[1] — студент, e-mail: s180817@stud.spmi.ru;
Николайчук Любовь Анатольевна[1] — канд. экон. наук, доцент,
email: nikolajchuk_la@pers.spmi.ru, ORCID: 0000-0001-5013-1787;
[1] Санкт-Петербургский горный университет.
Для контактов: *Ромашева Н. В.,* e-mail: smirnova_nv@pers.spmi.ru.

INFORMATION ABOUT THE AUTHORS

Romasheva N. V.[1], Cand. Sci. (Economic), Associate Professor,
e-mail: smirnova_nv@pers.spmi.ru, ORCID ID: 0000-0003-3074-5137;
Babenko M. A.[1], student, e-mail: s180817@stud.spmi.ru;
Nikolaichuk L.A.[1], Cand. Sci. (Economic), Associate Professor,
email: nikolajchuk_la@pers.spmi.ru, ORCID: 0000-0001-5013-1787;
[1] Saint-Petersburg Mining University, 199106, Saint-Petersburg, Russia.
Corresponding author: *Romasheva N. V.*, e-mail: smirnova_nv@pers.spmi.ru.

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