

## Environmental protection and sustainable development of the mining industry in Murmansk Region, Russia

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### Abstract

The mining complex of the Murmansk region (Russia) has a negative impact on natural ecosystems and worsens the quality of the environment, since the development of non-renewable mineral resources is associated with a significant transformation and destruction of natural communities. In the Murmansk region, where the mining industry forms the basis of the regional economy, the research aimed at achieving sustainable development goals involves the search for 1) new integrated approaches to ensure the development and implementation of environmentally friendly technologies for the extraction and processing of minerals; 2) managerial decisions supporting the transition to a circular economy; 3) the establishment and development of protected areas, including compensatory; 4) the restoration of disturbed landscapes; 5) the development of nature-like technologies for the recovery of valuable components from minerals, and 6) the protection of the environment. Furthermore, there is need for a constant search for some balance of interests of local communities and mining corporations in the context of environmental protection and economic development in order to maintain social sustainability. Without designing the foundations of the state policy for the transition to a closed-loop economy, the implementation of even existing technologies will be too slow. There is a survey of nature-like technologies developed in the Kola Science Center of the Russian Academy of Sciences for processing minerals and protecting the environment, rehabilitation of disturbed areas exposed to industrial air pollution, reclamation of the water and land areas polluted by oil and oil products as well as examples of territorial nature conservation that do not block the development of processing minerals.

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## Охрана окружающей среды и устойчивое развитие горнопромышленного комплекса Мурманской области

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### Реферат

Горнопромышленный комплекс Мурманской области (ГПК) оказывает негативное влияние на природные экосистемы и ухудшает качество окружающей среды, поскольку освоение невозобновляемых минеральных ресурсов связано со значительным преобразованием и разрушением природных сообществ. Для Мурманской области, где ГПК является основой экономики, исследования по достижению целей устойчивого развития сопряжены: 1) с поиском новых комплексных подходов по обеспечению разработки и внедрения в производство экологически дружественных технологий добычи и переработки минерального сырья; 2) поиском управленческих решений, обеспечивающих переход к экономике замкнутого цикла; 3) созданием и развитием особо охраняемых природных территорий, в том числе компенсационного типа; 4) восстановлением нарушенных территорий; 5) развитием природоподобных технологий извлечения ценных компонентов из минерального сырья и 6) охраной окружающей среды. Кроме того, необходимо осуществлять постоянный поиск баланса интересов местных сообществ и горнодобывающих корпораций в контексте сохранения окружающей среды и экономического развития для поддержания социальной устойчивости. Без создания основ государственной политики по внедрению подходов экономики замкнутого цикла, использование даже уже существующих технологий будет идти медленными темпами. В статье приведен обзор разработанных в Кольском научном центре РАН дружественных к окружающей среде технологий переработки минерального сырья и защиты окружающей среды, реабилитации нарушенных территорий в условиях воздушного промышленного загрязнения, очистки воды и почвы от загрязнения нефтью и нефтепродуктами, а также примеры территориальной охраны природы, не блокирующие развитие ГПК.

### Для цитирования

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## Introduction

The Murmansk region is an area with the largest enterprises of the mineral resource complex of the Arctic zone of the Russian Federation and the country as a whole. The region supports a major share of the national economy demand for phosphate ore, zirconium (baddeleyite), niobium, tantalum, rare-earth metals. Copper-nickel and iron ores, nepheline and ceramic raw materials, facing stone and building materials are also extracted. The region's mining industry sites and operations are the main employer in many cities and towns, where a third of the region's population resides, and its output represents more than 60 % of the region's industrial production. On the one hand, this makes the Murmansk region one of the nation's leaders in terms of socio-economic performance, while on the other, the mining industry has a major negative impact on natural ecosystems and the quality of the environment as a whole, since the development of non-renewable mineral resources brings major changes in and disturbance of natural communities. For example, 210.5 million tons of mining waste (concentration tailings, overburden and sinking rock, etc) was generated in 2017 alone (99.9 % of the combined waste generated in the Murmansk region), an increase of 5.7 % compared to the previous year<sup>1</sup>.

The Sustainable Development Goals 2030 provide for the transition to sustainable models of production and consumption (Goal 12)<sup>2</sup>. This goal calls for "doing more and better with limited resources". In the Murmansk region, where the mining and metals industry forms the backbone of the regional economy, the efforts to achieve this sustainable development goal should be coupled with the search for new integrated approaches to ensure the development and implementation of environmentally friendly technologies for the extraction and processing of minerals, the search for managerial decisions that support the transition to a circular economy, the search for and implementation of technological and managerial innovations. In the Murmansk region, large number of natural protected areas (PAs) have been established (*Боровичев и др., 2018*). Furthermore new PAs are planned pursuant to the strategy<sup>3</sup>. So, further development of the mining industry is only possible under the condition of it's significant "greening", reducing the area of the landscape disturbed by mining operations and by the infrastructure being built, and under the condition of a major effort focused on the restoration of disturbed landscapes and vegetation cover. Environmental protection in the Murmansk region takes two forms – dynamic (reducing the negative impact of the mining, minerals, and metals industries on the residents, fauna and flora, soil, subsoil, atmosphere, ground and surface water, including restoration of disturbed areas/water bodies/atmosphere) and static (prevention of economic activity that disturbs ecosystems, creation of PAs).

To date, a number of nature-like technologies have been developed for processing minerals and protecting the environment, rehabilitation of disturbed areas exposed to industrial air pollution, reclamation of the water and land areas polluted by oil and oil products, etc (*Исаева и др., 2018; Корнейкова и др., 2018; Макаров и др., 2018*). Studies have been undertaken aimed at inventorying and protecting biodiversity, including the development of scientific foundations for the conservation and monitoring of rare and endangered species, biologically valuable and rare plant communities, the preparation of Red Data Books and the rationale for the establishment of a system of PAs in the Murmansk region (*Исаева и др., 2018; Константинова и др., 2011a; b*). Since 2013, interdisciplinary research has been intensively growing in the region, aimed at finding ways to improve the socio-economic sustainability of the extraction and processing of minerals in the Arctic in the context of the nature preserving (*Виноградова и др., 2015; Koivurova et al., 2015; Nysten-Haarala et al., 2015; Riabova et al., 2015; Suopajarvi et al., 2016; Söderholma et al., 2015*).

## Results and discussion

### *Technology solutions*

Presently, the total amount of the mining waste generated in the Murmansk region has reached about 8 billion tons. Keeping overburden and slag dumps, tailings and sludge storage facilities environmentally safe requires significant investment. Large volumes of displaced rock mass disrupt the existing geological balance, gas and dust emissions from mining operations, dusting of dumps and tailings, and the seepage of pollutants into surface and ground water adversely affect ecosystems and human health. Integrated and environmentally friendly development of mineral resources requires that the mining and processing waste is redeveloped as anthropogenic deposits<sup>4</sup> (*Lottermoser, 2011; Nevskaya et al., 2016; Riabova et al., 2015*).

For processing of low-grade natural and anthropogenic resources, the close-to-nature heap bioleaching technology appears to be promising (*Walling, 2015*). In the implementation of closed-loop circuits for the

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<sup>1</sup> Доклад о состоянии окружающей среды Мурманской области в 2017 г. // Правительство Мурманской области. URL: [https://gov-murman.ru/upload/iblock/a35/Doklad\\_za-2017-god\\_ITOG\\_1.pdf](https://gov-murman.ru/upload/iblock/a35/Doklad_za-2017-god_ITOG_1.pdf).

<sup>2</sup> Цели устойчивого развития человечества 2030 // ООН. URL: <https://www.un.org/sustainabledevelopment/ru/sustainable-development-goals/>.

<sup>3</sup> Концепция функционирования и развития сети особо охраняемых природных территорий Мурманской области до 2018 года и на перспективу до 2038 года утверждена постановлением Правительства Мурманской области от 24 марта 2011 г. № 128-ПП.

<sup>4</sup> Towards a circular economy: A zero waste programme for Europe // OECD. URL: <https://www.oecd.org/env/outreach/EC-Circular-economy.pdf>.

circulation of process solutions and the disposal of waste in the construction industry, the introduction of these technologies will facilitate a phased transition to a circular economy (McDonough et al., 2003).

The created classification of substandard copper-nickel ores and technogenic formations of the Murmansk region according to their potential environmental hazard and suitability for processing by the method of physical and chemical geotechnology allows enterprises, potential waste processors, to minimize the cost of selecting technologies and justify the economic efficiency of creating new industries. In addition, to assess the risk posed by a number of natural and industry sites, studies of material composition were carried out, balances between the ability of mineral associations to produce and neutralize acids were estimated (Abrosimova et al., 2015; Karlsson et al., 2018; Lèbre et al., 2017). The results are summarized in the table. The value of the resulting net acid potential (NAP) allows to predict the composition of the waste rock dump runoff. Comparing the estimates with actual observations, studying newly formed mineral phases, modeling hypergenesis processes in a laboratory setting made it possible to rank sites according to the potential environmental hazard level and from the standpoint of suitability for processing by heap bioleaching (Светлов, 2018).

Table. Potential environmental hazard and suitability for bioleaching of low-grade copper-nickel ores and technogenic mineral formation

Таблица. Потенциальная экологическая опасность и пригодность к переработке методом биовыщелачивания некондиционных медно-никелевых руд и техногенных образований

Site	NAP	Potential environmental hazard	Heap leachability
Low-grade Monchepluton Cu-Ni ores			
Deposit Nyud II (Monchegorsk District)	+81.99	Elevated. AMD*, heavy metal migration	Good
Deposit Nyud Terrace (Monchegorsk District)	+36.51	Average. AMD, heavy metal migration	Satisfactory
Deposit Morozhkovoye Lake (Monchegorsk District)	+63.57	Average. AMD, heavy metal migration	Good
Deposit Nittis-Kumuzja-Travjanaja (Monchegorsk District)	+91.87	Elevated. AMD, heavy metal migration	Good
Technogenic mineral formation			
Allarechensk mine dumps (Pechenga District)	+104.37	High. AMD, intensive heavy metal migration	Good
Concentration tailings of Cu-Ni ores (Pechenga District)	+5.35	Moderate. AMD neutralization, heavy metal precipitation by hydrosilicates	Satisfactory. Agglomeration required. Increased sulfuric acid feed rate
Dump slags (Pechenga District)	+4.84	Moderate. Sulfides in the silicate matrix limit AMD	Satisfactory. Grinding and agglomeration required

Notes. \*AMD – acid mine drainage.

All the necessary prerequisites are present in Russia for the widespread adoption of metal recovery by heap bioleaching. Obstacles include, of course, the adverse climatic conditions in Russia's mining regions, including the Murmansk region. At the same time, the experience of heap leaching of precious metals in Arctic and Subarctic climatic conditions with negative average annual temperatures shows the possibility of using these methods in the geotechnological processing of non-ferrous sulfide ores. Investigations of cryomineralogenesis in natural and anthropogenic sulfide-containing rock masses, the development of methods for the passive leaching of gold and silver-bearing rocks and mobilization of metals at below-zero temperatures using new oxidizing agents deserve attention and comprehensive experimental testing as applied to sulfide copper-nickel ores.

The use of geochemical barriers is another example of nature-like technologies and one of the promising methods for protecting natural water bodies and treating wastewater from mining and minerals operations. The essence of the methods is to immobilize the pollutants. Geochemical barriers act as filters, making possible the use of existing and establishment of engineered geochemical barriers.

Applications of artificial geochemical barriers, in addition to the purification of natural and waste water from heavy metals, radioactive elements, and oil products, include (Максимович, 2010; Baltrėnaitė et al., 2018; Chanturiya et al., 2014):

– further recovery of valuable components from natural and anthropogenic mineral feeds using methods of physical and chemical geotechnology;

- waterproofing of tailings and sludge storage facilities, storage tanks, sedimentation tanks, etc;
- soil stabilization in civil engineering.

Given the huge amounts of mining and metals waste, the construction industry may become the primary consumer as a highly material-intensive one. Processing of waste into building materials is aimed at addressing social and environmental problems, improving the living conditions of the local residents, creating jobs. In the production of building materials from recycled waste, the economic efficiency can be measured as the environmental damage avoided and the associated reduction in compensatory payments.

An urgent technological and economic challenge is producing composite building materials with improved performance characteristics. In particular, modern materials are expected to possess a combination of structural and operational properties, such as high strength at low density, stable thermal conductivity, durability, chemical and biological stability, fire safety. The developed building materials should ensure high energy efficiency of buildings and structures in the cold climate of the Russian Arctic. Especially important from an environmental and economic point of view is the use of recycled materials in the production of building materials (*Muñoz et al., 2016; etc*).

Some new methods have been developed for the production of glass, glass crystalline, ceramic, and hyper-pressed building materials from the mining and minerals industry's waste in the Murmansk region (*Макаров и др., 2018; etc*). It should be noted that the components of the new building material are exclusively waste, with no primary materials consumed. These approaches are fully consistent with the principles of the circular economy<sup>5</sup> and contribute to the achievement of the Sustainable Development Goal 12. However, the use of existing technologies and proven approaches is hampered due to the poorly developed state policy governing the transition to the closed-loop economy and, consequently, the lack of regulatory and economic tools that would make existing technologies for the processing of anthropogenic resources relevant to the industry.

Also, effective technologies have been designed to restore the terrestrial and aquatic ecosystems disturbed by the mining and metals industry. The experiments conducted since 1997 on the development of scientifically based approaches to the restoration of the soil and vegetation cover in the areas affected by the copper and nickel industry – more than 80 ha in the vicinity of the city of Monchegorsk, more than 15 ha in the vicinity of the communities of Nickel and Zapolyarny – have demonstrated good results (*Исаева и др., 2018*). As a result of the experiments, a technology was developed for the accelerated reclamation of these areas based on using the carpet sod from perennial cereals in combination with vermiculite soil substitute, serpentinite and carbonatite mining and minerals waste (*Иванова и др., 2014*).

To prevent pollution of aquatic ecosystems, a technology has been developed for the removal of mineral nitrogen compounds from wastewater using the biotechnology potential of higher plants and microorganisms. A floating bioplate and phytomat technology was developed for the sediment pond of the Kirovogorsk Open Pit Mine operated by JSC OLKON in the vicinity of Olenegorsk. It was shown that the bioplate technology is effective in the conditions of the Arctic. According to the experimental data, in 2013–2016 the content of ammonium and nitrite forms of nitrogen in the water of the sediment pond decreased to the MPC level, the concentration of nitrate nitrogen also began to decrease (*Корнейкова и др., 2018*).

#### *Biodiversity protection: Management approaches*

The Murmansk region due to its geographical location, has a common border with European countries, where special attention is paid to the quality of the environment, and should become the storefront of Russia as a nation that takes nature conservation seriously and adopts modern management practices in nature conservation. For this, it is necessary to take into account and simultaneously develop two main components – nature conservation and regional socio-economic development.

The mining industry is a source of livelihood for a large share of the population of the Murmansk region, offering jobs and investing in the local development as part of the corporate social responsibility policies. However, despite a significant contribution to the region's economic sustainability, the mining industry poses significant risks to social sustainability. In our approach, social sustainability is interpreted as having two dimensions – procedural and contextual. Procedural social sustainability concerns planning and decision-making as part of mining operations. Contextual social sustainability encompasses specific local landscapes, including the historical experience of extractive industries and the prevailing views of the local community. Our research indicates that, from a procedural point of view, local communities need knowledge and understanding of environmental changes caused by the extraction and processing of minerals and want to be heard when decisions on mining are made. The contextual aspect of the social sustainability as applied to the Arctic communities is a dilemma, which is, on the one hand, anxiety about the negative impact of mining on the environment, and on the other hand, fears concerning the prospects of the Arctic communities, for example, in terms of employment opportunities, wages, quality of social infrastructure (*Suopajarvi et al., 2016*). Thus, there is a need for a constant

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<sup>5</sup> Towards a circular economy: A zero waste programme for Europe // OECD. URL: <https://www.oecd.org/env/outreach/EC-Circular-economy.pdf>.

search for a balance of interests of local communities and mining corporations in the context of environmental protection and economic development in order to maintain social sustainability.

The main regulatory tool designed to prohibit or restrict economic activity in certain areas of land (or water) in order to protect rare habitats, natural, historical, and cultural heritage is the establishment of protected natural areas (PAs).

As of November 2019, the total area of PAs in the Murmansk region is 1,947,799.4 hectares, or 13.4 % of the region's PAs, and includes three State Nature Reserves, one National and two Nature parks, 12 State Reserves (Zakazniks), 55 Nature Monuments, and the protected areas of the Polar-Alpine Botanical Garden of Kola Science Centre of RAS.

Despite the impressive statistics, the PAs network is suboptimal and not very effective: only the State Nature Reserves and one National park, one of the two Natural parks in the region, two Zakazniks, and seven nature monuments can effectively perform their environmental protection functions (their combined area is only 4.2 % of the region's area), the protection regimes in the other NPAs fail to match the existing threats (*Suopajarvi et al., 2016*). In a "polarized landscape" (*Родоман, 1974*), an effectively functioning PAs system is a guarantee of social and economic sustainability.

For several years now, the Ministry of Natural Resources and Ecology of the Murmansk region (MNR of the Murmansk region) has been conducting focused work to assess the effectiveness of the regional network of protected areas (in 2016, natural monuments in the Pechenga district were surveyed, in 2017 in the Apatity, Kirov, and Monchegorsk districts, in 2018 in the Lovozero district) and to reorganize some of the largest protected areas (Rybachy and Sredny Peninsulas Nature Park, Kolvitsa and Ponoy Ornithological Zakazniks).

In addition to the expensive PAs, a cheaper and faster method is available – issuing prescriptions limiting economic activity in certain areas to prevent disturbance to identified protected species of plants, lichens, fungi, and animals (*Красная книга..., 2014*). In 2018, the MNR of the Murmansk region issued its first after 2003 prescription for the protection of the rare species of vascular plants inhabiting the Luvenga Swamp in the Kandalaksha district (*Кожин, 2015*).

Ignoring statutory requirements in the field of protection of rare species and their habitats can lead to the destruction of the habitat of Red Data Book listed species, which entails administrative and criminal liability and increases social tension in the region. Another solution to the contradiction between the economic interests of the mining industry and environmental protection needs is the establishment of compensatory PAs that would ensure the conservation of the same protected species and their habitats, as a compensation for the territories to be disturbed as part of the industry project and subsequent land reclamation after the decommissioning of the project. The Concept of functioning and development of the network of PAs developed and adopted in 2011 secured the possibility of establishing compensatory protected areas in the vicinity of the community of Teriberka<sup>6</sup> in order to support the implementation of the Shtokman oil and gas project, but the plan never materialized as the project was suspended.

## Conclusions

The Murmansk region can be considered an example of a "polarized landscape" according to the concept proposed by Rodoman (*1974*), where the environmental effect of regulating and supporting ecosystem services in PAs is greatly reduced in the areas accommodating major mining and metals projects, and the scope of economic damage caused by the environmental impacts of the industry is not compensated by adequate environmental protection efforts. On the contrary, significant in area and, most importantly, interconnected undisturbed natural areas (both existing and contemplated) produce a tremendous scope of ecosystem services, and therefore it is advisable to consider these as the core of further socio-economic development of the region. Supporting of resilience and productive functioning of the intact territories of the Murmansk region must be taken into account when developing strategies. Such strategies should exclude as much as possible the development of new mineral deposits in cases where similar useful components can be recovered from industrial and mining waste. To meet the needs of the economy in one or another useful component, it is advisable to search for new technologies and approaches to the use of accumulated mining waste. This will exclude low-grade ore occurrences from geological development plans. The development strategy of the mineral resource base of the Russian Federation until 2030 (draft version dated September 12, 2016) lists among measures aimed at protecting the environment reclamation of land areas disturbed as a result of the development of mineral deposits, decommissioning of mine workings, underground structures, and boreholes, restoration of the original landscapes and ecosystems. To do this, it is possible to use the already created technologies for the restoration of damaged lands.

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<sup>6</sup> Концепция функционирования и развития сети особо охраняемых природных территорий Мурманской области до 2018 года и на перспективу до 2038 года утверждена постановлением Правительства Мурманской области от 24 марта 2011 г. № 128-ПП.

To achieve the sustainable development goals in the mining industry of the Murmansk region, there is a need for a constant search for a balance of interests of local communities and mining corporations in the context of environmental protection and economic development in order to maintain social sustainability. Without designing the foundations of the state policy for the transition to a closed-loop economy, the implementation of even existing technologies will be too slow.

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