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ТЕНДЕНЦИИ ВНЕДРЕНИЯ ТЕХНОЛОГИЙ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА И РОБОТОТЕХНИКИ В АРКТИКЕ: ОПЫТ РОССИЙСКОЙ ФЕДЕРАЦИИ

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Аннотация: искусственный интеллект (ИИ) позволяет компьютерам обучаться на собственном опыте, решая трудно формализуемые задачи, адаптируясь к новым параметрам и условиям. В большинстве случаев для решения задач ИИ крайне важна возможность глубокого обучения и обработки естественного языка. Благодаря этим технологиям компьютеры можно «научить» выявлению закономерностей на основе обработки большого объема данных и использования их для принятия решений. В исследовании проводится анализ тенденций внедрения ИИ и робототехники в Арктической зоне Российской Федерации (АЗРФ), их перспективы, с целью определиться в каких направлениях необходимо продвигаться для осуществления цифровизации Арктического региона, что уже следует применять к реализации развития этой части Земли, от которой зависит и будущее России. Исследование основывается на истории и сферах применения ИИ и робототехники в АЗРФ, с учетом состояния окружающей среды и экологической обстановки этого региона.

Ключевые слова: Арктика, Russian Arctic, искусственный интеллект, робототехника.

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Trends in artificial intelligence and robotics technologiesin the Arctic: the Russian experience

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Abstract: Artificial intelligence (AI) allows computers to learn from their own experience, solve hard-to-formalize tasks, and adapt to new parameters and conditions. In most cases, deep learning and natural language processing capabilities are extremely important for solving AI tasks. Thanks to these technologies, computers can be "taught" to identify patterns based on the processing of large amounts of data and use them to make decisions. The study analyses trends and prospects for the introduction of AI and robotics in the Arctic zone belonging to the Russian Federation (AZRF). Its aim is to identify the directions that the digitalization of the Arctic region should move in, determine what already needs to be implemented for the development of this part of the Earth, on which the future of the country largely depends. The study is based on the history and applications of AI and robotics in the Russian Arctic, taking into account the state of the environment and the environmental situation of this region.

Key words: Arctic, Арктическая Российской федерации, artificial intelligence, robotics.

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Introduction

In the Russian Federation, work on the development of the Arctic region and the intellectualization of technologies used in the Russian Arctic is based on two strategies: the state policy of the Russian Federation in the Arctic **until 2035** [64] and the strategy for the development of artificial intelligence in the Russian Federation until 2030 [65].

Today, the Russian North provides a significant share of the country's export revenues, and is of critical strategic and geopolitical importance for modern Russia [66]. Over the past thirty years, more than two dozen fields have been discovered on the territory of the Russian Arctic shelf [9]. These reserves, according to estimates of the Institute of Petroleum Geology and Geophysics of the Russian Academy of Sciences, amount to about 10 billion tons of oil. The total resources of the Russian shelf as a whole are estimated by domestic experts at about 100 billion tons of equivalent fuel [2]. According to other expert estimates [37], oil reserves in the Arctic zone of the Russian Federation amount to 7.3 billion tons and 55 trillion cubic meters of natural gas. It is the development of minerals that is the main component of the development of the Arctic [45, 46].

Along with this, the introduction of AI and robotics will simplify the solution of a number of problems related to mining, transportation and logistics in the difficult climatic conditions [54, 71].

Therefore, research in the AI field is an urgent problem and a priority of public policy [65].

1. Methods

The methodological basis of the study is based principles such as objectivity, consistency and scientific analysis. The systematic approach allowed us to consider the main trends in the development and application of AI and robotics systems as a set of measures necessary for the successful development of the Russian Arctic. This study also describes various aspects of the natural environment from the perspective of robotics, recent developments in this sphere and the prospects for advancing.

1.1 History of AI application in the Arctic

Currently, there are three chronological stages in the introduction of AI in technology for the Far North regions.

The first stage began in the mid-1960s, when programs for autonomous systems were first created [29].

The second stage began in 1984, when an integrated approach to Arctic development was introduced in the USA (Interagency Arctic Research Policy Committee, Arctic Research and Policy Act of 1984 (ARPA), Public Law 98 — 373 of 07/31/1984). To implement the strategy of federal coordination and U. S. global leadership in the exploration of the Arctic, the Arctic Research Commission (ARC) and the Interdepartmental Committee on Arctic Research Policy (IARPC) were established.

The third stage develops in the present and dates back to 1984, when other states set out the tasks of developing the Northern Territories.

1.2 Areas of application of artificial intelligence

The main directions of AI application in human economic activities in the Arctic will be the following: in mining and mineral processing , search and rescue operations, medicine, transport and logistics, construction, housing and communal services, energy [29].

Mining. A global trend in the development of oil and gas sector is the introduction of the "Intelligent field" and "Digitalization" concepts. Intellectualization extends to many stages across a wide range of IT components that are interconnected [7, 33, 50].

With the help of digitalization of technological processes, it is planned to reduce the costs associated with the exploration and production of hydrocarbons in difficult regional conditions, as well as with the development and production of special equipment [38, 72].

At the same time, thanks to this, it is possible to reduce environmental consequences [70], minimizing human presence in the region, and, ideally, reducing it to zero, ensuring technological and environmental safety, by transferring competencies to the level of robotic systems [41].

Digitalization of the mining industry, including in the Arctic region, is not possible without the creation of fully automatic systems with AI elements, working without human participation. The main trends are considered in the work of A. Makhovikov, E. Katuntsov, O. Kosarev, P. Tsvetkov "Digital transformation in oil and gas extraction" [38], and a specific example of implementation is presented in the paper "Modeling of industrial IoT complex for underground space scanning on the base of Arduino-based platform 'Topical issues of rational use of natural resources'" [35].

Intelligent automated process control systems. Gas production in the Arctic is associated with the need to solve a problems. An example is the problem of hydrate formation in gas collecting plumes for gas production companies. Its solution is found by feeding methanol into the pipelines. To minimize methanol consumption, OOO Gazprom Dobycha Yamburg has developed an innovative technology for preventing hydrate formation, implemented by an intelligent automated process control system [8, 14].

Safety. Along with the implementation of the Fundamentals of State Policy of the Russian Federation in the sphere of protection of population and territories from emergencies until 2030 and the Strategy for the Development of Civil Defence , protection of the population and Territories from emergencies, special attention is paid to the problematic issues of ensuring safety in the Arctic zone of the Russian Federation [26]. Since the peculiarity of the region does not allow the use of traditional methods and technologies of response to the occurrence/prevention of emergencies when assistance is required, there is a need to introduce robots. That is why the creation of effective robotic unmanned rescue systems (RURS) is an urgent task. Innovative directions of the development of such systems are, first of all, the ability to long-term autonomy with the possibility of remote control [19]. Such a rescue service based on robots, drones and AI was created jointly by the Ministry of Emergency Situations of Russia and the Central Research Institute of RTK. Two types of robots are used — ground-based and airborne. These drones will be able to scout the route and create an electronic map of the territory in real time. A ground unit in the form of robotic platforms will search for and transport people in distress. It is assumed that one drone will be able to evacuate up to twenty people [17].

Medical care. One of the main problems in the Russian Arctic is the poor quality of medical care and shortage of staff and medical facilities, especially in hard-to-reach areas where indigenous peoples live. Based on this and desperate for solutions, regional state authorities are turning to modern remote methods such as telemedicine, which makes it possible to diagnose and prescribe treatment from a distance [27]. In Russia, there are few ready-made solutions to this situation based on the results of AI. One of them is the work on speech recognition and online diagnosis of diseases based on medical images [12, 24].

Transport. Over the past five years, various Russian agencies and research centers have announced their intention and readiness to create fully automated vehicles and logistics solutions to be used in the Arctic [29, 48, 49, 53, 55, 58, 61]. Most important is the use of unmanned technologies. The Center for Advanced Research is developing an unmanned aerial transportation system (T-BAS), thanks to which companies and residents of the Far North will be able to quickly deliver and receive cargo, while scientists, for example, will be able to study from the air metrological characteristics and their changes, as well as the migration of animals[6]. It is necessary to note the work of scientists at the Russian Federal Nuclear Center, who are developing a digital model of a crewless marine vessel, the advantage of which is the increased efficiency and safety of maritime transportation in the Arctic [5].

Construction. An in-depth study of innovative technologies in the sphere of construction using AI is already being implemented on construction sites not only abroad, but also in Russia; it is becoming more and more in demand. According to experts, AI can manage Smart Cities in the Far North. The concept of a "smart city" with energy efficiency, self-sustaining efficiency of the territory makes the basis for the future of the Arctic cities [18, 20].

Power supply. The idea of energy development in the Russian Arctic implies the creation of a full-fledged energy infrastructure, the ability of which is to ensure high reliability of power supply and the possibility of stimulating new industrial development in the region [73, 75]. Rosatom State Corporation has developed about 20 projects of power plants based on small nuclear reactors, showing considerable interest in the power supply in the Arctic. The best known is the 70 MW Academik Lomonosov floating nuclear power plant (NPP) ". This project is based on the development of a new reactor plant for the "Arctica" nuclear icebreaker, currently under construction. The peculiarity of the reactor is its operability for 7—10 years without the need of nuclear fuel elements to be maintained [21].

Another phenomenon worth highlighting is the technology of autonomous power supply based on traditional and renewable energy sources developed by Peter the Great St. Petersburg Polytechnic University (SPbPU) for harsh climatic conditions, as well as a 200 kW diesel generator for Arctic conditions, presented by their partner company President-Neva Energy Center. The machine has an intelligent automatic control system. The solutions are claimed to have no analogues in the world [10, 28].

Modern power supply systems are needed to improve the stability of information technology systems functioning in the Arctic region. One approach to improving such systems involving elements of intellectualization is described in the paper by S. Kryltsov, A. Makhovikov, M. Korobitsyna "Novel approach to collect and process power quality data in medium-voltage distribution grids"

[36]. Another important aspect in this area is the decentralized energy supply, which can be carried out with the help of low-tonnage production of liquefied natural gas. The economic aspects of this approach are considered in the work of P. Tsvetkov, A. Cherepovitsyn, A. Makhovikov "Economic assessment of heat and power generation from low-tonnage liquefied natural gas in Russia" [43].

History, archaeology, tourism. The development of tourism in the Arctic zone of the Russian Federation is determined not only by the creation of new infrastructure facilities, but also by the introduction of modern digital services. Virtual tourism in the Arctic is a new trend with the use of virtual and augmented reality technologies, creating digital doubles of the territories. The use of space monitoring, panoramic photography and photogrammetry from manned and unmanned aerial vehicles for the virtual Arctic tourism will make cultural and natural objects of the Russian Arctic more accessible and attract new Russian and foreign tourists for a real visit to the polar regions. Virtual Reality (VR) is a world created by technical means (objects and subjects) andtransmitted to a person through his/her senses: vision, hearing, smell, touch and others. Augmented Reality (AR) includes digital objects, which are the result of introducing any sensory data into the sphere of perception in order to supplement information about the environment and improve perception of the information, while the outside world does not change in any way. The closest to the reality sensations is Mixed Reality (MR), the environment that is created using the software taking into account the situation in the real world, when the coexistence of real and virtual objects, the superimposition of non-existent virtual objects on the human environment [51].

Robotic systems application. Marine robotics is actively developing in Russia [60]. One of the key regions for the application of new robotic systems is the Arctic. The leading positions in the development of robotic complexes for marine applications are occupied by St. Petersburg State Marine Technical University, the Institute of Marine Technology Problems (Far Eastern Branch of the Russian Academy of Sciences), as well as the Research and Production Enterprise of Underwater Technologies Oceanos [31]. Recently, the latest classes of underwater robots have been implemented, for example, underwater gliders with the hydrostatic principle of motion, vehicles with the ability to stay underwater for a long time, capable of working among thin ice, surfacing and penetrating under ice masses, solving problems of operational oceanology and hydrography, and as data repeaters for civil data processing centers and for facilities of the Russian Ministry of Defense [13]. Speaking of robotics, it should be noted that more than 1.5 million industrial robots work in the world, which indicates their great potential for the future, in particular for the Arctic [4, 15, 23].

The use of digital doubles. The creation of integrated infrastructure monitoring systems in the oil and gas producing regions of the Far North, based on the use of heterogeneous mathematical models (digital twins), is a promising science-intensive direction [34, 44].

Forecasting the ship logistics parameters. Here the progress of Russian science is evident, achievements in this sphere, for example, are listed in [47], namely — various approaches to modeling the movement of ships in ice and determining the duration of voyages are analyzed; semi-empirical models for calculating ice resistance, numerical methods of modeling ship-ice interaction, as well as statistical models based on regression ratios or artificial intelligence methods are considered. The concept of creating a universal calculation model, which could be used as a part of modern software systems which provide intellectual support for Arctic navigation, is proposed.

Monitoring and control, geoinformation systems. The works [52, 59, 62] describe the intellectual property objects patented in Russia for monitoring and control in the conditions of the Arctic and the Far North. They also present a dispute on promising directions for the development of such systems; these tasks are linked to visualization on electronic interactive maps in real time [74].

Environment. It should be noted that AI, due to its autonomous operation, requires significant energy costs, resulting in problems with the well-being of the environment of the region [42]. Due to the natural and geographical features of the Arctic, there is a high probability that the existing environmental problems will grow from regional to global. Therefore, the development and subsequent introduction of robots in oceanographic, hydrographic, environmental and geological research in the Russian Arctic should ensure the safety of the ecosystem of this region.

The main measures to implement the state policy to ensure environmental safety in the Arctic Zone of the Russian Federation are : the establishment of special regimes of environmental management and environmental protection, including monitoring of its pollution; disposal of toxic industrial waste, reclamation of natural landscapes, as well as ensuring chemical safety. It is worth noting that in the Arctic there are many facilities that pose a potential radiation hazard. For example, the Kola NPP, where nuclear-powered surface and submarine ships of the civilian and naval fleets are based and repaired, a significant part of which is subject to disposal. Moreover, on the coast of the Barents and White Seas, there are facilities for storageof irradiated nuclear fuel.

The basic principles and mechanisms of state policy implementation are based on "maximum preservation of the environment (application of environmental standards and technologies)". The list of main activities of this program planned for 2021 – 2023includes the construction of an environmentally safe fleet to ensure federal state environmental supervision in the seas and on the continental shelf in the Russian Arctic. However, there yet are no clear methods of combating environmental risks in the state program [56, 57].

2. Results and discussion

As a summary, one should single out some modern know-hows that are of the most important socio-economic importance for the country, as well as admit the experience of foreign partners in the implementation of robotics for oceanographic, hydrographic, environmental and geological research in the Arctic. As a summary, we should highlight some modern know-how of crucial socio-economic importance for the country, as well as recognize the experience of foreign partners in implementing robotics for oceanographic, hydrographic, environmental and geological research in the Arctic.

2.1. Oceanos marine robots for environmental monitoring

The traditional monitoring system based on the use of ships, lowered and towed sensors, long-term stationary and floating buoys, is becoming increasingly inapplicable due to the harsh climate and difficult natural conditions of the Arctic. It is indisputable thatthe Arctic region currently establishes and dictates a significant need for the facilities with the following properties: ability to perform tasks clearly, high autonomy, no need for frequent lifting, minimized costs when providing operations from the surface. Thus, within the framework of this concept and based on the fundamental requirements, the system should consist of a group of autonomous underwater vehicles of various types and a system for their support.

Oceanos Underwater Technology Research and Production Enterprise is developing such a system, namely a group of efficient marine robotic vehicles for environmental monitoring, oceanographic observations and sampling of water and soil anywhere in the World Ocean, including the Arctic region. They design, manufacture and test examples of underwater robotics with hydrodynamic and hybrid principles of motion [1].

Oceanos works in cooperation with St. Petersburg State Marine Technical University as well as with many leading Russian companies. Since 2011, the company has been conducting and implementing its own developments of autonomous uninhabited underwater vehicles of the glider type, capable of diving to a depth of up to 1000 m and having autonomy of 6 months or more, marine robots specially trained for the harsh Arctic conditions. In 2015—2017, during the practical tests — descents of the device, scientists determined the requirements for navigation, maneuverability and speed of the robotic vehicle, developed the optimal mode of passage of the specified points and achieving the optimal energy efficiency planning mode [3].

Modern developments will be applied within the framework of the EcoCleanOcean international project, focused on cooperation in the sphere of ecosystem restoration and cleaning of the oceans, elimination of garbage islands. In 2020, within EcoCleanOcean project and with the support of the UN Environment Programme Assistance Committee UNEPCOM, Oceanos conducted tests of glider-type ANPAs. They worked out new algorithms of the mission planner and control systems, modes of ANPA movement along complex spatial trajectories, including detecting obstacles and maintaining the optimal trajectory of the vehicle. At the next stage, it is planned to integrate the obtained results into the system of group control over heterogeneous robotic means and conduct full-scale tests of the system [3].

2.2. The "Iceberg" Project

The Central Design Bureau of Marine Engineering "Rubin" took up the unique unimplemented projects of the 1980s to create underwater systems for exploration of minerals in the Arctic seas, namely the "Iceberg cipher", their extraction and delivery. This project consisted of a number of projects united by the common task of creating technologies and technical means to ensure fully underwater development of hydrocarbon deposits in the zone of permanent ice cover. In order to ensure the functioning of the technical means of underwater development of hydrocarbons, a nuclear power plant in the form of an autonomous underwater unmanned structure was developed jointly with the Afrikantov Experimental Design Bureau of Mechanical Engineering. The useful electrical capacity of the module is 16 MW (can be increased to 25 MW), autonomy is up to 1 year (without maintenance), and the total lifetime of up to 30 years. Reliability of operation of the submerged unmanned structure without the presence of operating maintenance personnel and without maintenance itself during the period of continuous operation is ensured by the use of reactor unit integral type with fully natural circulation of primary circuit coolant over the entire power range, the use of cassette-type core, a reduction in the auxiliary systems composition and the nuclear power plant equipment, as well as the use of highly automated control, protection, radiation and technological systems [11].

It will be accompanied by an underwater autonomous drilling complex, an underwater seismic survey vessel, an underwater transport and installation and maintenance complex. In terms of development level, the project and the technologies implemented in it are close to the space industry and, if successfully implemented, "Iceberg" will create a new and very important technological reserve for the Russian industry. At the moment, 3D modeling of future objects of the underwater complex has already been performed, which is very important. The Rosatom structures, the Ministry of Defense of Russia, Gazprom, the United Shipbuilding Corporation and the already mentioned Rubin Central Design Bureau for Marine Engineering participate in its creation. The work has been underway since 2015. Implementation of these research and development works (R&D) will give a powerful impetus to the development of technologies in oil and gas production, nuclear energy, seismic exploration and other related spheres.

According to the developers, the Iceberg project will solve two main tasks, the implementation of which is hampered by the ice cover in the Far North — seismic exploration and drilling. For seismic prospecting it is proposed to use underwater towed seismic pumps. The situation with underwater drilling is much more complicated. At the moment, there are no analogues of such drilling complexes. It was also proposed to use the technology of continuous drilling with constant flushing of wells. This, in its turn, will significantly reduce developers' risks associated with the labor intensity of the technological process. The project of the drilling complex is currently at the stage of preliminary design [22].

The following overall characteristics of the complex are given. The total displacement is 17670 cubic meters, length — 100.7 m, width — 35 m, height — 16.5 m. In the above — water position, the draft of the complex is 8.1 m. The transportation zone is 48.6 m long, which allows to transport cargoes weighing up to 300 tons. Immersion depth is up to 400 m, speed in transition mode is 7 knots. Its autonomy is 90 days. In the current plan, the Icebergproject will consist of five modules: the powe module, the drilling module, the module with the technical means of integrated safety system, the module with the technical means of seismic exploration, the underwater towed capsule with seismic cables (stranded cables for transmitting signals from seismic receivers to the seismic station) [22].

2.3. Robotic underwater and surface vehicle

Another interesting project for the Arctic is a robotic underwater-surface vehicle with increased autonomy with variable hull geometry. The device was presented by engineers of St. Petersburg State Marine Technical University. The aim of the project is to conduct various studies, including those in the northern seas. These can be oceanographic, hydrographic, environmental and geological studies. In particular, the robotic device is designed to study the development, protection and extraction of biological resources; conduct search and rescue operations and perform tasks of the coastal guard; collect information about the ice and hydrometeorological conditions; as well as to provide information support for navigation on the Northern Sea Route. Given the demand for transport and logistics in the Arctic region in recent years, this area may be particularly relevant [22].

The multifunctionality of an underwater surface vehicle with variable hull geometry consists in performing all the functions and tasks that are currently being performed and solved separately by surface, semi-submersible and underwater unmanned civilian and military vehicles. In addition, the vehicle is capaable of operating effectively in the harsh conditions of the Arctic [67, 68].

2.4. The Tan'so 4500 autonomous underwater robot

In October of this year, Chinese scientists announced the successful completion of research work in the Arctic: they created an autonomous deep-sea robot Tan'so 4500. It was developed by the Shenyang Institute of Automation unde the Chinese Academy of Sciences as part of a pilot strategic science and technology project called "Metabolism and Energy in the Tropical Area of the Western Pacific Ocean and Its Impact". The robot was technically modernized and modified, adapted to the new, cold environment, and conFig.d for navigation in the high-latitude zone. The research was carried out within the framework of the 12th Chinese scientific expedition in the high-latitude zone. Four researchers studied the Arctic shelf on the expedition icebreaker "Xuelong-2" [25]. Thanks to the successful immersion of the Tan'so 4500, the Arctic zone received the most important statistical data necessary for more detailed research, understanding of geological processes, studying the multicyclicity of energy and substance exchange in the Mid-Atlantic Ridge area. The project became the scientific basis for China's active participation in the protection of the Arctic environment.

Due to the high density of ice in the area of the Arctic scientific expedition, a group of researchers developed an innovative technology for extracting samples from under the ice. It consists of acoustic remote control and automatic guidance, allowing the underwater robot to overcome various obstacles caused by the fast moving ice and a limited area of open sea to return to the ship. Thanks to this robotic technology, diving of the underwater robot in the high-latitude zone of the Arctic seas covered by dense ice was successfully completed, as well as its safe return to the ship [25].

Staying near the bottom, the Tan'so 4500 collected data necessary to study the topographic and geomorphological features of the Mid-Atlantic Ridge, its magma and hydrothermal activity.

2.5. IceNet — a new prediction tool with artificial intelligence

In the *Nature Communications* journal, an international team of researcher, led by the British Antarctic Survey and the Alan Turing Institute, describes a new AI tool called IceNet. IceNet has the potential to predict the sea ice situation and, according to the authors, works thousands of times faster than traditional methods. The tool can predict the presence of sea ice two months ahead with an accuracy of 95%. Unlike conventional prediction systems that try to directly model the laws of physics, IceNet is based on the concept of deep learning. Researchers uploaded decades of ice sea level observations, as well as thousands of years of climate modeling data into the artificial intelligence tool. This makes IceNet a dynamic forecasting tool that continues to learn and adapt [39].

The next goal of scientists is to develop a model that will estimate the amount of ice in real time, similar to a weather forecast. This could work as an early warning system of the risks associated with rapid loss of sea ice. As we know, this is currently an urgent problem, which, in its turn, affects climate change not only in the Arctic region, but also on the planet.

3. Conclusions

The following conclusions were made as a result of the study. According to the potential of the Arctic, and today it is the export income of the country, the greatest attention is paid to the extraction and processing of minerals, while the current Iceberg project is aimed specifically at the underwater system of mineral exploration in the Arctic zone of the Russian Federation. Given that this project is still under completion, it already claims to be a success, as well as the following projects: robots for marine environmental monitoring Oceanos, a robotic underwater and surface vehicle of increased autonomy with variable hull geometry demonstrate a significant advancs towards a successful future of the development of the Arctic. With the use of digital technologies in the fuel and energy complex and intelligent, robotic automation of production, this area of AI implementation is taking the lead over everything else. In other areas, painstaking work is being carried out, and a general concept of using AI and robotics in Russia's Arctic zone has been suggested and id being promoted.

It is worth noting the significant progress of our foreign partners, such asthe autonomous underwater robot Tan'so 4500 from China and the forecasting tool with artificial intelligence — IceNet from England. Obviously, the West is ahead of Russia in the development of intelligent technologies due to good funding from the state and a strong advantage in their quality [69, 76]. Despite the work which already began to introduce AI and robotics i in the Arctic, as well as the scale of all projects and ideas, in Russia the work process will be more difficult and it will take years to implement all the projects initiated. Moreover, despite the experts' opinion on the prospects of AI by 2030, the use and gradual introduction of AI and robotics in the Arctic zone of the Russian Federation will happen later, taking into account all the factors of the socio-economic sphere development of the whole Russia, the pace of decision-making, the implementation of each concept.

Since the Arctic is extremely rich in minerals, and a significant part of the country's fossil resources are already being extracted in the Russian Arctic, the struggle and conflicts of the Arctic countries are quite intense. However, on the environmental side, additional agreements and global conventions are being signed to protect the environment and the environmental situation in the Far North, such as the Reykjavik Declaration of 2021, which contains instructions and calls for enhanced conservation of biodiversity and increased viability for 2021—2035 in the Arctic; the importance of the ecosystem approach to managing the Arctic marine environment; the importance of the the Arctic Marine Environment Protection Strategic Plan for 2015—2025 [40].

First of all, when implementing projects to introduce robotics, it is necessary to take into account all the risks affecting climate change in this region [77, 78], which subsequently leads to melting of Arctic ice, pollution of northern seas with oil and chemical compounds, and these problems, in their turn, affect the whole world. Therefore, it is extremely important for Russia, as well as for all the Arctic countries, to unite their efforts according to certain standards in order to avoid natural disasters.

REFERENCES

1. Oceanos prepares marine robots for environmental monitoring in the Arctic. SUDOSTROENIE INFO. URL: https://sudostroenie.info/novosti/31151.html/ (Access date: 10.02.2022).

2. Academician: oil reserves in the Arctic are comparable to the reserves in Western Siberia. MIA «Russia Today». URL: https://ria.ru/20151012/1300499673.html/ (Access date: 10.02.2022).
3. Oceanos — Arctic Joint-Stock Company «Scientific and Production Enterprise of Underwater Technologies" — a place for robots. korabel.ru. URL: https://www.korabel.ru/news/comments/arktika_-_mesto_dlya_robotov.html/ (Access date: 10.02.2022).
4. Bondareva, N. (2017). The use of robots in the Arctic. Russia: trends and prospects of development, 526–527 .
5. Rosatom is creating a digital model of an unmanned vessel for the Arctic. RIA Novosti. URL: https://ria.ru/atomtec/20180405/1517956613.html/ (Access date: 10.02.2022).
6. Russian Helicopters: Active use of UAVs in the Arctic may begin within two years. Aviation Explorer. URL: https://www.aex.ru/news/2017/12/5/178623/ (Access date: 10.02.2022).
7. Vlasov, A. (2018). Review of technologies: from digital to intellectual deposit / Mozhchil, A. PRONEFT. Professionally on oil, no. 3 (9), 70–74. DOI:10.24887/2587–7399–2018–3-68–74.
8. Gazprom needs artificial intelligence. Sever-Press-Yamal News IA. URL: https://sever-press.ru/2017/10/10/gazpromu-nuzhen-iskusstvennyj-intellekt/ (Access date: 10.02.2022).
9. Gerasimova, I. (2019). Service of the Arctic level. Neftegaz.RU Offshore. Arctic Level Service, 5 (89), 2–15.
10. Dementiev, A. (2016). Smart energy supply system — for the Far North. ENERGOSMI. URL: http://energosmi.ru/archives/23874 (Access date: 10.02.2022).
11. OSC Magazine Iceberg Project. magazine.aosk. URL: http://magazine.aoosk.ru/10/Made-in-USC-Subsea-hydrocarbon-extraction/Project-Iceberg/ (Access date: 10.02.2022).
12. Zaidullin, R. The future has already come: the way artificial intelligence is used in medicine. VC.RU. URL: https://vc.ru/32237-budushchee-uzhe-nastupilo-kak-iskusstvennyy-intellekt-primenyaetsya-v-medicine (Access date: 10.02.2022).
13. Ivanov, Y. United Shipbuilding Corporation and the Foundation for Advanced Research will create robots together. Weapons of Russia. URL: https://www.aoosk.ru/press-center/news/osk-i-fond-perspektivnykh-issledovaniy-sozdadut-robotov/ (Access date: 10.02.2022).
14. Artificial intelligence on the Arctic shelf. All people need to do is to control. North-Press–Yamal News IA. URL: https://sever-press.ru/2017/10/15/iskusstvennyj-intellekt-na-arkticheskom-shelfe-ot-lyudej-tolko-kontrol/ (Access date: 10.02.2022).
15. The use of industrial robots: an overview of the robotics market in Russia and the world. BUSINESS PROFILE Group. URL: https://delprof.ru/press-center/open-analytics/ispolzovanie-promyshlennykh-robotov-obzor-rynka-robototekhniki-v-rossii-i-mire/ (Access date: 10.02.2022).
16. Research and development. RTK. URL: https://rtc.ru/issledovaniya-i-razrabotki/ (Access date: 10.02.2022).
17. Kruglov, A., Ramm, A. (2018).Robots will be engaged in rescue in the Arctic. MIT Izvestia. URL: https://iz.ru/699859/aleksandr-kruglov-aleksei-ramm/roboty-zaimutsia-spaseniem-v-arktike (Access date: 10.02.2022).
18. Larrik, D. (2017). AU Russia 2017 will tell you how to combine BIM and artificial intelligence at a construction site. Archspeech. URL: http://archspeech.com/article/na-au-russia-2017-rasskazhut-kak-sochetat-bim-i-iskusstvennyy-intellektna-stroyke (Access date: 10.02.2022).
19. Lopota, A. (2018). Conceptual issues of the robotic systems development for the search and rescue of people in distress in the Arctic. Robotics and technical cybernetics, 1 (18), 3–9.
20. Ministry of Construction of the Russian Federation. Intelligent accounting systems can be implemented in housing and communal services within 6 years. Association of Siberian and Far Eastern Cities. URL: http://www.asdg.ru/news/359816/ (Access date: 10.02.2022).

21. Floating nuclear power plants will supply energy to Russian drilling rigs in the Arctic. Center for Strategic Assessments and Forecasts. URL: www.csef.ru/ru/politica-i-geopolitica/501/plavuchie-aes-budut-snabzhat-energiej-rossijskie-burovye-ustanovki-v-arktike-7827 (Access date: 10.02.2022).

22. Polunin, A. (2018). Underwater robots for the conquest of the Arctic. SUDOSTROENIE INFO. URL: https://sudostroenie.info/novosti/25296.html (Access date: 10.02.2022).

23. Vasilyeva, N. V., Boikov, A. V., Erokhina, O. O., & Trifonov, A. Y. (2021). Automated digitization of radial charts. *Journal of Mining Institute*, 247, 82–87. DOI: 10.31897/PMI.2021.1.

24. Russian and Israeli scientists have created artificial intelligence for arrhythmia treatment. TASS. URL: http://tass.ru/nauka/4891675. (Access date: 10.02.2022).

25. Svintsova, E. (2021). An autonomous robot took samples from the bottom of the Arctic to study the Mid-Atlantic Ridge. Neftegaz.RU. URL: https://neftegaz.ru/news/standarts/700306-avtonomnyy-robot-otobral-obraztsy-so-dna-arktiki-dlya-izucheniya-sredinno-atlanticheskogo-khrebta/ (Access date: 10.02.2022).

26. Simanov, S., Nesterov, I., Bagaev, Yu. (2019). Safety technologies for the Arctic zone of the Russian Federation (using advanced robotic complexes of the Ministry of Emergency Situations of Russia). St. Petersburg: Publishing House of the University of the Ministry of Emergency Situations of Russia, 190–192.

27. Arctic and Antarctic Council under the Federation Council at the Federal Assembly of the Russian Federation. On the state and problems of legislative support for the implementation of the fundamentals of the state policy of the Russian Federation in the Arctic for the period up to 2035. Moscow: Publication of the Federation Council, 2020.

28. Smart power supply system for the Far North. State Public Scientific and Technical Library of the Siberian Branch at the Russian Academy of Sciences. URL: http://www.sib-science.info/ru/news/umnaya-energ-14112016 (Access date: 10.02.2022).

29. Fedotovskikh, A. (2018). The use of artificial intelligence systems in the conditions of a new stage of Arctic exploration. Analytical review. Moscow: Volume I.

30. Shimberg, A. Will robots take over the Arctic? REGNUM Informational agency. URL: https://regnum.ru/news/ 2409600.html (Access date: 10.02.2022).

31. Yudina, A. Center of Robotics at the Ministry of Defense of the Russian Federation: micro-robots of «pocket» format will appear in the Arctic. TASS. URL: https://tass.ru/interviews/4502372 (Access date: 10.02.2022).

32. Abukova, L., Borisenko, N., Martynov, V., Dmitrievsky, A., Eremin, N., (2017). Digital modernization of the gas complex: Scientific research and personnel support. Neftyanoe Khozyaistvo. Oil Industry, 4, 3–12. DOI: 10.24887/0028–2448–2017–10–54–58.

33. AVIST: universal platform of the intellectual field. The oil and gas vertical. URL: http://www.ngv.ru/magazines/article/avist-universalnaya-platforma-intellektualnogo-mestorozhdeniya/news/rfikitaybudutsovmestnoosvaivatarktiku/ (Access date: 10.02.2022).

34. Gabov, V., Babyr, N., Zadkov, D. (2021). Mathematical modelling of operation of the hydraulic support system of the powered support sections with impulse-free continuous regulation of its resistance to the roof rock lowering. IOP Conference Series Materials Science and Engineering, 1064(1), 012045. DOI: 10.1088/1757–899X/1064/1/012045.

35. Kosarev, O., Tsvetkov, P. , Makhovikov, A., Zulin, V., Bykasov, D. (2019). Modeling of Industrial IoT complex for underground space scanning on the base of Arduino platform. Topical issues of rational use of natural resources, 1, 407–411.

36. Kryltcov, S., Makhovikov, A., Korobitsyna, M. (2021). Novel approach to collect and process power quality data in medium-voltage distribution grids. Symmetry, 13(3), 460. DOI:10.3390/sym13030460.

37. Litvinenko, V. (2020). The Role of Hydrocarbons in the Global Energy Agenda: The Focus on Liquefied Natural Gas. Resources, 9(5), 59. DOI: 10.3390/resources9050059.

38. Makhovikov, A., Katuntsov, E., Kosarev, O., Tsvetkov, P. (2018). Digital transformation in oil and gas extraction. In Innovation-Based Development of the Mineral Resources Sector: Challenges and Prospects; CRC Press: Boca Raton, FL, USA, 531–538.
39. New Artificial Intelligence Tool Can Predict the Future of Arctic Sea Ice. High North News. URL: https://www.highnorthnews.com/en/new-artificial-intelligence-tool-can-predict-future-arctic-sea-ice (Access date: 10.02.2022).
40. REYKJAVÍK DECLARATION. Arctic Council Secretariat. URL: https://oaarchive.arctic-council.org/handle/11374/2600.
41. Samylovskaya, E., Kudryavtseva, R-E., Medvedev, D., Grinyaev, S., Nordmann, A. (2020). Transformation of the Personnel Training System for Oil and Gas Projects in the Russian Arctic. Resources, 9(11), 137. DOI: 10.3390/resources9110137.
42. Stroykov, G., Babyr, N. Ilin, I., Marchenko, R. (2021). System of comprehensive assessment of project risks in energy industry. International Journal of Engineering, Transactions B: Applications, 34(7), 1778–1784. DOI: 10.5829/ije.2021.34.07a.22.
43. Zhukovskiy, Y., Tsvetkov, P., Buldysko, A., et al. (2021). Scenario modeling of sustainable development of energy supply in the Arctic. Resources, 10(12), 124. DOI: 10.3390/resources10120124.
44. Piirainen, V. Yu., Denisov, V. M., Timofeev, A. V. (2021). The concept of integrated monitoring of the Far North and the Arctic infrastructure based on the use of digital twins and artificial intelligence methods. Innovations and prospects for the development of mining engineering and electromechanics: IPDME-2021: Collection of abstracts of the 8th International Scientific and Practical Conference, 365–378.
45. Vopilovsky, S. S. (2021). Infrastructural projects — a general resource for increasing the economic potential of the Arctic.The Arctic and the North, 43, 19–31. DOI: 10.37482/issn2221–2698.2021.43.19.
46. Brodt, L. E. K. (2021). Best practices of oil and gas companies on gas fields development in the Arctic shelf. Arctic and North, 44, 30–44. DOI: 10.37482/issn2221–2698.2021.44.30.
47. Tarovik, O. V. (2021). Models for forecasting parameters of ship voyages in the Arctic: existing approaches and possible ways of development. Arctic: ecology and economics, 3, 422–435. DOI: 10.25283/2223–4594–2021–3-422–435.
48. Leonov, S. N., Zaostrovskikh, E. A. (2021). The influence Northern Sea Route ports have on the formation of focal zones for the development of the Eastern Arctic. The Arctic: Ecology and Economics, 11, 1, 6–18. DOI: 10.25283/2223–4594–2021–1-6–18.
49. Leonov, S. N., Zaostrovskikh, E. A. (2021). The development of the Northern Sea Route and the growth of China's activity in the Arctic as prerequisites for strengthening the transport framework of the Far East. Regional studies, 8(2), 54–70. DOI: 10.14530/reg.2021.2.54.
50. Andreeva, P. A. (2021). Analysis of Arctic countries' strategies and their impact on industrial enterprises. Problems of Market Economy, 2, 59–71. DOI: 10.33051/ 2500- 2325-2021- 2- 59- 71.
51. Fedotovskikh, A. V. (2021). The use of digital realities and digital twins in Arctic tourism. World Civilizations, 6(1), 159–167.
52. Shegelman, I. R., Vasiliev, A. S., Ivashnev, M. V. (2020). Patentable solutions based on the use of artificial intelligence for monitoring and control in the Arctic and the Far North. Scientific and educational space: Development prospects: Collection of materials of the 16th International Scientific and Practical Conference, 117–118.
53. Sobolevskaya, E. Yu., Levchenko, N. G., Glushkov, S. V. (2020). Information intelligent system of organization and management of the Arctic sea cargo transportation — a module for calculating the route between two ports taking into account the ice situation. IOP Conference Series Materials Science and Engineering, 918(1), 012042. DOI:10.1088/1757–899X/918/1/012042.

54. Pilyasov, A. N. (2020). Industrial policy in the Arctic: new priorities at the federal level. The North and the market: the formation of an economic order, 2(68), 73–83. DOI 10. 37614/2220–802X.2.2020.68.007.
55. Glushkov, S. V., Sobolevskaya, E. Yu., Levchenko, N. G. (2020). Formation of a training sample for an information intelligent system of Arctic sea cargo transportation organization and management. Marine intelligent technologies, 1–2(47), 230–235. DOI: 10.37220/MIT.2020.47.1.073.
56. Gagiev, N. N., Goncharenko, L. P., Sybachin, S. A., Shestakova, A. A. (2020). National Projects in the Arctic Zone of the Russian Federation. Arktika i Sever [Arctic and North], 41, 113–129. DOI: 10.37482/issn2221- 2698.2020.41.11.
57. Pilyasov, A. N., Putilova, E. S. (2020). New projects for the Russian Arctic development: this space is significant!. The Arctic and the North, 38, 21–43. DOI: 10.37482/issn2221–2698.2020.38.21.
58. Sobolevskaya, E. Yu., Glushkov, S. V., Levchenko, N. G. (2020). The development stage of an intelligent transport and logistics management information system taking into account the harsh climatic conditions of navigation. Bulletin of the Maritime State University, 86, 40–45.
59. Simakov, E. A., Bogdanov, E. V., Pronin, P. I. (2019). Development of a remote monitoring system for research robotics complexes. KOGRAF-2019: a collection of materials of the 29th All-Russian Scientific and Practical Conference on Graphic Information Technologies and Systems, Nizhny Novgorod, 166–170. DOI: 10.1007/978–3-319–19656–5_28.
60. Bugakov, I. A., Tsarkov, A. N. (2019). On «real» artificial intelligence for Arctic exploration. Izvestiya of Engineering Physics Institute, 2(52), 93–100.
61. Kabaldin, Yu. G., Shatagin, D. A., Kiselev, A. V. (2018). The intelligent construction concept for unmanned vehicles route using cloud technology and augmented reality in the Arctic and the Far North. Vestnik Mashinostroeniya, 7, 55–58.
62. Makarov, V. S.(2017). Development of scientifically based technical solutions for the creation of mobile coastal zone monitoring complexes. Proceedings of the NSTU, 3(118), 157–167.
63. Sobolevskaya, E. Yu. (2017). Architecture of the intellectual system for Arctic sea cargo transportation organization. Modeling, optimization and information technologies, 4(19), 27.
64. Decree of the President of the Russian Federation dated 26.10.2020 no. 645. On the Strategy for the Development of the Arctic Zone of the Russian Federation and ensuring national security for the period up to 2035. URL: http://www.kremlin.ru/acts/bank/45972 (Access date 10.02.2022).
65. Decree of the President of the Russian Federation no. 490 dated 10.10.2019. On the development of artificial intelligence in the Russian Federation. URL: http://www.kremlin.ru/acts/bank/44731 (Access date 10.02.2022).
66. Lipina, S. A., Smirnova, O. O., Kudryashova, E. V. (2019). Arctic: Development strategy. Arkhangelsk: Northern (Arctic) Federal University named after M. V. Lomonosov, 338.
67. Taradonov, V. S., Blinkov, A. P., Kozhemyakin, I. V., Shamanov, D. N. Conceptual appearance of a robotic underwater-surface vehicle of increased autonomy with a variable hull geometry. News of the SFU. Technical sciences, 1(203), 38–49. DOI: 10.23683/2311–3103–2019–1-38–49.
68. FSASI Central Research and Development Institute of Robotics and Technical Cybernetics (Central Research Institute of RTC). URL: https://rtc.ru/ (Access date 10.02.2022).
69. Samylovskaya, E., Makhovikov, A., Lutonin, A., et al. (2022). Digital Technologies in Arctic Oil and Gas Resources Extraction: Global Trends and Russian Experience. Resources, 21100808642, 11. DOI: 10.3390/resources11030029.

70. Rybak, J., Khayrutdinov, M. M., Kuziev, D. A., Kongar-Syuryun, Ch. B., Babyr, N. V. (2022). Prediction of the geomechanical state of the rock mass when mining salt deposits with stowing. *Journal of Mining Institute*, 253, 61–70. DOI: 10.31897/PMI.2022.2.

71. Temkin, I., Myaskov, A., Deryabin, S., Konov, I., Ivannikov, A. (2021). Design of a Digital 3D Model of Transport–Technological Environment of Open-Pit Mines Based on the Common Use of Telemetric and Geospatial Information. Sensors, 21(18), 6277. DOI: 10.3390/s21186277.

72. Rogalev, A. N., Sokolov, V. P., Sokolova, J. V., Milukov, I. A., Bratukhin, A. G. (2018). Methodology of reasonable application of digital technology for creating competitive high-tech products. International Journal of Mechanical Engineering and Technology, 9(10), 670–678.

73. Lisin, E., Kurdiukova, G. (2021). Energy Supply System Development Management Mechanisms from the Standpoint of Efficient Use of Energy Resources. IOP Conference Series: Earth and Environmental Science, 666(6), 062090. DOI: 10.1088/1755–1315/666/6/062090.

74. Ustinov, A. Y., Kulikov, R. S., Zakharova, E. V., Zamolodchikov, V. N. (2019). Vehicles Cooperative Navigation Using GNSS for Coordinates and DSRC for Mutual Heading. 12th International Scientific and Technical Conference «Dynamics of Systems, Mechanisms and Machines», 8601468. DOI: 10.1109/Dynamics.2018.8601468.

75. Rogalev, N., Sukhareva, Y., Mentel, G., Broz˙yna, J. (2018). Economic approaches for improving electricity market. Terra Economicus, 16(2), 140–149. DOI: 10.23683/2073–6606–2018–16–2-140–149.

76. Gekht, A. B., Eidemiller, K. Yu., Kudryavtseva, R.-E. A., Samylovskaya, E. A., Kulik, S. V. (2020). History of Iceland formation as main Arctic crossroad. IOP Conference Series: Earth and Environmental Science, 2020, 434(1), 012003. DOI: 10.1088/1755–1315/434/1/012003.

77. Tcvetkov, P., Cherepovitsyn, A., & Fedoseev, S. (2019). The Changing Role of CO2 in the Transition to a Circular Economy: Review of Carbon Sequestration Projects. Sustainability, 11(20), 5834. DOI: 10.3390/su11205834.

78. Kopteva, A., Kalimullin, L., Tcvetkov, P., & Soares, A. (2021). Prospects and Obstacles for Green Hydrogen Production in Russia. Energies, 14(3), 718. DOI: 10.3390/en14030718 ГИАБ

ИНФОРМАЦИЯ ОБ АВТОРАХ

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АНАЛИЗ ЭКОЛОГИЧЕСКОЙ И ЭКОНОМИЧЕСКОЙ БЕЗОПАСНОСТИ ПРИБРЕЖНЫХ РЕГИОНОВ АРКТИКИ

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Аннотация: особую актуальность приобретают вопросы и проблемы обеспечения экологической и экономической безопасности регионов в условиях ухудшения экологической обстановки, а также продолжающегося санкционного давления и распространения коронавирусной инфекции. В то же время регионы Арктической зоны Российской Федерации, где сосредоточены основные запасы нефти, природного газа, алюминия, золота, платины и других полезных ископаемых, подвергаются воздействию неблагоприятных факторов в большей степени, чем регионы, расположенные в центральной и южной частях страны. Это связано с промышленной направленностью экономической деятельности большинства арктических городов, а также с суровыми условиями жизни, характерными для регионов этой группы. В статье определено, что, несмотря на значительное количество научных статей, монографий и других работ, посвященных проблемам обеспечения эколого-экономической безопасности, существует определенный пробел в вопросах, связанных со сравнительным анализом эколого-экономической безопасности территориальных систем. Также делается вывод о том, что ключевым элементом при проведении сравнительного анализа является выбор показателей, которые должны отражать состояние окружающей среды, а также экономики региона. показатели должны быть не только репрезентативными, то есть объективными, но и простыми для интерпретации. Анализ, проведенный в рамках исследования, показал, что из всех регионов Арктической зоны Российской Федерации Ямало-Ненецкий автономный округ обладает самым высоким уровнем экологической и экономической безопасности. Аутсайдерами оказались Республика Карелия и Красноярский край. В ходе сравнительного анализа Республика Коми, не имеющая границ с морем/океаном, была исключена из арктических прибрежных регионов.

Ключевые слова: экологическая безопасность, экономическая безопасность, Арктика, прибрежные регионы.

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Analysis of environmental and economic security of the Arctic coastal regions

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Abstract: the issues and problems of ensuring the environmental and economic security of the regions in the context of a deteriorating environmental situation, as well as the ongoing sanctions pressure and the spread of coronavirus infection, are of particular relevance. At the same time, regions of the Arctic zone of the Russian Federation, where the main reserves of oil, natural gas, aluminum, gold, platinum and other minerals are concentrated, are exposed to adverse factors more than regions located in the central and southern parts of the country. This is due to the industrial orientation of the economic activity of most Arctic cities, as well as the harsh living conditions typical of the regions of this group. the article determines that, despite the significant number of scientific articles, monographs and other works devoted to the problems of ensuring environmental and economic security, there is a certain gap in issues related to the comparative analysis of environmental and economic security of territorial systems. It is also concluded that the key element in conducting a comparative analysis is the choice of indicators, which should reflect the state of the environment, as well as the economy of the region. the indicators should not only be representative, i.e., objective, but also easy to interpret. The analysis carried out as part of the study showed that of all the regions of the Arctic zone of the Russian Federation, the Yamalo-Nenets Autonomous District has the highest level of environmental and economic security. The Republic of Karelia and the Krasnoyarsk Territory turned out to be outsiders. During the comparative analysis, the Komi Republic, which has no borders with the sea/ocean, was excluded from the Arctic coastal regions.

Key words: environmental safety, economic security, Arctic, coastal regions.

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The Arctic territories have always been of particular importance for the development of the Russian Federation. It is here that the main reserves of copper, aluminum, tin, platinum, gold and other rare earth metals are concentrated, as well as the overwhelming majority of the explored reserves of natural gas and oil [1]. Despite the difficult climatic conditions of life — low temperatures, long winter period, alternation of polar day and night, industrial development of these territories is a matter of national security. Even though federal budget revenues from the sale of oil and natural gas have somewhat decreased (from 51% in 2010 to 29% by the end of 2020), they are still a key source of budget replenishment, and will remain so in the near future [2]. At the same time, the industrial development of the Arctic territories has an extremely negative impact on the fragile ecosystem of the Arctic, and the problems of ensuring environmental security come to the fore [3, 4, 5, 6]. In order to reduce the pressure on the environment, the mandatory introduction of resource-saving technologies and cyclically closed production is proposed. [6]. As for the economic component, the ongoing sanctions pressure, as well as the fight against the spread of the COVID-19 coronavirus infection, have a negative impact on the economy of the Russian Federation as a whole, and the regions of the Arctic zone of the Russian Federation (hereinafter — the Russian Arctic). It should be reminded that part of the sanctions — the ban on the purchase of equipment and technologies that allow deep-sea drilling, the refusal of Russian oil and gas companies in long-term lending and cooperation with major foreign partners, are aimed precisely at complicating the work of domestic companies on the development of oil and natural gas fields, primarily on the shelf of the Arctic seas. Thus, the relevance of the article is beyond doubt, and the main goal is to compare the Arctic coastal (sea/ocean-facing) regions of Russia in terms of environmental and economic security and to identify trends in the economic development of the designated territories.

1. Overview of the main sources of research and publications

Many scientific articles and monographs [7, 8, 9, 10] are devoted to the issues and problems of assessing the environmental and economic security of states and regions. Of particular interest are the first works of Russian scientists, in which the national level of economic security was highlighted, and attempts were made to develop a system of indicators and threshold values [11, 12, 13, 14, 15, 16]. The success of such developments is confirmed by their recognition and application by the state authorities to assess the state of the economy of the Russian Federation in the mid-1990s.

However, the use of existing systems of indicators at the regional level was not so effective. This is due to the presence of peculiarities in the development of certain groups of regions that were not taken into account in the system of indicators developed for the national level. Therefore, there was a need not just to highlight the regional level of economic security as a separate object of study, but also to determine the features in their development, grouping, development of new indicators and their threshold values. It should be noted that in recent years, many scientific papers have been devoted to the problems of economic security of territorial systems. Among the most interesting and significant is the work of V. K. Senchagov *Economic security of the regions of Russia*, which examines in detail the existing levels of economic security, as well as factors that have a decisive impact on the economic development of the regions. One of the main conclusions is “ensuring the national interests of the country begins at the regional level” [17]. As for ensuring the environmental and economic security of the Arctic regions, these issues are discussed in detail in the works of V. S. Selin [9]. In particular, the features characteristic of the development of these regions are highlighted, the indicators that take these features into account are defined, and the main threats to environmental and economic security are identified.

The analysis showed that, despite a significant number of scientific articles and monographs devoted to topical issues of ensuring ecological and economic security of regions, there is a certain gap in the issues of comparative analysis of security between regions.

2. Comparative analysis of economic security of Arctic coastal territorial systems

According to Decree of the President of the Russian Federation No. 296 of

02.05.2014 (as amended by Decree No. 287 of June 27, 2017, No. 220 of May 13, 2019), the territories of the following regions are fully or partially assigned to the Arctic zone of the Russian Federation: Arkhangelsk Region, Krasnoyarsk territory, Murmansk region, Nenets autonomous district, Republic of Karelia, Komi Republic, Republic of Sakha (Yakutia), Chukotka autonomous district and Yamalo-Nenets autonomous district [18, 19, 20].

As part of an earlier study, it was found that both coastal and Arctic regions are considered to have a coastal coastline and belong to the Russian Arctic, that is, all of the regions listed above, except for the Komi Republic [10].

The earlier study showed that in practice there are several methods for assessing the economic security of regions: rating assessment; the use of a system of indicators and threshold values; methods of applied mathematics. However, the approach based on a comparative analysis of the economic situation of territorial systems seems to be the most preferable for comparing regions with each other according to criteria and indicators of economic security. The essence of this method consists in performing the following steps:

– Setting the oscillation range. Based on the above, we can say that:

$$B_{max} - B_{min}, \tag{1}$$

where B_{max} is the maximum value of a specific indicator, and B_{min} is the minimum.

– Setting the interval value — D:

$$D = \frac{(B_{max} - B_{min})}{k}, \tag{2}$$

where k is the number of intervals,

$$k = p - 1, \tag{3}$$

where p is the number of objects that participate in the comparative analysis.

– We can find the value of each indicator (F) for each territorial system — F_n:

$$F_n = \frac{(B_{max} - B_{min})}{k} + 1, \tag{4}$$

The resulting score of economic security indicators is found by adding each of the ten components:

$$РБ = F1 + F2 + F3 + F4 + F5 + F6 + \\ + F7 + F8 + F9 + F10, \tag{5}$$

$$КБ = F1 + F2 + F3 + F4 + F5 + F6 + \\ + F7 + F8 + F9 + F10,$$

where $F1$ is the value of GRP per capita (thousands of rubles); $F2$ is investments in fixed assets per capita (thousands of rubles); $F3$ is the monetary income of the population per capita (thousands of rubles); $F4$ is the population with incomes below the subsistence minimum (%); $F5$ is the unemployment rate (%); $F6$ is retail trade turnover (thousands of rubles); $F7$ is household spending on housing and communal services (% of total consumer spending); $F8$ is the commissioning of residential buildings (per 1000 people, m2); $F9$ is volume of pollutants released into the atmospheric air (thousands of tons); $F10$ — population per doctor (person).

The choice of indicators is a key point in assessing the level of economic security. On the one hand, each of the selected indicators should reflect the state in a particular area of economic activity, and on the other hand, be representative, that is, objective, and at the same time easy to interpret. The basic one is the so-called gross regional product, which not only reflects the real level of development of a particular region, but also gives a total cost estimate of the goods produced and services rendered. The unit of measurement is thousands of rubles per capita. Another indicator — “Investments in fixed assets”, reflects the total amount of costs that are aimed at incrementing the cost of fixed assets. This may be the purchase of new machinery and equipment, including as part of the modernization and/or expansion of production, software, as well as other elements of intellectual property.

Monetary income of the population per capita is a generalized value reflecting the average income of 1 person, in this case for a month. It is calculated as the sum of all incomes of the population of the region divided by the total number of residents of the region. Despite the unequal number of pensioners, workers, children and other categories of the population from region to region, this indicator allows us to compare the average per capita income of the population between regions of the same group — the Arctic coastal zone of the Russian Federation.

The next indicator — "population with incomes below the subsistence minimum" — provides information in percentage terms about what part of the population has incomes below the required level, which is defined by the state as the minimum. This indicator allows us to determine which part of the population of a particular region is below the so-called poverty line.

Unemployment rate: this indicator reflects what part of the working-age population is currently unemployed for one reason or another, but is actively looking for work. We can say that this indicator indirectly characterizes the efforts of regional authorities to create new jobs.

The indicator — "retail trade turnover" — is the amount of money received from sale of goods to the population, both for personal needs and for use in the household. At the same time, the proceeds received from the sale of goods to individual entrepreneurs and legal entities are not taken into account in the retail turnover, as well as the turnover of public catering is not accounted.

The next indicator — "household expenditures on housing and communal services"– is the amount of money spent by an individual family each month to pay for housing and communal services — electricity, cold and hot water, heating, garbage collection, maintenance and repair. In this case, it is % of the total family spending on consumer needs. At the same time, consumer spending refers to all family's expenses for the purchase of goods and services, with the exception of those funds that were used to purchase certain categories of goods, such as jewelry, works of art, etc. This indicator allows us to estimate how large is the share of compulsory payments in the total consumer spending of the region's population.

The indicator "commissioning of residential buildings (m2 per 1,000 people)" represents the volume of residential space commissioned per 1,000 people. The higher the value of this indicator, the more attractive the region is for the population. It indirectly characterizes the capabilities of the construction industry and reflects the current socio-economic situation in a particular region.

The indicator "volume of pollutants released into the atmospheric air" characterizes the volume of emissions of pollutants that have a negative impact on human health and the environment released into the atmospheric air, the unit of measurement is thousands of tons.

The indicator "population per doctor" is calculated as the ratio of the total number of doctors to the average annual population of the region. This indicator characterizes the availability of doctors to the population of a particular region.

Further, with the help of expert evaluation, the significance of each of the indicators — fn — is determined. Thus,

Table 1

Ranking of regions by criteria of economic security [2]

Region	F1 Th. R. M/B	F2 Th. R. M/B	F3 Th. R. M/B	F4 % M/B	F5 % M/B	F6 Th. R. M/B	F7 % M/B	F8 m² M/B	F9 Th. tons M/B	F10 People M/B	Scores	Posi-tion
Murmansk Region	828.4 6/7.68	230.1 5/7.49	44.2 5/6.23	10.6 4/3.87	5.4 4/3.87	240.4 3/3.51	13 8/8.00	60 7/7.58	231 5 / 1.62	193 6/7.20	58.26	6
Arkhangelsk Region	509.9 8/8.00	85.8 7/7.97	33.9 6/7.6	12.7 5/5.08	6.2 5/6.02	240.2 4/3.53	8.8 2/1.88	294 5/4.68	137 4/1.35	179.7 4/5.58	51.68	5
Republic Of Karelia	527.8 7/7.98	78.2 8/8.00	30.9 8/8.00	15.7 6/6.80	7.4 7/7.42	209.6 7/7.08	10.1 4/3.77	450 3/2.75	122 3/1.30	193.3 5/7.19	60.29	7
Republic Of Sakha (Yakutia)	1258.7 4/7.25	393.1 4/6.95	45.5 4/6.05	17.8 8/8.00	6.9 6/6.83	254.7 2/1.85	9.7 3/3.19	580 2/1.14	288 6/1.78	162.4 2/3.54	46.58	4
Nenets Autonomous District	7530.5 1/1.00	2176.3 1/1.00	81 3/1.32	9.4 3/3.18	7.9 8/8.00	223.6 5/5.46	10.1 4/3.77	430 4/2.99	67 2/1.14	194.3 7/7.30	35.17	2
Yamalo-Nenets Autonomous District	5710.5 2/2.81	1592.3 2/2.95	83.1 2/1.04	5.6 1/1.00	1.9 1/1.00	262 1/1.00	8.2 1/1.00	268 6/5.00	763 7/3.16	176.3 3/5.18	24.14	1
Krasnoyarsk Territory	938.0 5/7.57	148.6 6/7.77	31.7 7/7.89	17.3 7/7.72	4.5 3/4.03	201.7 8/8.00	11.9 7/6.40	591 1/1.00	2432 8/8.00	200.2 8/8.00	66.38	8
Chukotka Autonomous District	1898.6 3/6.61	518.4 3/6.53	83.4 1/1.00	8.5 2/2.67	3.8 2/3.22	209.9 6/7.05	11.4 6/5.67	26 8/8.00	18 1/1.00	140.9 1/1.00	42.74	3

Table 2

Ranking of regions by economic security indicators

	Z(F1-F3) = 3			Z(F4-F6) = 2			Z(F7-F10) = 1					
	F1 f1 = = 1.0	**F2 f2 = = 0.69**	**F3 f3 = = 0.8**	**F4 f4 = = 0.56**	**F5 f5 = = 0.51**	**F6 f6 = = 0.46**	**F7 f7 = = 0.24**	**F8 f8 = = 0.2**	**F9 f9 = = 0.16**	**F10 f10 = = 0.38**	**Gint**	**Posi-tion**
Murmansk Region	7.68	5.17	4.98	2.17	2.59	1.61	1.92	1.52	0.26	2.74	15.57	VI
Arkhangelsk Region	8	5.50	6.08	2.85	3.07	1.62	0.45	0.94	0.22	2.12	14.03	V
Republic Of Karelia	7.98	5.52	6.4	3.81	3.78	3.26	0.91	0.55	0.21	2.73	16.46	VII
Republic Of Sakha (Yakutia)	7.25	4.80	4.84	4.48	3.49	0.85	0.77	0.23	0.29	1.34	12.67	IV
Nenets Autonomous District	1	0.69	1.06	1.78	4.08	2.51	0.91	0.60	0.18	2.78	9.58	II
Yamalo-Nenets Autonomous District	2.81	2.03	0.83	0.56	0.51	0.46	0.24	1.00	0.51	1.97	6.38	I
Krasnoyarsk Territory	7.57	5.36	6.32	4.33	2.06	3.68	1.54	0.2	1.28	3.04	17.52	VIII
Chukotka Autonomous District	6.62	4.51	0.8	1.49	1.64	3.24	1.36	1.6	0.16	0.38	10.67	III

the most significant indicator was $F1$ — the value of GRP per capita — 1.0, and the least significant — $F9$ — the volume of pollutants released into the atmosphere (thousand tons) — 0.16. Further, $F2$ — investments in fixed assets per capita — 0.69; $F3$ — monetary income per capita — 0.8; $F4$ — population with incomes below the subsistence minimum — 0.56; $F5$ — unemployment rate — 0.51; $F6$ — retail trade turnover — 0.46; $F7$ — household spending on housing and communal services — 0.24; $F8$ — commissioning of residential buildings — 0.2; $F10$ — population per doctor — 0.38.

The G ranking for each region is determined within the significance of each of the levels of indicators:

$$Gi = \sum_{p-1}^{k} Fn\,f\,/\,z, \qquad (6)$$

where z is the significance of the points.

At the same time, the integral ranking is determined by the formula:

$$G\text{int} = \sum_{i=1}^{a} Gi. \qquad (7)$$

The sum of all indicator rankings gives the final indicator of the economic situation of territorial systems, relative to each other, based on ten components (values of 10 economic indicators).

Tables 1 and 2 provide calculations and data on the economic situation of the Arctic coastal regions. The Yamalo-Nenets Autonomous District has the highest level of economic security, followed by the Nenets and Chukotka Autonomous Districts.

The data presented in the tables show that the Yamalo-Nenets Autonomous District, like the Chukotka Autonomous District, are among the top three in all groups of indicators, while the Nenets Autonomous District is the undisputed leader only in the first group of indicators. This group includes such indicators as — “GRP”, “investments in fixed assets” and “monetary incomes of the population”, all indicators are given per capita. At the same time, this region is characterized by the highest unemployment and extremely low provision of the population with doctors.

The obvious outsiders are the Krasnoyarsk territory — the eighth place, and the Republic of Karelia — the seventh place. At the same time, the Krasnoyarsk Territory took the last place among all the coastal Arctic regions, when assessing such indicators as “retail trade turnover”, “emissions of pollutants into the atmosphere” and “provision of the population with doctors”. Also extremely low values were noted for such economic indicators as “the number of people with incomes below the subsistence minimum” (seventh place) and “per capita monetary incomes of the population” (seventh place). The positions of the Republic of Karelia were also extremely weak –seventh place when assessing such an indicator as “GRP per capita”, eighth place — “investments in fixed assets”, “monetary incomes of the population per capita” — also eighth place, “unemployment rate” — seventh place, “retail trade turnover” — seventh place.

3. Conclusions

Based on the above, a number of conclusions can be drawn:

1. Despite the significant number of scientific articles and monographs devoted to topical issues of regional environmental and economic security , there is a certain gap in the issues of comparative analysis of security between regions.

2. The choice of indicators is a key point in assessing the level of environmental and economic security. On the one hand, each of the selected indicators should reflect the state in a particular area of

economic activity, on the other hand, be representative, that is, objective, and at the same time easy to interpret. At the same time, the simultaneous use of indicators characterizing the environmental and economic components of regional security is an effective method of obtaining consolidated information about the development of the regions.

3. The comparative analysis carried out within the framework of the study showed that among all the territorial systems referred to the coastal Arctic regions, — Nenets, Chukotka and Yamalo-Nenets Autonomous Districts have the highest level of environmental and economic security. Krasnoyarsk Territory and the Republic of Karelia are the outsiders.

REFERENCES

1. Samylovskaya, E., Makhovikov, A., Lutonin, A., et al. (2022). Digital Technologies in Arctic Oil and Gas Resources Extraction: Global Trends and Russian Experience. Resources, 21100808642, 11 DOI: 10.3390/resources11030029.

2. Federal state statistics service. URL: http://www.gks.ru (Access date: 10.02.2022).

3. Govorova, N. V., Zhuravel, V. P., Samylovskaya, E. A. (2018). Russian Arctic: problems of international cooperation, Contemporary Europe-Sovremennaya Evropa, 201(1), 156–159.

4. Matveeva, V. A., Alekseenko, A. V., Karthe, D., et al. (2022). Manganese Pollution in Mining-Influenced Rivers and Lakes: Current State and Forecast under Climate Change in the Russian Arctic, Water (Switzerland), 21100255400, 14 (7), 1091. DOI: 10.3390/w14071091.

5. Dvoynikov, M., Buslaev, G., Kunshin, A., Sidorov, D., Kraslawski, A., & Budovskaya, M. (2021). New Concepts of Hydrogen Production and Storage in Arctic Region. Resources, 10(1), 3. DOI: 10.3390/resources10010003.

6. Romasheva, N., Dmitrieva, D. (2021). Energy resources exploitation in the russian arctic: Challenges and prospects for the sustainable development of the ecosystem. Energies, 62932, 14. DOI: 10.3390/en14248300.

7. Chromcak, J., Farbak, M., Ivannikov, A., Sasik, R., Dibdiakova, J. (2021). Remote Sensing Data Analysis for the Ecological Stability Purposes. IOP Conference Series: Earth and Environmental Science, 906(1), 012068. DOI 10.1088/1755–1315/906/1/012068.

8. Rybak Y., Khayrutdinov M., Kongar-Syuryun C., Tyulyayeva Y. (2021). Resource-saving technologies for development of mineral deposits.Sustainable Development of Mountain Territories, 13(3), 405–415. DOI: 10.21177/1998–4502–2021–13–3-406–415.

9. Selin, V. S. (2012). Economic security and reduction of the uneven spatial development of the Russian North and the Arctic (Apatity: Publishing House of the Kola Scientific Center of the Russian Academy of Sciences), 232.

10. Ulchenko, M., Badylevich, R., Kondratovich, D. (2019) Specific features of ensuring economic security of coastal Arctic regions. IOP Conf. Series: Earth and Environmental Science, 302(1), 012104. DOI:10.1088/1755–1315/302/1/012104.

11. Glazyev, S. Yu. (1997). Basis of economic security of the country: alternative reformation course. Russian journal, 1, 12–18.

12. Samylovskaya, E., Kudryavtseva, R. E., Medvedev, D., et al. (2020). Transformation of the personnel training system for oil and gas projects in the Russian Arctic, Resources, 21100808642, 9(11), 137. DOI: 10.3390/resources9110137.

13. Abalkin, L. I. (1994). Economic security of Russia: threats and their reflection Economic Issues, 12, 4–16.

14. Tatarkin, A. I. (1996) Economic security as an object of regional research. Economic Issues, 6, 79–85.

15. Lisin, E., Rogalev, N., Okley, P. (2019). The impact model of the production capacities structure of the energy system and the regional energy security. Terra Economicus, 17(2), 96–111. DOI: 10.23683/2073–6606–2019–17–2-96–111.

16. Lisin, E., Kurdiukova, G. (2021). Energy Supply System Development Management Mechanisms from the Standpoint of Efficient Use of Energy Resources. IOP Conference Series: Earth and Environmental Science, 666(6), 062090. DOI: 10.1088/1755–1315/666/6/062090.
17. Senchagov, V. K. (2014). Economic security of the regions of Russia (Nizhny Novgorod: Publishing House Nizhny Novgorod State Technical University named after R. E. Alekseev), 254.
18. Decree of the President of the Russian Federation no.296 dated 02.05.2014 «On land territories of the Arctic zone of the Russian Federation». URL: http://www.kremlin.ru/acts/bank/38377 (Access date: 10.02.2022).
19. Decree of the President of the Russian Federation no.287 dated 27.06.2017 «On amendments to the Decree of the President of the Russian Federation dated may 2, 2014 no.296». URL: http://www.kremlin.ru/acts/bank/42021 (Access date: 10.02.2022).
20. Decree of the President of the Russian Federation no.220 dated 13.05.2019 «On amendments to the Decree of the President of the Russian Federation dated may 2, 2014 no.296». URL: http://www.kremlin.ru/acts/bank/44231 (Access date: 10.02.2022) ГИАБ

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КОНЦЕПЦИЯ УПРАВЛЕНИЯ СОЦИО-ЭКОЛОГО-ЭКОНОМИЧЕСКОЙ СИСТЕМОЙ АРКТИЧЕСКОЙ ЗОНЫ НА ОСНОВЕ СТЕЙКХОЛДЕРСКОГО ПОДХОДА

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Аннотация: актуальность исследования определяется необходимостью создания научно обоснованных подходов к управлению социо-эколого-экономической системой Арктической зоны на основе учета и оценки интереса всех заинтересованных сторон. Государственное управления развитием данного региона на основе стейклохолдерского подхода будет способствовать устойчивому развитию данной территории. Более того, существенно повышается продолжительность и качество взаимосвязей всех заинтересованных сторон, что способствует усилению кооперационного взаимодействия на территории в решении социальных, экономических и экологических проблем. Целью исследования является изучение концепции стейкхолдерского подхода к государственному управлению развитием территории и обосновании методов градации и управления различными группами заинтересованных сторон. Задачами проводимого исследования выступают: систематизация теоретических подходов к изучению концепции управления заинтересованными сторонами; уточнение содержания стейкхолдерского подхода в системе государственного управления; обоснование методики картирования стейкхолдеров для выбора оптимальной модели стратегического взаимодействия с ними. Для анализа материала по заявленной проблематике авторы использовали такие методические приемы и инструменты как: методы структурного и системного анализа, ретроспективная оценка и текстмайнинг. Основными результатами исследования являются уточнение концепции стейкхолдерского подхода к управлению социо-эколого-экономической системой Арктической зоны; обоснование целесообразности использования метода картирования для дифференциации и управления стейкхолдерами в целях повышения эффективности принятия стратегических управленческих решений, направленных на гармоничное взаимодействие человека и природы. Научная значимость заключается в расширении теоретических представлений о значимости стейкхолдерского подхода в управлении социо-эколого-экономическими системами. Практическая значимость заключается в формировании методических основ понимания градации заинтересованных сторон и их вовлечения в процессы интеграции экологической составляющей в систему социально-экономических отношений на уровне Арктической зоны.

Ключевые слова: социо-эколого-экономическая система, устойчивое развитие, Арктическая зона, государственное управление, стейкхолдерский подход, метод картирования, стратегические управленческие решения.

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The concept of the socio-environmental and economic system of the Artic zone on the basis of stakeholder approach

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Abstract: The relevance of the study is determined by the need to create science- based approaches to the state management of the socio-environmental and economic system of the Arctic zone based the consideration and assessment of the interests of all stakeholders. The state management of the development of the region employing the stakeholder approach will contribute to the sustainable development of the area. Moreover, the duration and quality of communication of all stakeholders increases significantly, which, in its turn contributes to the cooperative interaction to solve social, economic and environmental problems in the area. The main results of the study are the clarification of the concept of the stakeholder approach in the management of the social, environmental and economic system of the Arctic zone; clarification of the feasibility of applying the method of mapping for differentiation and stakeholder management to improve the efficiency of strategic governmental management decisions aimed at the harmonious interaction between man and nature. The scientific significance lies in the expansion of theoretical knowledge about the importance of the stakeholder approach in the state administration of the solution of social, economic and environmental systems. The practical significance lies in the formation of methodological grounds for understanding the gradation of stakeholders and their involvement in the processes of integration of environmental parameter in the socio-economic relations at the level of the Arctic zone.

Key words: socio-environmental and economic system, sustainable development, Arctic zone, state management, stakeholder approach, method of mapping, strategic management decisions.

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1. Introduction

The object of the study is the stakeholder approach as an effective instrument of state management of the social, environmental and economic system of the Arctic zone.

The issue of multilateral development of Russia's Arctic zone has received increased attention in recent years as state authorities look for ways to combat the negative consequences of the outflow and aging of the population and its natural loss prevailing since the collapse of the USSR.

Due to the length of the Russian Arctic, Russia must diplomatically insist on the role of environmental leader and "vanguard," which will confirm the status of the Arctic country which, more than anyone else understands the scale of threats in the region and bears effective responsibility for its future.

The relevance of the study is due to the lack of integrity and completeness of the fundamental principles and practical mechanisms to provide the effective interaction of natural and anthropogenic components of the Arctic zone. As a result, the divergence of economic, social and environmental vectors of the development of the Arctic territory, s often observed in practice, is the reason for its spontaneity and fragility. Moreover, the rapid development of the strategic interest of foreign countries and national economy in the resources of the Arctic requires the improvement of organizational and managerial mechanisms of interaction between territorial and sectoral authorities, the maximum involvement of all stakeholders with a special emphasis on the key groups of the local community for the sustainable development in the region. The purpose of the research is to study the essence of the stakeholder approach, its role in the effective administration of social, environmental and economic development of the territory and to substantiate the tool of differentiation of all parties involved to choose a balanced model of sustainable development of the Arctic zone.

The objectives of this study are systematization of the theoretical approaches to the study of the essence of social, environmental and economic system and its content in relation to the Arctic zone; clarification of the concept of stakeholders management in the system of administration of social, environmental and economic development of the Arctic zone on the basis of the stakeholder approach; clarification of the feasibility of the mapping method for scaling and selection of a model to interact with stakeholders.

Issues of the content of the socio-environmental-economic system and its transformation, in the light of modern challenges and threats, are considered in the works of Russian and foreign scholars. In their works, they pay much attention to the organizational and managerial mechanisms of interaction between man and nature.

American researchers define environmental quality as a set of peculiar properties and characteristics of epy general or local plan in terms of their impact on people and other living beings, as well as in terms of compliance with human needs or goals of life [4, 5, 8]. According to the interpretation of the European Environment Agency, the condition of the environment in urbanized areas can be defined by various characteristics related to the natural and artificial environment, as well as its possible impact on the physical and mental health of individuals and the results of human activity [1].

A significant contribution to the development of a new conceptual ideology of socio-environmental and economic management of territories belongs to the Los Angeles School of Urbanism [17]. Unlike the Chicago School, which embodies the concept of classical urbanism, its representatives emphasized the polycentricity of the territory. At the same time, the emphasis is placed on the processes of de-industrialization and re-industrialization. The study conducted by the authors of the article showed that the concept of sustainable development for several decades has been the dominant modern approach to the management of territorial socio-environmental and economic systems of different levels. The authors of the article agree with the views of F. Berkes, K. Folke and J. Kolding, who consider sustainable development as a process contributing to the satisfaction of human needs and improvement of their quality of life, allowing ecosystems to be preserved and renewed [2, 25]. It is necessary to note the views of D. McLaren and J. Agyeman, who consider sustainable development as a hierarchy of elements of the habitat, including nature, society and economic relations that do not threaten the environment [18]. Among the works of Russian scientists, it is worth noting the works of O. S. Pchelintsev. He interprets sustainable territorial development as the system management of socio-demographic, environmental and economic processes occurring within the boundaries of the territory [16].

In this context, the views of M. Jenks and M. Dempsey deserve attention, who interpret socio-environmental and economic development as the pursuit to improve quality of life, including positive dynamics of environmental, cultural, political, institutional, social and economic components, not accompanied by negative consequences for future generations [6].

In general, summarizing the positions of domestic and foreign scholars in the management of the socio-environmental and economic system of the territory, it should be noted that this approach to territorial development contributes to the formation of opportunities for reaching a qualitatively new level of socio-economic, demographic and technological development. At the same time, in relation to the territory of the Arctic zone, there is a great diversity of participants in the socio-environmental and economic system, as well as the diversity of their versatile and mutually beneficial interests [7]. This circumstance requires a scientific rethinking of the concept of management of the socio-environmental-economic system of the Arctic zone on principles of the stakeholder approach.

The term "stakeholder" emerged in the 1960-s in management, and the stakeholder approach was proposed by the American economist Edward Freeman in 1984 [15] and became widespread already in the 1990s. In the studies of of L. Vuorinen M. Martinsuo stakeholders (in English stakeholder is a person having interest in...) are defined as "groups without whose support the organization will cease to exist" [28].

J. Hörisch., S. Schaltegger, R. E. Freeman, Å. Knaggård., D. Slunge, A. Ekbom, M. Göthberg, U. Sahlin, M. C. Pucheta-Martínez, I. Bel-Oms, L. L. Rodrigues [10, 13, 19, 22] deal with the classification of stakeholder classification and study their role in different spheres.

Moreover, A. Vallet, B. Locatelli, H. Levrel, C. Barnaud, Y. Q. Conde developed models to identify the significance of interested organizations [27], the concept of balancing the requirements of various stakeholders with the interests of the organization are considered in the works of R. Volk , R. Müller, J. Reinhardt, F. Schultmann [28]. M. Shahzad, Y. Qu, A. U. Zafar, X. Ding , S. U. Rehman . study the coordination of interests and interactions between the key participants of the decision-making process in environmental policy [23, 26]. J. Jiao, C. Liu, Y. Xu consider the stakeholder theories as applied to a company or firm [11]. In the study [25], in order to create favorable conditions for improving the socio-ecological and economic situation, the authors propose the mandatory introduction of cyclic closed production and resource-saving technologies. At the same time, the relevant terminology also penetrates into public administration, for example, in the form of the concept of "Open government" [30]. And also in higher education, in the system of training specialist managers [26].

Currently, according to the stakeholder approach, there are six groups of stakeholders: company owners, shareholders, investors, board of directors; government agencies; employees; customers, consumers; non-profit organizations, activist groups, social movements, social media, and local communities.

Thus, there are several definitions and approaches to the concept of stakeholders. Summarizing them, the following definition can be considered the most sound: stakeholders are persons, institutions, organizations, formal and informal groups whose interests may be affected and (or) can influence the decisions and actions of the company. Theoretical, methodological and applied aspects of the problem of managing the socio-environmental -economic system of the Arctic zone, studied by the above authors, do not cover all the stages of this process, in particular, the features of socio-environmental- economic interaction on the basis of the stakeholder approach. This determines the need to develop a concept for the management of the socio-environmental-economic system of the Arctic zone, taking into account the diversity of stakeholders and their participation in the management of sustainable development of the territory.

2. Materials and Methods

The work uses the methods of structural and system analysis to study the essence of the stakeholder approach in the management of socio-environmental-economic systems. The retrospective assessment and textual analysis of domestic and foreign experience in studying the essence of socio-environmental-economic system made it possible to define its content in relation to the Arctic zone and propose the concept of the stakeholder approach which allows to differentiate the interests of the parties and choose the most effective strategy of interaction for sustainable development of the region.

3. Results

For a long time, the priority of state management in the territory of the Arctic zone has been an economically oriented approach to addressing key issues, which does not often take into consideration the specifics of the interaction between man and nature in the territory. These circumstances reinforce, and practically directly create the negative impact of a set of factors determining unsustainable trends in the development of the socio-environmental-economic system of the Arctic zone.

The study presents the Arctic zone as a set of interdependent relationships, which find their manifestation in the socio-environmental-economic geosystem and are formed under the influence of its constituent elements, which are directly dependant on each other.

Any territorial socio-environmental-economic system should be studied immanently in the framework of its interaction with various elements forming the environment of the system [14, 21]. In this context, the Arctic zone is formed as socio-environmental-economic system, which is an interdependent set of territory and a set of economic, environmental and social factors that directly determine the direction of its development processes.

It is necessary to point out the following main contradictions that determine the current environmental problems of the Arctic zone:

1) between the development goals of an area and the growing g scarcity of natural resources

2) between the increasing impact on the environment and limited technologies for studying natural processes

3) between the inadequate reflection in the public consciousness of the problems of human relations with the environment and the possibilities of innovative approaches to reforming the above relations.

The set of environmental problems is reflected in the strategic documents on the planning of socio-economic development, which highlight the negative factors slowing down the advancement of the Arctic zone towards achieving sustainable development goals. At that the same time, these problems, on the one hand, are mainly conditioned by the peculiarities of the modern spatial development of the Arctic zone, and on the other hand, they themselves form a set of obstacles that limit this development. In our opinion, this is due to the lack of management culture and the low priority of environmental objectives in the work if public authorities, which prevents timely identification and prompt response to from the needs of the residents of the Arctic zone to ensure their environmental well-being. The Arctic zone is an open system, and its forming elements are characterized by the presence of internal and external interrelations reflected in the movement of energy, substance and information flows [20, 24]. To ensure the normal functioning and development of the Arctic zone, external resources of various origin are needed. At the same time, the result of the sustainable systemic functioning of the territory is the material and spiritual benefits, as well as the accompanying production waste polluting the environment, which in its turn allow to define the systemic elements that create the socio-environmental and economic system of the Arctic zone. The concept of managing the development of the socio-environmental-economic system of the Arctic zone is shown in Fig. 1.

According to the authors of this study, it is advisable to include the concept of stakeholder management in the most promising approaches, aimed at achieving the goals of sustainable development of the Arctic zone.

An important socio-environmental-economic goal of the stakeholder approach is taking into account mutual interests and implementing joint management actions that allow solving social and environmental problems of the Arctic zone and meeting the needs of the economic sphere. The mechanism of the stakeholder approach is in good agreement with the provisions of the concept of sustainable development .

The stakeholder management methodology provides for the use of various forms of citizen involvement in the management of the territory development, including their participation in the selection of priority investment projects, regional competitions and grants, public hearings, and in the work of public councils in order to use the potential of actors to achieve results [3, 9, 12, 29].

The need to take into account the interests is due in accordance with the conflict nature of development, which is characteristic of network structures of different levels, including regions. The number of actors interested in the socio-economic development of the territory,

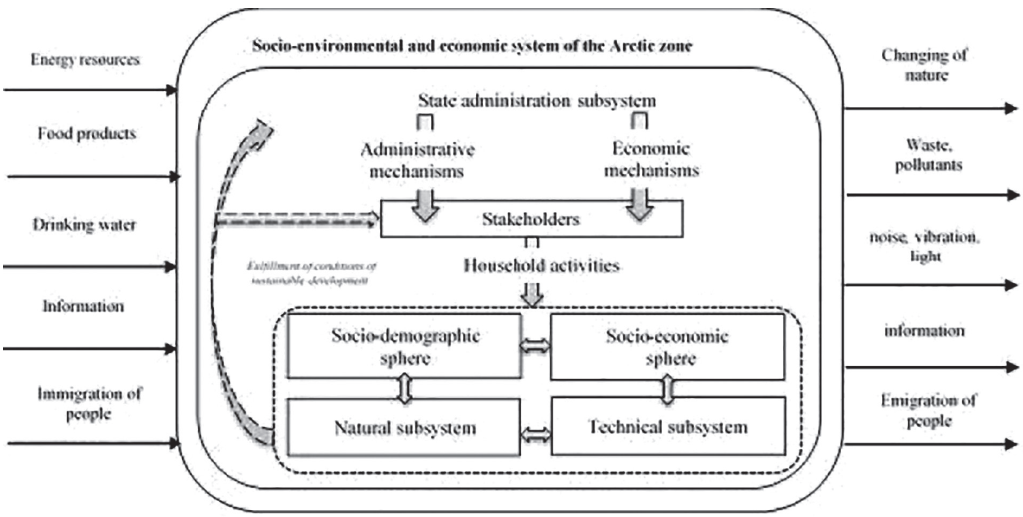

Fig. 1. The concept of managing the development of socio-environmental and economic system of the Arctic zone (supplemented by the authors)

in addition to the authoritiesof the federal and regional levels, includes the population and business structuress that own economic zones in different regions.

The content of the stakeholder approach to managing the socio-environmental and economic system of the Arctic zone is shown in Fig. 2.

Thus, the management of the socio-environmental and economic system of the Arctic zone should be formed and implemented in the course of interaction and cooperation among the main stakeholders including representatives of regional and federal authorities, experts, scientific researchers, representatives of civil society and business structures.

The mechanism of extended partnership of all stakeholders makes it possible to increase their social and environmental responsibility in the Arctic. Harmonizing the interests stakeholder

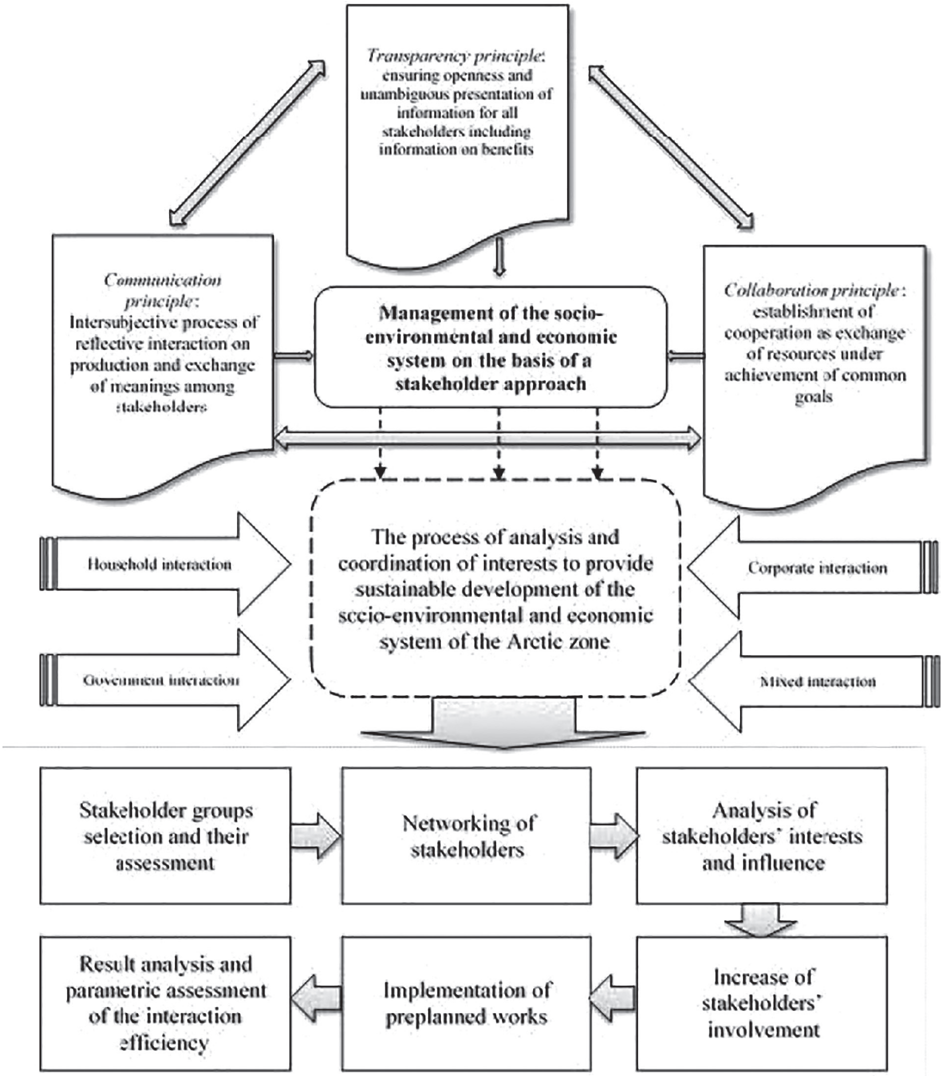

Fig. 2. The concept of the stakeholder approach to managing the the socio-environmental and economic system of the Arctic zone (supplemented by the authors)

requires the formation of a common vision of the prospects for sustainable development of the Arctic zone and mechanisms of its achievement. The Arctic combines complex structural ties of economic elements, which interact with the environment to solve internal social, environmental and economic problems, satisfying the needs of the subjects of socio-environmental-economic system. However, under the conditions of limited resources within the socio-environmental--economic system, there is inevitably a conflict of interests of its constituent stakeholders, which leads to a violation of sustainability. In this regard, an important task of management in the socio-environmental-economic system is the analysis of conflict situations and reconciliation of the interests of stakeholders to achieve common goals. In the opinion of the authors of the study, it is reasonable to distinguish two main types of interests in the socio-environmental-economic system: the system of mutual interests of business and government, the system of mutual interests of business and society. The mechanisms of interaction of the key elements of the socio-environmental-economic system of the Arctic zone in the context of their mutual interests are shown in Fig. 3.

Coordination of interests of business structures, population and authorities

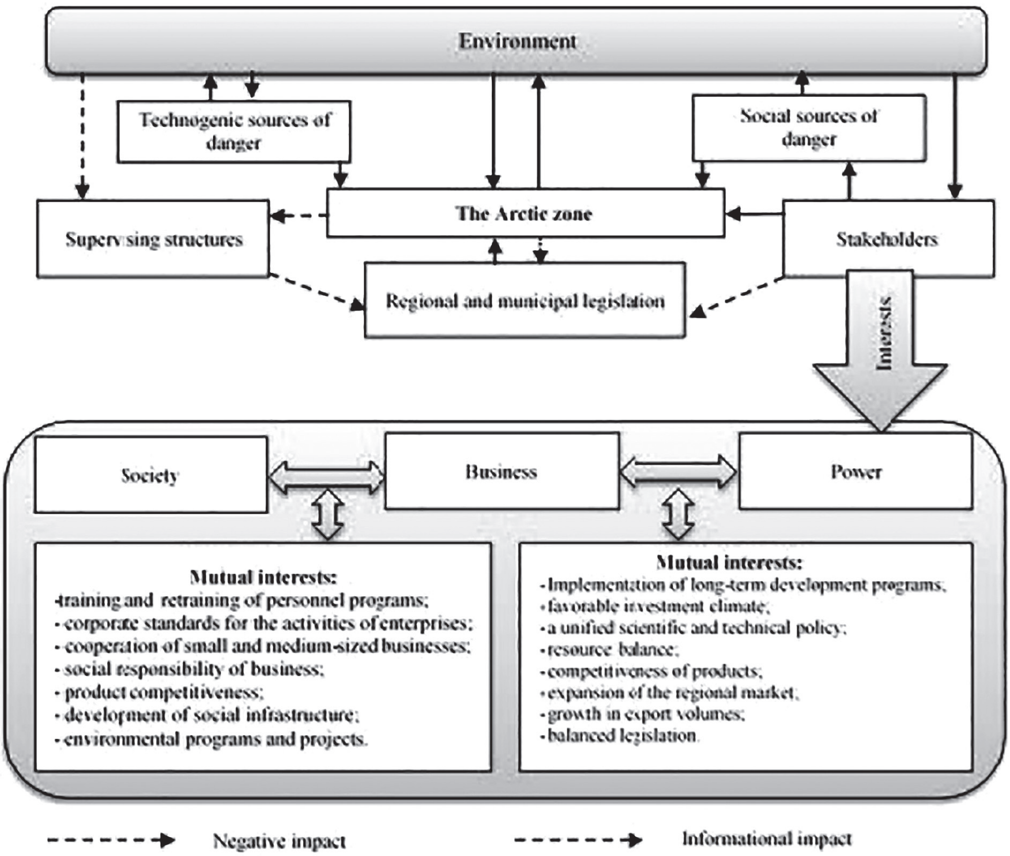

Fig. 3. Mechanisms of the key elements interaction in socio-environmental and economic system of the Arctic zone in the context of their mutual interests (supplemented by the authors)

allows to develop socio-economic space of subjects of the Federation in three directions: as an economic zone, as a living environment and as an object of state management. The interests of the population, which is the most numerous and therefore the most important group of stakeholders, are based on the ability to meet vital needs, including physiological needs, comfort and sf of habitat, level of employment, attractiveness of the from the position of personal self-development.

The territory of the Arctic zone is the region with diverse and diversified groups of stakeholders.

Given the intensified involvement of various stakeholders in the process of developing directions for the socio-economic development of the territory, they include: control, supervision, regulation bodies; founders, shareholders, investors, lending institutions, business partners, expert community, local communities.

Among the most frequently used methods for positioning stakeholders are the models of O. Mendelow, Mitchell-Egle-Wood, G. Savage, and the RACI table.

According to the authors of the study from the scientific and practical points of view, the mapping method of determining the stakeholders of the territories' development is of great interest. This method is of major interest due to the fact that in the socio-environmental economic system of the Arctic zone for sustainable development, a large number of stakeholders function not only with common interests, but also with completely polar ones. The method of mapping makes it possible to identify the most significant groups for the sustainable development of the Arctic zone. The essence of this method is in the gradation of stakeholders into four groups according to the degree of influence and interest, each of which occupies one place on the four-dimensional map (Fig. 4).

According to the position of this method four groups of stakeholders can be distinguished:

– Promoters – the group of stakeholders located in the top segment of the map is the most important for strategic state administration. Promoters have a strong interest in administrative decisions of government bodies and can help make them more effective. Regarding the socio-environmental and economic system of the Arctic zone, it is advisable to include such groups as: the owners, shareholders of the company, investors, the board of directors; government agencies; employees.

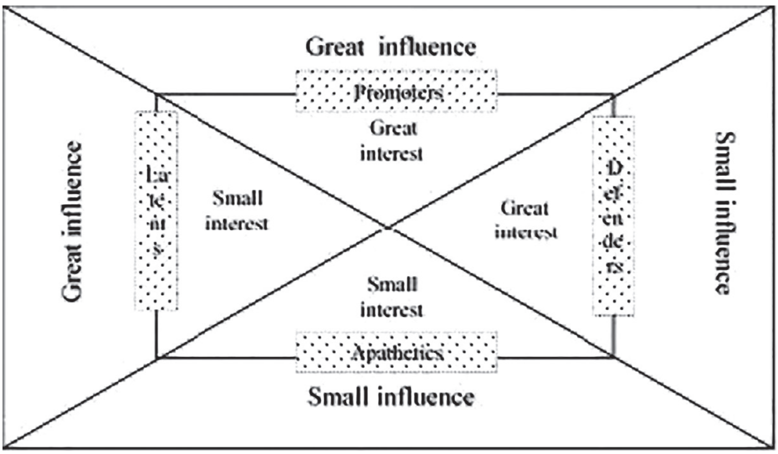

Fig. 4. Map of stakeholders (supplemented by the authors)

– Apathetics — the group of stakeholders placed in the lower segment of the map is the least significant in the system of state administration. The apathetics show little interest and potential, they may not even be aware of the existence of management decision or measure to implementate it. Regarding the socio-environmental and economic system of the Arctic zone, it is advisable to include such groups as: non-profit organizations, activist groups, public movements, the media.

– Advocates are a group of stakeholders placed in the right-hand segment of the map. The advocates have a vested interest and can support state authorities, but have no real potential (resources and capabilities) to influence any managerial decision. Regarding the socio-environmental and economic system of the Arctic zone, it is advisable to include such groups as: the owners, shareholders of the company, investors, board of directors; buyers, consumers; local communities.

– Latents are a group of stakeholders placed in the left-hand segment of the map. The latents have no particular interest and do not participate in decision-making, but can strongly influence them if they become interested. When applied to the socio-environmental and economic system of the Arctic zone, it is advisable to include such groups as buyers and consumers.

In practice, to implement this approach, it is advisable to use the method of expert assessment with the involvement of qualified experts — subjects of the Arctic zone. The level of the total score will form the rating of each stakeholder, determine the degree of their interest and influence on the processes of management of the socio-environmental-economic development of the Arctic zone.

From the perspective of managing the socio-environmental- -economic system of the Arctic zone, the role of mapping is that the most important stakeholders are those who have suffered the most, those who have least implemented their interests. From this perspective, it does not matter which group the stakeholders belong to, even if they were in the apathetic group before the start of the interests alignment. They are distinguished by their appreciation of the authorities' managerial decisions that affect the conditions of their activities in the Arctic zone. If their attitude to the authorities is positive and they can really make efforts to solve strategic state tasks and can invest in solving socio-economic problems of the Arctic zone, then they should be involved, creating favorable conditions. In turn, public authorities should involve these groups in the strategic planning process, which will be considered by all parties as a significant contribution to the overall efforts. They should feel responsibility for some of the strategic decisions of state authorities. It is also very important to pay attention to the views of stakeholders and agree with them where it is in the common interest.

Given the currentconditions for the development of the Arctic zone, the most significant goal of state authorities should be to bring together the importance and influence of all stakeholder groups that can contribute to the creation of creation of a comprehensive plan for the socio-environmental and economic development of the territory. The most influential groups should ensure the involvement of other groups in the planning process, ensure the collection and analysis of sound opinions, proposals, problems, and initiate the development of a legal and regulatory framework to create a favorable environment for interaction. Passive and less influential parties should see themselves as part of socio-environmental and economic environment, see their opportunities and needs, boost their position while developing strategic government decisions and their further implementation.

4. Conclusion

The model presented will contribute into the increase of fundamental knowledge in the sphere of improving the efficiency of management of socio-environmental and economic development of the Arctic zone, taking into consideration the characteristics of the territory, the interests of state authority bodies and stakeholders, will ensure the development of existing approaches to modeling organizational and managerial processes in the system of public administration. Scientific results of the study are aimed at achieving the most important state goals, solvig urgent issues of the socio-environmental and economic development of the territory, formation of needed infrastructure of innovation optimizing the balance of interests of state authorities and stakeholders.

The result of the study is the possibility of practical application of mechanisms of state management of socio-environmental and economic development of the Arctic zone, models of public-private partnership based on regulation of the distribution of effects between stakeholders that meet geopolitical, strategic and environmental interests in this territory, goals and objectives for the development of the North, preservation of its originality and uniqueness.

REFERENCES

1. Aarts, N., Drenthen, M. (2020). Socio-environmental interactions and sustainable development — introduction to a special. Sustainability (Switzerland), 12(17), 6967. DOI:10.3390/su12176967.

2. Allen, C., Metternicht, G., Verburg. P, Inacio da C. M.,Sanchez, S. M. (2020). Delivering an enabling environment and multiple benefits for land degradation neutrality: Stakeholder perceptions and progress. Environmental Science and Policy, 114, 09–118. DOI:10.2478/euco-2019–0035.

3. Belokon, A. I. (2018). The analysis of the significance of the stakeholders of the project. Bulletin of DABA, 2, 239–240.

4. Buslaev, G., Tsvetkov, P., Lavrik, A., et al. (2021). Ensuring the sustainability of arctic industrial facilities under conditions of global climate change. Resources, 21100808642, 10(12), 1–15. DOI: 10.3390/resources10120128.

5. Cherepovitsyn, A. E., Tsvetkov, P. S., Evseeva, O. O. (2021). Critical analysis of methodological approaches to assessing sustainability of arctic oil and gas projects. *Journal of Mining Institute*, 24113336, 249, 463–478. DOI: 10.31897/PMI.2021.3.15.

6. Das, M., Das, A., Seikh, S., Pandey, R. (2021). Nexus between indigenous ecological knowledge and ecosystem services: a socio-environmental analysis for sustainable ecosystem management. Environmental Science and Pollution Research. DOI: 10.1007/s11356–021–15605–8.

7. Dmitrieva, D., Cherepovitsyna, A., Stroykov, G., et al. (2022). Strategic sustainability of offshore arctic oil and gas projects: Definition, principles, and conceptual framework. Journal of Marine Science and Engineering, 21100830140, 10(23), 1–24. DOI: 10.3390/jmse10010023.

8. Dragicevic, A. Z., Shogren, J. F. (2021). Preservation Value in Socio-Ecological Systems. Ecological Modelling, 443, 09451. DOI: 10.1016/j.ecolmodel.2021.109451.

9. Grill, C. (2021). Involving stakeholders in research priority setting a scoping review. Research Involvement and Engagement, 7(1), 75. DOI: 10.1186/s40900–021–00318–6.

10. Hörisch, J. (2020). Integrating stakeholder theory and sustainability accounting A conceptual synthesis. Journal of Cleaner Production, 275, 124097. DOI:10.1016/j.jclepro.2020.124097.

11. Jiao, J. (2020). Effects of stakeholder pressure, managerial perceptions, and resource availability on sustainable operations adoption. Business Strategy and the Environment, 29(8), 3246–3260. DOI:10.1002/bse.2569.

12. Kienko, E. V. (2021). Legal Basis for Cooperation between the People's Republic of China and the Arctic States in the Development of Arctic Subsoil. *MIAB. Mining Inf. Anal. Bull.*, 3(1), 199–213. DOI: 10.25018/0236_1493_2021_31_0_199.

13. Knaggård, Å. (2019). Researchers' approaches to stakeholders: Interaction or transfer of knowledge. Environmental Science and Policy, 97, 25–35. DOI: 10.1016/j.envsci.2019.03.008.

14. Kolesnikova L. A., Kovalchuk T. V. Problems and prospects of environmental safety of mining regions. *MIAB. Mining Inf. Anal. Bull.* 2021;(2—1):275–286. [In Russ]. DOI: 10.25018/0236-1493-2021-21-0-275-286.

15. Laur, I., Danilovic, M. (2020). Enabling change within new forms of organisations: an empirical investigation of change patterns and stakeholder influence on core intermediary activities. Journal of Organizational Change Management, 33(6), 1041–1070. DOI: 10.1108/JOCM-01–2020–0026.

16. Lyubovny, V. Y., Pchelintsev, O. S. (2017). Other Crisis cities in Russia ways and mechanisms of socio-economic rehabilitation and development. Regionologiya, 3, 31.

17. Martínez-Fernández, J. (2021). An integral approach to address socio-ecological systems sustainability and their uncertainties. Science of the Total Environment, 762, 144457. DOI:10.1016/j.scitotenv.2020.144457.

18. McLaren, D., Agyeman, J. (2017). Sharing Cities A Case for Truly Smart and Sustainable Cities. New Political Science, 39(3), 1–3. DOI:10.1080/07393148.2017.1339416.

19. Pucheta-Martínez, M. C. (2020). Does stakeholder engagement encourage environmental reporting? The mediating role of firm performance. Business Strategy and the Environment, 29(4), 3025–3037. DOI:10.1002/bse.2416.

20. Romasheva, N., Dmitrieva, D. (2021). Energy resources exploitation in the russian arctic: Challenges and prospects for the sustainable development of the ecosystem, Energies, 14(24), 8300. DOI: 10.3390/en14248300.

21. Rybak, Y., Khayrutdinov, M., Kongar-Syuryun, C., Tyulyayeva, Y. (2021). Resource-saving technologies for development of mineral deposits. Sustainable Development of Mountain Territories, 13(3), 405–415. DOI: 10.21177/1998–4502–2021–13–3-406–415.

22. Rybak, J., Ivannikov, A., Egorova, A., Ohotnikova, K., Fernandes, I. (2017). Some remarks on experience based geotechnical education. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 17(12), 1003–1012. DOI: 10.5593/sgem2017/12/S02.127.

23. Samylovskaya, E., Kudryavtseva, R. E., Medvedev, D., et al. (2020). Transformation of the personnel training system for oil and gas projects in the Russian Arctic, Resources, 21100808642, 9, 1–20. DOI: 10.3390/resources9110137.

24. Samylovskaya, E., Makhovikov, A., Lutonin, A., et al. (2022). Digital Technologies in Arctic Oil and Gas Resources Extraction: Global Trends and Russian Experience, Resources,21100808642, 11. DOI: 10.3390/resources11030029.

25. Shadyzheva, S. B. (2021). Development of theoretical foundations of the concept of sustainable development and its models. *MIAB. Mining Inf. Anal. Bull.*, S15, 3–14. DOI: 10.25018/0236_1493_2021_10_15_3.

26. Shahzad, M. (2020). Translating stakeholders' pressure into environmental practices — The mediating role of knowledge management. Journal of Cleaner Production, 275 124163. DOI: 10.1016/j.jclepro.2020.124163.

27. Vallet, A. (2019). Linking equity, power, and stakeholders' roles in relation to ecosystem services. Ecology and Society, 24(2), 14. DOI: 10.5751/ES-10904–240214.

28. Volk, R. (2019). An Integrated Material Flows, Stakeholders and Policies Approach to Identify and Exploit Regional Resource Potentials. Ecological Economics, 161, 292–320. DOI: 10.1016/j.ecolecon.2019.03.020.

29. Vuorinen, L., Martinsuo, M. (2019). Value-oriented stakeholder influence on infrastructure projects. International Journal of Project Management, 37(5), 750–766. DOI: 10.1016/j.ijproman.2018.10.003.

30. Williamson, V., Eisen, N. (2016). The impact of Open Government: Assessing the evidence Center for Effective Public Management at Brookings Washington DC U. S. ГИАБ

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ТЕХНОЛОГИЧЕСКАЯ УСТОЙЧИВОСТЬ КАК ОСНОВА УСТОЙЧИВОГО ПРОМЫШЛЕННОГО РАЗВИТИЯ РЕГИОНОВ АРКТИКИ

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Аннотация: рассмотрены различные виды устойчивости и соответствующие им определения. Целью статьи является рассмотрение новых понятий «технологическая устойчивость» и «устойчивое технологическое развитие», возможности достижения производственными системами такого состояния развития и оценка влияния технологической устойчивости производства в условиях перехода мировой экономики на концепцию развития «Индустрия 4.0» на экономическую, экологическую и социальную устойчивость развития экономических систем разного уровня, в том числе арктических регионов России. Исследование базируется на введенном в научный оборот понятии жизненного цикла технологического развития производственных систем (производственных фирм и отраслей производства), состоящем из шести стадий, где каждая стадия показывает изменение значений во времени (увеличение либо уменьшение) показателей материалоотдачи, фондоотдачи и самое важное — коэффициента уровня технологичности производства как отношения материалоотдачи к фондоотдаче. Устойчивое технологическое развитие производственных систем обеспечивается лишь на одной стадий из шести возможных, когда одновременно увеличиваются значения материалоотдачи, фондоотдачи и коэффициента уровня технологичности производства. В результате за счет существенного повышения уровня материалоотдачи, а значит снижения уровня материалоемкости, при внедрении технологических инноваций снижается расход сырья , материалов и энергии на единицу выпускаемой продукции и тем самым снижается воздействие производства на природную среду, в том числе и за счет уменьшения объема отходов производства, то есть обеспечивается экологическая устойчивость. Рассмотренные теоретико-методологические положения были использованы для оценки устойчивости промышленного технологического развития четырех регионов — субъектов Федерации, полностью входящих в Арктическую зону РФ, за период 2005—2016 гг.

Ключевые слова: технологтческая устойчивость, устойчивое промышленное развитие, регионы Арктики, жизненный цикл технологического развития.

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Technological sustainability as a basis for sustainable industrial development of the Arctic regions

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Abstract: Various types of stability and their corresponding definitions are considered in the literature. The purpose of the article is to consider the new concepts of "technological sustainability" and "sustainable technological development", the possibility of achieving such a state of development by production systems and to assess the impact of technological sustainability of production in the context of the transition of the world economy to the concept of development "Industry 4.0" on the economic, environmental and social sustainability of the development of economic systems of various levels, including the Arctic regions of Russia. The research is based on the concept of the life cycle of technological development of production systems (manufacturing firms and industries) introduced into scientific circulation, consisting of six stages, where each stage shows a change in values over time (increase or decrease) in material productivity, capital productivity and, most importantly, the coefficient of the level of manufacturability of production as the ratio of material productivity to capital productivity. The sustainable technological development of production systems is ensured only at one stage out of six possible, when the values of material productivity, capital productivity and the coefficient of the level of manufacturability of production simultaneously increase. As a result, due to a significant increase in the level of material output, which means a decrease in the level of material consumption, the introduction of technological innovations reduces the consumption of raw materials, materials and energy per unit of output and thereby reduces the impact of production on the natural environment, including by reducing the volume of production waste, that is, environmental sustainability is ensured. The theoretical and methodological provisions considered were used to assess the sustainability of the industrial technological development of four regions — subjects of the Federation, which are completely included in the Arctic zone of the Russian Federation, for the period 2005—2016.

Key words: technological sustainability, sustainable industrial development, Arctic regions, the life cycle of technological development.

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1. Introduction

Modern scientific ideas about the sustainability of economic systems since 1987, that is, after the report to the UN General Assembly of the World Commission on Environment and Development under the leadership of Norwegian Prime Minister G. H. Brundlandt [1], have undergone significant changes and are now shifting their view from environmental protection to the triad of sustainability assessment: environmental, economic and social [2—4]. Currently, most scientists recognize that innovation is needed for the sustainable development of such systems, the development of an intelligent person, and the state [5,6,7].

Accordingly, when implementing the "Industry 4.0" development concept in the world economy, attention is being increased to assessing the impact of technological aspects of the IV Industrial Revolution from various positions — environmental, economic and social [8,9], that is, the task is to assess the sustainability of economic systems using technological innovations, digitalization of the economy and the introduction of artificial intelligence elements into production management systems [10—12].

At the same time, the results of scientific research on the assessment of the impact on the stability of the life cycle of systems are actively published in modern foreign literature [13], however, these results are still diverse and fragmentary. The most developed studies are on the environmental assessment of the life cycle [14, 15] and, to a certain extent, the assessment of the cost of life products (goods) [16]. There are very few results of research on the life cycle of processes, primarily technological ones [17,18]. In this regard, the research of S-curves has been significantly developed [19,20], in the study of which, in relation to changes in production technologies at the level of an individual firm, Prof. K. Christensen made a significant contribution [21]. However, research in this direction is primarily related to changes in the effectiveness (productivity) of technologies over time and does not determine the relationship of changes in production costs with changes in the stages of production technology.

In the last decade, foreign literature has also been actively discussing, but mainly at the theoretical level, issues related to the development of various business models, including those related to the use of technological innovations [22], however, the assessment of the sustainability of enterprises is not considered. Also recently, the mutual influence of technological, managerial and marketing innovations has been discussed [23] from the point of view of assessing the possible increase in the efficiency of firms in various sectors of the economy. However, as a rule, conclusions are based on the results of processing a variety of data using correlation analysis methods and are not related to the stability of firms. At the same time, specific indicators of innovation performance have not yet been determined, the values of which clearly show a connection with the sustainability of firms [24].

The purpose of the article is to consider the new concepts of "technological sustainability" and "sustainable technological development", the possibility of achieving such a state of development by production systems (enterprises and industries) and to assess the impact of technological sustainability of production in the context of the transition of the world economy to the concept of development "Industry 4.0" on the economic, environmental and social sustainability of the development of economic systems of different levels.

2. Materials and methods

When considering the economic development of the country and regions, the determining factor is the achievement of a state of economic stability, but at the same time, in order to ensure the maximum possible rates of economic growth, it is necessary to achieve maximum efficiency in the use of basic production resources — material, labor and physical capital (fixed assets). In economic theory, at the macroeconomic level, this is well demonstrated by the curve of production capabilities, which is the boundary of achieving such a state. However, it is possible only with the use of the most efficient production technologies. Accordingly, the question arises — how is the use of production technologies directly related to the efficiency of the use of production resources at the micro level, that is, at the enterprises level?

From the point of view of the theory of the development of complex systems and the consideration of their life cycle, stability is ensured only at certain stages of the life cycle curve and, above all, at the stage of quantitative accumulation of elements in the system, that is, at the stage of growth, until the moment when negative external and internal conditions of the development of the system lead it to a state of instability and then to the point of bifurcation characterizing revolutionary changes in the system.

Any technology used in the production of goods can also be considered as a system from the point of view of its development, that is, its introduction into production, improvement, obsolescence and subsequent replacement with a new technology. However, it is not clear how these stages are directly related to the efficiency of the use of production resources and how to determine this efficiency when using production resources together?

We have developed the foundations of a new type of economic analysis of the activity of production systems — the analysis of their technological renewal, where it is shown that there is a proportional analytical dependence between the capital intensity of production and its material intensity [25]. Such dependence as a measure of proportionality is quantitatively expressed by the coefficient of the production manufacturability level (Cpml), since the increase in its value is directly determined by the degree of renewal of the main production assets of the enterprise, and above all their active part, that is, machinery, equipment and vehicles. Quantitatively Cpml is calculated by the ratio of the value of the capital intensiveness of production to the material intensity of products or by the ratio of the value of material efficiency to the efficiency of capital. As a result of a joint study of changes in the values of material intensity and capital productivity (as the inverse of the value of capital intensity) and the corresponding change in the values of Cpml the example of the activities of many industrial enterprises over a long fifteen-year period of time, we have developed a matrix of possible directions of their development, and based on it — a graphical model of the life cycle of technological development of production systems (enterprises and industries) in the form of a curve, which in appearance corresponds to the schedule of development of any system [26]. The resulting curve shows the change in the level of material output values as the inverse of the material intensity, depending on the degree of renewal of fixed assets and the corresponding changes in the values of the level of capital output and the coefficient of the level of manufacturability of production. Thus, this curve directly shows the influence of the level of novelty of the technology used simultaneously on the economic efficiency of using all three main types of production resources, since it is known that the increase in the level of capital return is an intensive factor in increasing the level of labor productivity.

3. Results and discussion

The curve of the life cycle of technological development of production shows that, firstly, the technology used makes it possible to increase the value of material output, that is, to reduce the material intensity of production, only to a certain level, even with its improvement, and this level can be calculated for each specific enterprise based on the analysis of its reporting data. Secondly, one full cycle of technology development includes six stages, in which at three stages the values of material return, capital return and the coefficient of the level of manufacturability of production increase, and at the other three decrease, and only at one stage the values of all three indicators increase simultaneously. Thus, only at this single stage of technology development, the maximum possible efficiency of the use of material, labor resources and physical capital is achieved, and therefore the maximum possible increase in profit from each unit of manufactured and sold products. Accordingly, the technological development of production systems at this stage, which corresponds to the concept of “technological stability”, ensures their economic stability, but not only it.

The fact is that, firstly, with the improvement of technology, a decrease in the material intensity of production due to an increase in material output leads to a decrease in the volume of production waste, and the introduction of a new technology will allow the use of previously accumulated production waste, that is, the environmental sustainability of production is ensured. Secondly, due to the maximization of the level of capital return due to the intensive renewal of fixed assets, the level of labor productivity will significantly increase, and hence the level of average wages at enterprises and in production sectors. If at the same time, at enterprises due to the active use of technological innovations, the growth rate of the average salary will exceed the average industry rate or the average for the country as a whole, then it becomes possible to use part of the salary fund to form a guaranteed income fund to pay the personnel of enterprises released as a result of productivity growth or for other social activities. Accordingly, social sustainability will be ensured at the enterprises.

Thus, when production systems achieve technological sustainability, economic, environmental and social sustainability will be ensured at the same time, which will correspond to the concept of "sustainable technological development". It is very important to keep in mind that with this type of development of production systems, the main economic interests of enterprises, regions-subjects of the Federation and the state are combined, since a decrease in the level of material intensity of production simultaneously leads to an increase in the profit of enterprises per unit of sales volume, as well as to an increase in the share of value added in this volume, which means that the growth of the gross regional product (GRP) of the regions-subjects of the Federation and the growth of the gross domestic product (GDP) of the country is ensured. At the same time, the regions and the country receive additional amounts of tax deductions, therefore they should be interested in accelerating the technological renewal of production systems, therefore they should create the necessary preferences for enterprises and manufacturing industries, primarily in the formation of an effective system for stimulating innovation.

The above theoretical provisions were used to assess the sustainability of the technological industrial development of the four Arctic regions — the subjects of the Federation, which are completely included in the Arctic zone of the Russian Federation, for the period 2005—2006 (table 1).

The calculated data given in the table show that in all regions the production of electricity, gas and water has been developing more technologically steadily, but the maximum efficiency of using resources (development stage 1—1): material, labor and physical capital (fixed assets) was achieved in each region only in certain years.

Mining has been developing relatively technologically steadily (with a lower level of resource efficiency) in all regions.

Accordingly, of the three types of industrial activity, the most problematic situation with the sustainability of technological development has developed in the processing industry, especially in the Nenets National District and in the Murmansk Region, where in the analyzed period of time the values of the coefficient of the level of manufacturability of production had a tendency to decrease.

Conclusions

For the sustainable development of economic systems, innovations are necessary, primarily technological ones, but their specific impact on the achievement of economic, environmental

Table 1

Parameters for assessing the sustainability of technological development of the Arctic regions by types of industrial activity[a]

Regions	Indica-tors	2005	2010	2011	2012	2013	2014	2015	2016
Nenets Autonomous Okrug									
Mining	MI	0,207	0,253	0,286	0,330	0,282	0,272	0,268	0,183
	EC	0,986	0,590	0,595	0,509	0,493	0,455	0,418	0,346
	Cpml	4,90	6,69	5,87	5,95	7,19	8,07	8,91	15,79
	No		4 – 2	3	4 – 2	2	2	2	2
Processing	MI	0,611	0,746	0,610	0,592	0,524	0,905	0,947	0,966
	EC	2,654	4,212	3,050	3,455	1,889	10,670	19771	40,073
	Cpml	0,61	0,32	0,54	0,49	1,01	0,10	0,05	0,03
	No		3	2	1 – 2	2	3	3	3
Electricity, gas and water production	MI	0,195	0,224	Н.д	0,471	0,413	0,343	0,357	0,412
	EC	1,269	0,837	Н.д	0,750	0,825	0,888	0,801	0,911
	Cpml	4,02	5,33	Н.д	2,83	2,93	3,28	3,50	2,66
	No		4 – 2		4 – 1	1 – 1	1 – 1	4 – 2	3
Murmansk region									
Mining	MI	0,469	0,431	0,407	0,421	0,405	0,524	0,460	0,438
	EC	1,312	1,246	0,599	0,527	0,583	0,428	0,489	0,527
	Cpml	1,62	1,86	4,10	4,50	4,24	4,46	4.44	4,33
	No		2	2	4 – 2	1 – 2	4 – 2	1 – 2	1 – 2
Processing	MI	0,256	0,539	0,546	0,614	0,625	0,650	0,683	0,720
	EC	1,895	2,971	2,590	2,707	2,273	2,667	3,027	2,833
	Cpml	2,06	0,62	0,71	0,60	0,70	0,58	0,48	0,49
	No		3	4 – 2	3	4 – 2	3	3	4 – 2
Electricity, gas and water production	MI	0,629	0,656	0,680	0,678	0,673	0,655	0,607	0,588
	EC	0,584	0,617	0,482	0,491	0,456	0,327	0,377	0,426
	Cpml	2,72	2,47	3,05	3,01	3,26	3,85	4,37	3,99
	No		3	4 – 2	1 – 2	2	2	1 – 1	1 – 2
Yamalo-Nenets Autonomous Okrug									
Mining	MI	0,257	0,329	0,308	0,305	0,318	0,295	0,264	0,284
	EC	0,421	0,255	36,683	0,301	0,325	0,318	0,330	0,249
	Cpml	9,26	11,92	0,09	10,89	9,69	10,69	11,48	14,14
	No		4 – 2	1 – 2	2	3	2	1 – 1	4 – 2
Processing	MI	0,674	0,857	0,891	0,876	0,848	0,856	0,877	0,890
	EC	3,882	2,515	1,388	2,584	3,189	0,905	6,248	0,371
	Cpml	0,38	0,46	0,81	0,44	0,38	1,29	0,18	3,03
	No		4 – 2	4 – 2	1 – 2	1 – 2	4 – 2	3	4 – 2
Electricity, gas and water production	MI	0,504	0,428	0,347	0,419	0,350	0,320	0,366	0,363
	EC	0,397	0,292	0,282	0,296	0,351	0,247	0,222	0,119
	Cpml	4,99	7,99	9,34	8,05	8,14	12,68	12,34	23,15
	No		2	2	3	1 – 1	2	4 – 1	2

End of Table 1

Regions	Indica-tors	2005	2010	2011	2012	2013	2014	2015	2016
Chukotka Autonomous Okrug									
Mining	MI	0,650	0,581	0,517	0,494	0,576	0,620	0,612	0,603
	EC	2,127	2,217	2,207	1,680	1,096	1,675	2,023	1,620
	Cpml	0,72	0,78	0,88	1,20	1,58	0,96	0,81	1,02
	No		1 – 1	2	2	4 – 2	3	1 – 2	3
Processing	MI	0,824	0,414	0,639	0,849	0,867	0,826	0,649	0,562
	EC	40,143	0,541	0,670	0,541	0,585	0,959	0,799	0,606
	Cpml	0,03	4,46	2,33	2,18	1,97	1,26	1,93	2,94
	No		2	3	4 – 1	3	1 – 2	2	2
Electricity, gas and water production	MI	0,355	0,209	0,150	0,296	0,385	0,262	0,299	0,252
	EC	0,495	0,527	0,384	0,526	0,497	0,402	0,411	0,401
	Cpml	5,68	9,06	17,33	6,42	5,22	9,49	8,14	9,90
	No		1 – 1	2	3	4 – 2	2	3	2

[a] Calculated on the basis of data from the annual statistical collections “Regions of Russia. Socio-economic indicators”. MI — the material intensity of products, EC — the efficiency of capital, Cpml — the coefficient of the production manufacturability level, No — the number of the stage of development.

and social sustainability by production systems at the same time is not considered in the scientific literature.

To do this, it is proposed to use the concept of the life cycle of technological development of manufacturing enterprises and industries and a curve graphically reflecting such a cycle, including six stages. At the same time, the concept of “technological stability” corresponds to the development of the production system only at one stage, when the values of the efficiency of the use of three main types of production resources — material, labor and physical capital simultaneously increase (fixed assets). As a result, the simultaneous achievement of economic, environmental and social sustainability by the production system is ensured, which is proposed to be designated by the concept of “sustainable technological development”.

Since this state of development ensures the coordination of the economic interests of manufacturing enterprises with the interests of the regions-subjects of the Federation and the country as a whole, its achievement through active technological renewal of production should be supported by the state through the formation of an effective system of stimulating innovation.

The theoretical and methodological provisions considered in the article were used to assess the sustainability of the technological industrial development of four regions — subjects of the Federation, which are completely included in the Arctic zone of the Russian Federation, for the period 2005 – 2016.

REFERENCES

1. World Commission on Environment and Development (WCED). (1987). Our Common Future (NY: Oxford University Press).

2. Zhukovskiy, Y., Tsvetkov, P., Buldysko, A., et al. (2021). Scenario modeling of sustainable development of energy supply in the Arctic. Resources, 10(12), 124. DOI: 10.3390/resources10120124.

3. Strange, T., Bayley, A. (2008). Sustainable development: Linking economy, society, environment (Paris: OECD Insights), 142. DOI: 10.1787/9789264055742-en.

4. Dmitrieva, D., Romasheva, N. (2020). Sustainable Development of Oil and Gas Potential of the Arctic and Its Shelf Zone: The Role of Innovations. Journal of Marine Science and Engineering, 8, 1–18. DOI: 10.3390/jmse8121003.

5. Lee, S. M., Trimi, S. (2016). Innovation for creating a smart future. Journal of Innovation & Knowledge, 3(1), 18. DOI: 10.1016/j.jik.2016.11.001.

6. Zhang, Y. (2019). The Influence of Management Innovation and Technological Innovation on Organization Performance. A Mediating Role of Sustainability. Sustainability, 11(2) 495. DOI:10.3390/su11020495.

7. Samylovskaya, E., Makhovikov, A., Lutonin, A. (2022). Digital Technologies in Arctic Oil and Gas Resources Extraction: Global Trends and Russian Experience. Resources, 11(3), 29, 21100808642. DOI: 10.3390/resources11030029.

8. Tcvetkov, P., Cherepovitsyn, A., & Fedoseev, S. (2019). The Changing Role of CO2 in the Transition to a Circular Economy: Review of Carbon Sequestration Projects. Sustainability, 11(20), 5834. DOI: 10.3390/su11205834.

9. Dvoynikov, M., Buslaev, G., Kunshin, A., Sidorov, D., Kraslawski, A., & Budovskaya, M. (2021). New Concepts of Hydrogen Production and Storage in Arctic Region. Resources, 10(1), 3. DOI: 10.3390/resources10010003.

10. Vasilyeva, N. V., Boikov, A. V., Erokhina, O. O., & Trifonov, A. Y. (2021). Automated digitization of radial charts. *Journal of Mining Institute*, 247, 82–87. DOI: 10.31897/PMI.2021.1.

11. Litvinova T. E., Suchkov D. V. Comprehensive approach to the utilisation of technogenic waste from the mineral resource complex. *MIAB. Mining Inf. Anal. Bull.* 2022;(6–1):331–348. [In Russ]. DOI: 10.25018/0236_1493_2022_61_0_331.

12. Linkov, I. (2018). Governance Strategies for a Sustainable Digital World. Sustainability, 10(2), 440. DOI:10.3390/su10020440.

13. Finkbeiner, M. (2010). Towards Life Cycle Sustainability Assessment. Sustainability, 2 (10), 3309- 3322. DOI:10.3390/su2103309.

14. O'Brian, M. (1996). Social and Environmental Life Cycle Assessment (SELCA). The International Journal of Life Cycle Assessment, 1(4), 231–237.DOI:10.1007/BF02978703.

15. Khan, F. I. (2002). Effective environmental management through life cycle assessment. J. Loss Prev. Process Ind, 15,455–466.

16. Kloepffer, W. (2008). Life Cycle Sustainability Assessment of Products. The International Journal of Life Cycle Assessment, 13(2), 89–95.DOI:10.1065/lca2008.02.376.

17. Khan, F. I. (2002). GreenPro-I: A risk-based life cycle assessment and decision-making methodology for process plant design. Environmental Modelling and Software, 17(8), 669–691. DOI:10.1016/S1364–8152(02)00028–2.

18. Khan, F. I. (2004). Life cycle index (LInX): a new indexing procedure for process, and product design and decision-making. Journal of Cleaner Production, 12(1), 59–76. DOI:10.1016/S0959–6526(02)00194–4.

19. Becker, R. H., Speltz, L. M. (1983). Putting the S-Curve Concept to Work Research Management, 16 (5), 31–33.

20. Christensen, C. M. (1992). The Innovator's Challenge-. Understanding the Influence of Market Environment on Processes of Technology Development in the Rigid Disk Drive Industry D. B. A. dissertation. Graduate School of Business Administration (Cambridge, MA: Harvard University).

21. Christensen, C. M. (2009). Exploring the Limits of the Technology S-Curve. Part I: Component Technologies. Production and Operations Management, 1(4), 334–357. DOI:10.1111/j.1937–5956.1992.tb00001.x.
22. Teece, D. (2010). Business Models, Business Strategy and Innovation. Long Range Planning, 43, 172–194. DOI:10.1016/J.LRP.2009.07.003.
23. Zhang, Y. (2019). The Influence of Management Innovation and Technological Innovation on Organization Performance. A Mediating Role of Sustainability. Sustainability 11(2), 495. DOI: 10.3390/su11020495.
24. Dziallas, M., Blind, K. (2018). Innovation indicators throughout the innovation process: An extensive literature analisis. Technovation, (80–81), 3–29. DOI:10.1016/j.technovation.2018.05.005.
25. Zharov, V. S. (2018). Using innovative investment leverage to evaluate areas of technological development of industrial production.St. Petersburg State Polytechnical University Journal. Economics, 11(1), 177–187.DOI: 10.18721/JE.11116.
26. Zharov, V. S. (2018) The interrelation of technological and economic development of production systems. St. Petersburg State Polytechnical University Journal. Economics, 11(3) 32–44. DOI: 10.18721/JE.11303 ГИАБ

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

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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

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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

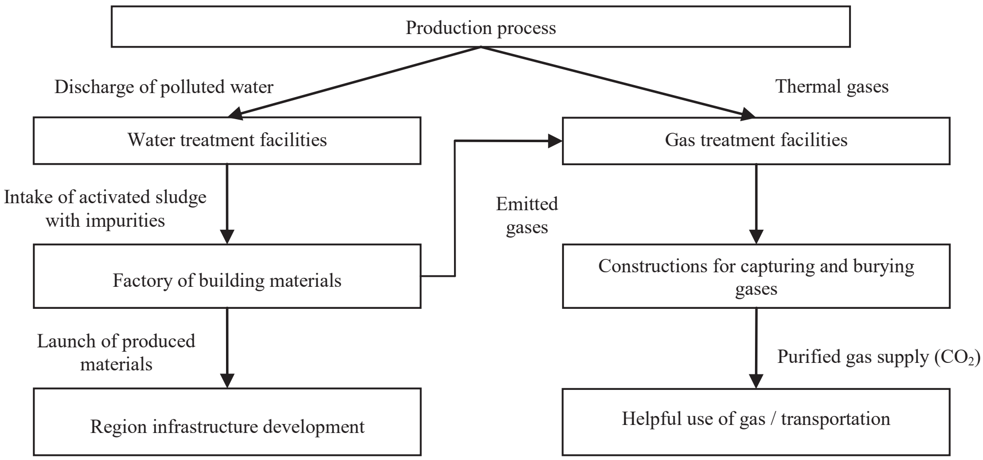

Fig. 1. Stages of cleaning industrial emissions

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 m^3 of water is filtered (this is the volume of untreated wastewater discharged by Norilsk Nickel's enterprises), 6.8 million m^3 (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.

REFERENCES

1. Cherepovitsyn, A. E., Lipina, S. A., Evseeva, O. O. (2018). Innovative approach to the development of mineral raw materials of the Arctic zone of the Russian Federation. *Journal of Mining Institute*, 232, 438. DOI: 10.31897/pmi.2018.4.438.

2. Fadeyev, A. M., Lipina, S. A., Zaikov, K. S. (2021). Innovative approaches to environmental management in the development of hydrocarbons in the Arctic shelf. The Polar Journal, 11(4). DOI: 10.1080/2154896X.2021.1889836.

3. Ilinova, A. A., Dmitrieva, D. M. (2018). The mechanism of innovative development of the Russian arctic zone. International Journal of Mechanical Engineering and Technology (IJMET), 9(9), 1439–1451.

4. Alekseeva, M. B., Bogachev, V. F., Gorenburgov, M. A. (2019). Systemic diagnostics of the Arctic industry development strategy. *Journal of Mining Institute*, 238 (4), 450–458. DOI: 10.31897/pmi.2019.4.450.

5. Kirsanova, N., Lenkovets, O., Hafeez, M. (2020). Issue of accumulation and redistribution of oil and gas rental income in the context of exhaustible natural resources in arctic zone of russian federation. Journal of Marine Science and Engineering, 8(12), 1–19. DOI:10.3390/jmse8121006.

6. Hassen, Y. A. (2016). The Impacts of Mining on Arctic Environment and Society from Corporate Social Responsibility and Sustainable Development Perspectives. URL: https://www.diva-portal.org/smash/get/diva2:930657/FULLTEXT01.pdf (Access date: 10.02.2022).
7. Ballinger, T. J., Overland, J. E., Wang, M., Bhatt, U. S., Hanna, E., Hanssen-Bauer, I, Kim, S. J., Thoman, R. L., Walsh, J. E. (2020). Surface air temperature Arctic Report Card. DOI:10.25923/gcw8–2z06.
8. Climate Change in the Arctic 2020. URL: https://nsidc.org/cryosphere/arctic-meteorology/climate_change.html (Access date: 10.02.2022).
9. The Bellona Foundation. (2015). Environmental considerations in the Arctic: sustainable resource exploitation. Bellona. URL: https://bellona.org/assets/sites/2/2015/12/Arktis-rapport-2015_lav.pdf (Access date: 10.02.2022).
10. Chromcak, J., Farbak, M., Ivannikov, A., Sasik, R., Dibdiakova, J. (2021). Remote Sensing Data Analysis for the Ecological Stability Purposes. IOP Conf. Ser.: Earth and Environmental Science, 906(1), 012068. DOI: 10.1088/1755–1315/906/1/012068.
11. Samylovskaya, E., Makhovikov, A., Lutonin, A. (2022). Digital Technologies in Arctic Oil and Gas Resources Extraction: Global Trends and Russian Experience. Resources, 11(9), 29. DOI: 10.3390/resources11030029.
12. Decree of the President of the Russian Federation from 02.05.2014 no.296 «On the land territories of the Arctic zone of the Russian Federation».
13. Decree of the President of the Russian Federation from 05.03.2020 no.164 «On the Fundamentals of the State policy of the Russian Federation in the Arctic for the period up to 2035».
14. Decree of the President of the Russian Federation from 26.10.2020 no.645 «Strategy for the development of the Arctic Zone of the Russian Federation and ensuring national security for the period up to 2035».
15. Official website of PAO Gazprom 2020 Gas and oil reserves. URL: https://www.gazprom.ru/about/production/reserves/ (Access date: 10.02.2022).
16. Melnikov, P. N., Skvortsov, M. B., Kravchenko, M. N., Agadjanyants, I. G., Grushevskaya, O. V., Uvarova, I. V. (2020). Exploration in the Arctic: resource potential and promising areas. Neftegaz.RU, 1 (97), 22–32.
17. Vasiltsov, V. S., Vasiltsova, V. M. (2018). Strategic planning of Arctic shelf development using fractal theory tools J. Min. Inst. 234, 663–672. DOI: 10.31897/pmi.2018.6.663.
18. Kondratev, V. B. (2020). Mineral resources and the future of the Arctic. Mining Industry, 1, 87–96. DOI:10.30686/1609–9192–2022–4-75–81.
19. Arctic Zone industry. URL: http://ruscp.ru/attachments/text_books/3.1Promishlennost'_v_Arkticheskom_regione.pdf (Access date: 10.02.2022).
20. Litvinova T. E., Suchkov D. V. Comprehensive approach to the utilisation of technogenic waste from the mineral resource complex. *MIAB. Mining Inf. Anal. Bull.* 2022;(6–1):331–348. [In Russ]. DOI: 10.25018/0236_1493_2022_61_0_331.
21. Mining enterprises of Russia, list of the largest companies. URL: https://geomix.ru/blog/gornoe-delo/gornodobyvayushhie-predpriyatiya-rossii-spisok-krupnejshih-kompanij/ (Access date: 10.02.2022).
22. Marmyshev, A. (2020). Oil spill at a thermal power plant in Norilsk. The main thing. TASS Russian News Agency. URL: https://tass.ru/proisshestviya/8638891 (Access date: 10.02.2022).
23. Rybak, J., Adigamov, A., Kongar-Syuryun, C., Khayrutdinov, M., Tyulyaeva, Y. (2021). Renewable-resource technologies in mining and metallurgical enterprises providing environmental safety, Minerals, 11–10, 1145. DOI:10.3390/min11101145.
24. Ponomarenko, T. V., Marinina, O. A. (2017). Corporate responsibility of mining companies: Mechanisms of interaction with stakeholders in projects implementation J. Apll. Econ. Sci. (12), 1826–1838.
25. Tolvanen, A., Eilu, P., Juutinen, A., Kangas, K. (2018). Mining in the Arctic environment. A review from ecological, socioeconomic and legal perspectives. J Environ Manage, 233, 832–844. DOI: 10.1016/j.jenvman.2018.11.124.
26. Matveeva, V. A., Alekseenko, A. V., Karthe, D., Puzanov, A. V. (2022). Manganese Pollution in Mining-Influenced Rivers and Lakes: Current State and Forecast under Climate Change in the Russian Arctic. Water, 14(7), 1091. DOI: 10.3390/w14071091.

27. Rybak, J., Khayrutdinov, M. M., Kuziev, D. A., Kongar-Syuryun, Ch.B., Babyr, N. V. (2022). Prediction of the geomechanical state of the rock mass when mining salt deposits with stowing. *Journal of Mining Institute*, 2022. 253, 61–70. DOI: 10.31897/PMI.2022.2.

28. Official website of PAO Akron 2020 Annual report of PAO Akron for 2019. Acron. URL: https://www.acron.ru (Access date: 10.02.2022).

29. Official website of PAO MMP Norilsk Nickel 2020 Annual report of PAO MMP Norilsk Nickel. Nornickel. URL: https://www.nornickel.ru (Access date: 10.02.2022).

30. Official website of PAO Severstal 2020 Annual report of PAO Severstal.Severstal. URL: https://www.severstal.com (Access date: 10.02.2022).

31. Official website of PAO PhosAgro 2020 Annual report of PAO PhosAgro. Fosagro. URL: https://www.phosagro.ru (Access date: 10.02.2022).

32. Adoption of the Paris Agreement. Framework Convention on Climate Change 2015. United Nations. URL: https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf (Access date: 10.02.2022).

33. Volkov, A. V. (2018). Strategic metals of the Russian Arctic. Go Arctic. URL: https://goarctic.ru/work/strategicheskie-metally-rossiyskoy-arktiki/ (Access date: 10.02.2022).

34. Golovina, E. I., Khloponina, V. S. (2020). Problems of modern legislation in the sphere of underground waters extraction management. Geology and Mineral Resources of Siberia, 8(1), 106–114. DOI: 10.20403/2078–0575–2020–1-106–114.

35. Official website of the Administration of St. Petersburg. Committee on Energy and Engineering. URL: https://www.gov.spb.ru/gov/otrasl/ingen/ (Access date: 10.02.2022).

36. Billo, E. V., Suharevskaya, E. C. (2019). Mining industry waste and methods of its processing. XI All-Russian Scientific and Practical Conference of Young Scientists Young Russia, 1, 70605.

37. Kruk, M. N., Alabev, V. R., Semenov, A. S. (2020). Economic efficiency of application of artificial air cooling for normalization of thermal conditions in oil mines. Scientia Iranica, 27(3), 1606–1615. DOI:10.24200/sci.2018.50549.1753.

38. Waste water sludge disposal: how to make money. URL: https://ecostandart.com/info/articles/poleznoe/biznes-na-utilizatsii-osadka-ot-o-s/ (Access date: 10.02.2022) ГИАБ

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АНАЛИЗ ЭФФЕКТИВНОСТИ ТЕПЛОИЗОЛЯЦИИ РУКАВОВ ВЫСОКОГО ДАВЛЕНИЯ БУРОВОЙ УСТАНОВКИ УРБ-2А2 НА ОСНОВЕ МАТЕМАТИЧЕСКОГО МОДЕЛИРОВАНИЯ

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Аннотация: темой статьи является проблема замерзания гидравлической системы при эксплуатации техники в суровых климатических условиях Северо-Востока и Арктики Российской Федерации. В данной работе авторы дают подробное описание осложнениям, которые возникают вследствие негативного влияния низких температур окружающей среды на гидравлическую систему техники. При проведении исследования было установлено, что основной причиной отказа техники в зимнее время является нарушение герметичности рукавов высокого давления вследствие потери упругих свойств резиновых составляющих, из которых они изготовлены из-за негативного воздействия низких температур окружающей среды на гидравлическое оборудование. В качестве решения вышеуказанной проблемы авторами статьи предлагается способ совершенствования гидравлической системы стандартного геологоразведочного оборудования на примере бурового станка УРБ-2А2 путем утепления её гидравлической системы теплоизоляционным материалом на основе минеральной ваты. Для подтверждения эффективности предложенного способа борьбы с проблемой замерзания гидрооборудования авторы статьи выполнили математическое моделирование тепловых процессов, возникающих в гидравлической системе и сделали сравнительный анализ скорости потери тепла рабочей жидкости в рукавах высокого давления без теплоизоляции и с применением теплоизоляции на основе минеральной ваты. Для численного решения дифференциальных уравнений использовался метод конечных элементов. Расчеты проводились на вычислительном пакете FEniCS. Результаты выполненного в статье математического моделирования доказывают, что теплоизоляция гидрооборудования является эффективным способом борьбы с замерзанием гидравлической системы техники. Следующим шагом авторов является проведение натурных испытаний предлагаемого способа решения проблемы на базе компании ООО «Арктик-Бур», на самоходных буровых установках УРБ-2А2 и УРБ-2Д3.

Ключевые слова: бурение, многолетняя мерзлота, метод конечных элементов, гидравлическое оборудование, FEniCS, теплоизоляционные материалы, рукава высокого давления, гидросистема, буровая установка, Арктика, рабочая жидкость, математическое моделирование.

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Analysis of the efficiency of thermal insulation of high-pressure hoses of the drilling rig URB-2A2 based on mathematical modeling

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Abstract: We consider the problem of freezing the hydraulic system during the operation of equipment in the harsh conditions of the North-East and the Arctic of the Russian Federation. The main reason for the failure of equipment in winter is the damage of high-pressure hoses due to the loss of elastic properties of the rubber components caused by low ambient temperatures. To solve this problem, we propose a way to improve the drilling rig URB-2A2 by insulating its hydraulic system with a thermal insulation material based on mineral wool. To confirm the effectiveness of the proposed approach, we performed mathematical modeling of thermal processes occurring in the hydraulic system. We compared the rate of heat loss of the working fluid in high-pressure hoses without and with thermal insulation. The finite element method is used for numerical solution of differential equations. The software implementation was carried out on the FEniCS computing package. The results of mathematical modeling prove that thermal insulation of hydraulic equipment is an effective way to combat freezing of the hydraulic system of equipment. Our next step is to conduct full-scale tests of the proposed method of solving the problem on the basis of the company “Arctic-Bur” LLC, on self-propelled drilling rigs URB-2A2 and URB-2D3.

Key words: drilling, permafrost, finite element method, hydraulic equipment, FEniCS, thermal insulation materials, high pressure hoses, hydraulic system, drilling rig, Arctic, working fluid, mathematical modeling.

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1. Introduction

During various operations, any equipment is affected by various negative factors that can lead to premature failure. In turn, any breakdown of equipment causes a loss of time and money. The reliability of equipment becomes especially relevant when operating equipment in the harsh conditions of the North-East and the Arctic of the Russian Federation. In these regions, huge territories are still not developed, and settlements are located at a great distance from each other. There is no necessary infrastructure for carrying out any work. In many areas, roads are available only in the cold season, and the ambient temperature in winter can drop to −60°.

As previous studies show, extremely low ambient temperatures have a negative impact on almost all elements of the hydraulic system of the equipment [1].

First, under the influence of low temperatures, hydraulic fluid properties deteriorate due to a significant increase in its viscosity and density and the formation of hydrates.

Secondly, under the influence of extremely low temperatures, deformation occurs, changes in the dimensions and gaps of hydraulic equipment parts, leading to an increase in friction forces, pinching of moving elements, and saturation of the working fluid with air [1].

Thirdly, at low temperatures, the elastic properties of the rubber of high-pressure hoses deteriorate, which can cause its rupture.

When operating equipment at an ambient temperature of −30° or less, all of the above complications usually coincide and can negatively affect the operation of hydraulic equipment or cause its destruction.

2. The negative effect of low temperatures on the hydraulic system of machinery

We studied the long-term experience of the "Arctic-BUR" LLC engineering and survey company, which is engaged in drilling operations on the territory of the Republic of Sakha (Yakutia) all year round. The company's main drilling rig for geological exploration is the URB-2A2, based on the KAMAZ vehicle equipped with a screw compressor. Due to their versatility and accessibility, these drilling rigs are among the most common in the Russian Federation and are mainly used in geological exploration and engineering survey work.

URB-2A2 is a fully hydroficated drilling rig and is equipped with a movable rotator and a lifting mast. All elements of the hydraulic system are connected through high-pressure hoses (HPH) (Fig. 1). As practice shows, they are the most vulnerable elements of the hydraulic system since, during operation, they are most often subjected to various mechanical loads and negative environmental influences.

Fig. 1. High-pressure hoses of the drilling rig URB-2A2

During equipment operation, working fluid temperature increases due to high pressure and friction, so, in winter, the optimum temperature is maintained inside the hydraulic system. When the temperature is below −40−50°, equipment operation is undesirable even with special frost-resistant hydraulic oils. At such extreme temperatures, the oil's viscosity increases, resulting in increased pressure losses in the hydraulic system, increased hydraulic flow resistance, and friction forces in the movable joints. Difficulties arise with starting the hydraulic drive, and the elastic properties of rubber seals and HPH occur. All of the above complications significantly increase the probability of failure of hydraulic equipment [1−5, 8−20].

To prevent and combat the problem of freezing the hydraulic system, we consider insulating the hydraulic equipment of the drilling rig with thermal insulation materials. We believe that due to the thermal insulation of the oil tank and high-pressure hoses, it is possible to significantly increase the efficiency of hydraulic equipment in winter since the heat generated by hydraulic oil will not instantly escape into the environment due to the high thermal conductivity of rubber and metal elements of the hydraulic system.

We propose to thermally insulate the hydraulic system of the drilling rig URB-2A2 with a thermal insulation material based on mineral wool, in particular, the oil tank and high-pressure hoses. The method of insulation is shown in Fig. 2.

3. Mathematical modeling

To study the thermal insulation of high-pressure hoses (rubber pipes), we perform mathematical modeling of hoses' interaction with the environment. Fig. 3 shows the computational domain consisting of three subdomains: Ω_1 − oil, Ω_2 − rubber, Ω_3 − insulation. To determine the temperature distribution T, we will solve the heat conduction equation [6]:

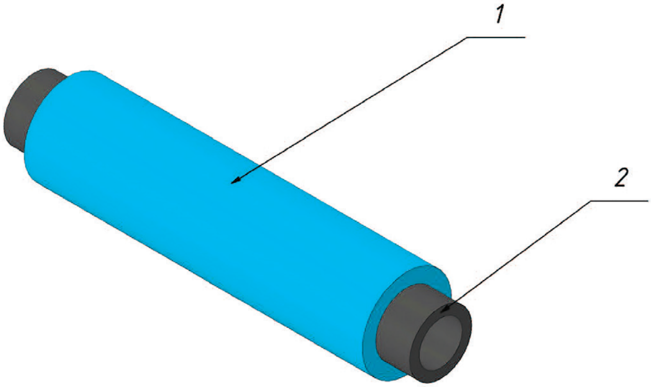

Fig. 2. Heat-insulated high pressure hose: 1 — thermal insulation layer; *2* — high pressure hose

$$c\rho\frac{\partial T}{\partial t}-\nabla\cdot(\lambda\nabla T)=0,\ x\in\Omega \quad (1)$$

Here, c — the specific heat, ρ — the density, λ — the thermal conductivity coefficient, which are defined as

$$c(x)=\begin{cases}c_1,\ x\in\Omega_1,\\ c_2,\ x\in\Omega_2,\\ c_3,\ x\in\Omega_3,\end{cases}$$

$$\rho(x)=\begin{cases}\rho_1,\ x\in\Omega_1,\\ \rho_2,\ x\in\Omega_2,\\ \rho_3,\ x\in\Omega_3,\end{cases}$$

$$\lambda(x)=\begin{cases}\lambda_1,\ x\in\Omega_1,\\ \lambda_2,\ x\in\Omega_2,\\ \lambda_3,\ x\in\Omega_3,\end{cases}$$

where subscripts 1, 2, and 3 denote oil, rubber and insulation properties, respectively. Also, equation (1) must be supplemented with boundary and initial conditions. Convective heat exchange with the environment will take place at the border

$$\lambda\frac{\partial T}{\partial n}=\alpha(T-T_{out}),\ x\in\Gamma_1, \quad (2)$$

where α — the heat transfer coefficient, T_{out} — the температура окружающей среды. The initial temperature is

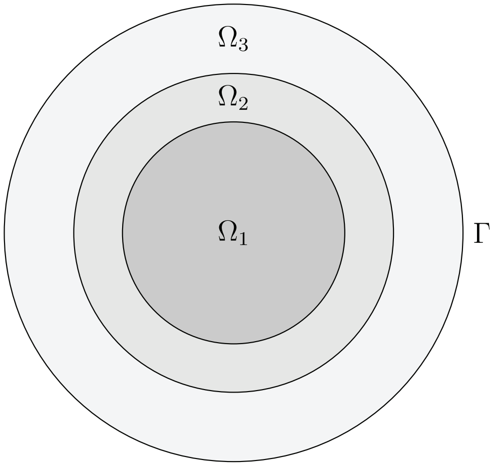

Fig. 3. Computational domain

$$T=T_0,\ x\in\Omega \quad (3)$$

For the numerical solution of the problem (1)–(3), we use the finite element method [7]. The software implementation is carried out on the FEniCS computational package [8]. This package allows us to automate the numerical solution of differential equations using the finite element method. The geometrical domain and the computational mesh (Fig. 4) are generated using the Gmsh program. All software used in the research are open source.

We modeled the cooling of the pipe without thermal insulation, and with thermal insulation was carried out for one hour. The initial temperature is equal to T_0 = 30°, the

Table 1
Thermophysical properties

Material	c, J/(kg · °C)	ρ, kg/m³	λ, W/(m · °C)	α, W/m² · °C
Oil	1860	870	0.1333	–
Rubber	1420	1500	0.175	65
Insulation	920	50	0.0356	3

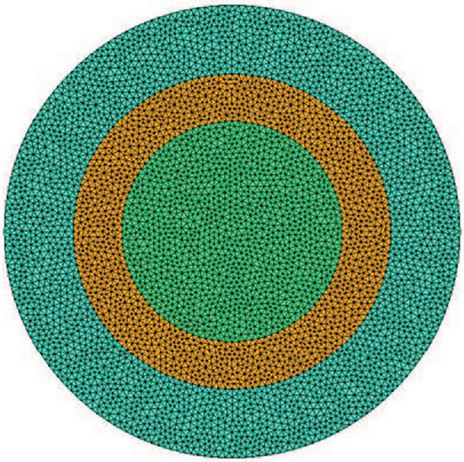

Fig. 4. Computational mesh

ambient temperature – T_{out} = = –50 °C. The outer diameter of the pipe is 46 mm, and the wall thickness is 7 mm. The pipe material is rubber. Mineral wool with a thickness of 10 mm is taken as a heat insulator. Thermophysical properties of oil, rubber, and insulation are presented in Table 1. Calculations are performed with a time step of 1 minute for 1 hour (60 timesteps).

We present calculation results in Fig. 5, where the temperature distribution without thermal insulation after 1 hour is shown on the left and with thermal insulation on the right. It can be seen that without insulation, the oil completely freezes, and its temperature will be –42 °C The oil does not freeze when the pipe is covered with insulation, and the temperature drops to 12 °C. Fig. 6 shows the change in maximum oil temperature over time. The solid blue line shows the temperature distribution with insulation, the dashed orange line without insulation. It can be seen that without insulation, the oil will freeze within 20 minutes.

4. Conclusion

We believe that improving the technical characteristics of equipment is primarily achieved by adapting them to working conditions. At the same time, it is necessary to achieve the desired result without serious modifications to existing equipment and significant financial investments. In our opinion, using this approach, we can achieve

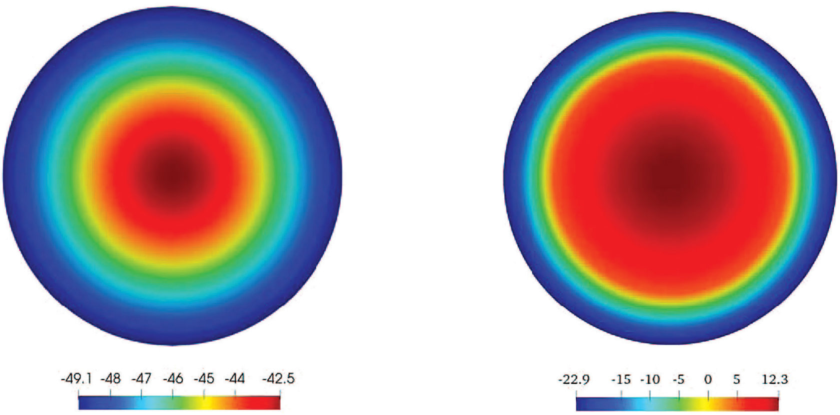

Fig. 5. Temperature distribution without insulation (left), with insulation (right)

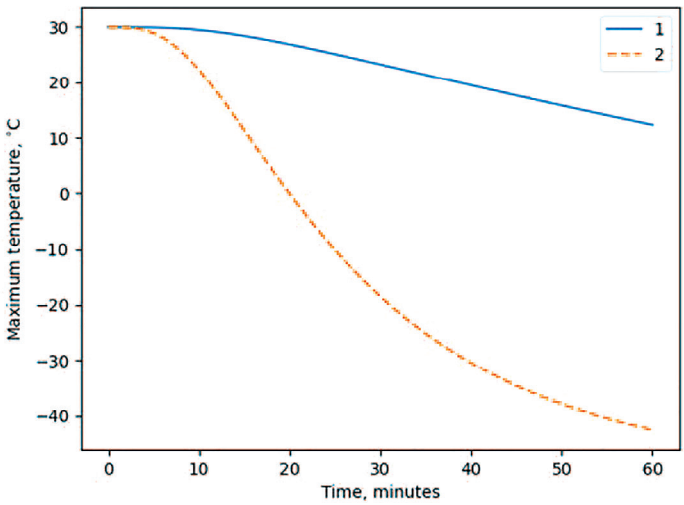

Fig. 6. Maximum temperature over time: 1 – with insulation, *2* – without insulation

success in the realities of the North-East and the Arctic of the Russian Federation.

The approach we have proposed to combat the problem of freezing of the hydraulic system meets all the above requirements and, in our opinion, it is practical and economical.

The results of mathematical modeling prove that thermal insulation of hydraulic equipment is an effective way to combat freezing of the hydraulic system of equipment.

Our next step is to conduct full-scale tests of the proposed method of solving the problem on the basis of the company "Arctic-Bur" LLC, on self-propelled drilling rigs URB-2A2 and URB-2D3.

REFERENCES

1. Yarkin, A. V. (2014). Improving the performance of hydraulic drive high-pressure hoses during operation in harsh climatic conditions. Electronic scientific journal «Engineering Bulletin of the Don» 3. URL: http://ivdon.ru/magazine/archive/n3y2014/2512 (Access date: 10.02.2022).

1. Kaverzin, S. V. (1998). Ensuring the operability of the hydraulic drive at low temperatures (Krasnoyarsk), 240.

2. Karnaukhov, N. N. (2013). Features of operation of hydraulic excavators in cold climatic conditions. Monthly scientific, technical and production journal. Construction and road machines, 9, 37–44.

3. Martin, J. M., Smith, W. K. (2006). Production and application of rubber products : translation from English (St. Petersburg: Profession), 477.

4. Kadantseva, A. I., Tverskoy, V. A. (2008). Carbon fibers. Study guide (Moscow MITHT named after M. V. Lomonosov), 55.

5. Samarskii, A. A., Vabishchevich, P. N. (1995). Computational Heat Transfer, 2 The Finite Difference Methodology (Chichester: John Wiley & Sons), 432.

6. Afanaseva, N. V., Kolesov, A. E. (2016). Numerical solution of the thermal influence of oil well cluster on permafrost. AIP Conference Proceedings, 1773(1), 110001. DOI:10.1063/1.4965005.

7. Alnæs, M. S. (2015). The FEniCS Project Version 1.5 Archive of Numerical Software, 100(3), 9–23. DOI: 10.11588/ans.2015.100.20553.
8. Sharikov, Y. V., Markus, A. A. (2013). Mathematical modeling of heat transfer in pipelines and pipe's objects. *Journal of Mining Institute*, 202, 235.
9. Kazantsev, E. I. (1964). Industrial furnaces. Moscow, 452.
10. Krivandin, V. A. (2002). Heat engineeringof metallurgicalproduction. Moscow, 1, 608.
11. Kutateladze, S. S. (1990). Heat transfer and flow resistance. Moscow, 1990, 367.
12. Mikheev, M. A. (1973). Fundamentals of Heat Transfer, Moscow, 1973, 319.
13. Insulation. Materials. Construction. Technology. Edited by S. M.Kocherhin. Moscow, 2008, 440.
14. Tkach S. M. Studies of the N. V. Chersky Mining Institute of the North to improve the geotechnologies, methods and tools for the efficient development of subsoil in permafrost. *MIAB. Mining Inf. Anal. Bull.* 2021;(12–1):5–14. [In Russ]. DOI: 10.25018/0236_1493_2021_121_0_5.
15. Ilinova, A., Solovyova, V., Yudin, S., et al. (2020). Scenario-based forecasting of Russian Arctic energy shelf development. Energy Reports, 21100389511, 6, 1349–1355 DOI: 10.1016/j.egyr.2020.11.022.
16. Samylovskaya, E., Makhovikov, A., Lutonin, A., et al. (2022). Digital Technologies in Arctic Oil and Gas Resources Extraction: Global Trends and Russian Experience, Resources, 21100808642, 11. DOI: 10.3390/resources11030029.
17. Litvinenko, V. (2020). Foreword: Sixty-year Russian history of Antarctic sub-glacial lake exploration and Arctic natural resource development, Chemie der Erde, 00092819, 80. DOI: 10.1016/j.chemer.2020.125652.
18. Kirsanov, A. N., Zinenko, V. P., Kardysh, V. G. (1981). Drilling machines and mechanisms. Moscow: Nedra, 448.
19. Timofeev, N. G., Scriabin, R. M., Tatarinov, D. M. (2017). On the problem of drilling wells with self-propelled drilling rigs in the conditions of the Far North. Drilling wells in complicated conditions: II International Scientific and Practical Conference, 57–59.
20. Timofeev, N. G., Petrov, V. L. (2018). The method of maintaining the operability of self-propelled drilling rigs in winter. Geosciences: problems, achievements and development prospects: materials of the All-Russian Youth Scientific and Practical Conference, 219–222 ГИАБ

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ИННОВАЦИОННАЯ АКТИВНОСТЬ СЕВЕРНЫХ ГОРНОПРОМЫШЛЕННЫХ ПРЕДПРИЯТИЙ КАК ВАЖНЕЙШИЙ ФАКТОР СНИЖЕНИЯ ВОЗДЕЙСТВИЯ НА ОКРУЖАЮЩУЮ ПРИРОДНУЮ СРЕДУ

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Аннотация: российские горнопромышленные предприятия, функционирующие на Севере и в Арктике, негативно влияют на окружающую природную среду. Следовательно, для осуществления «зеленой» революции необходима разработка и реализация технологических инноваций. Целью работы является количественный анализ уровня инновационной активности горнопромышленных предприятий северных регионов. Показано, что инновационная активность большинства северных горных предприятий низкая. Внедрение инновационных технологий освоения и переработки минерально-сырьевых ресурсов позволяют снизить материалоемкость производства и уменьшить объемы отходов. На основе использования нового методологического подхода выполнена количественная оценка уровня инновационной активности трех российских корпораций (АО «Олкон», АО «Карельский окатыш», ПАО «ГМК «Норильский никель») и шведской компании «Boliden Group». При отсутствии в России эффективной системы стимулирования инновационной активности предприятий, в том числе горнопромышленных, для активизации их инновационной деятельности предлагается порядок разработки каждым предприятием собственной стратегии инновационного развития. Формирование таких стратегий покажет, с одной стороны, возможности предприятий по достижению высоких значений целевых показателей инновационной активности, а, с другой стороны, определит целесообразность и возможность государственной финансовой поддержки.

Ключевые слова: Север и Арктика, горнопромышленные предприятия, инновационная активность, стратегия инновационного развития, стимулирование.

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Innovation activity of northern mining enterprises as the most important factor of reducing the impact on the environment

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Abstract: Russian mining enterprises operating in the regions of the North and the Arctic have a negative impact on the environment. Therefore, for the implementation of the "green" revolution it is necessary to develop and implement technological innovations. The aim of the work is a qualitative analysis of the innovation activity level of the mining enterprises of the northern regions. It is shown that the innovation activity of the majority of northern mining enterprises is low. Implementation of the innovation technologies for the exploitation and processing of mineral resources allow to decrease the material intensity of production and reduce the waste volume. Based on the use of a new methodological approach a quantitative assessment of the innovation activity level of three Russian corporations (JSC Olcon, JSC Karelsky Okatysh, PJSC MMC Norilsk Nickel) and the Swedish company Boliden Group was carried out. With the absence in Russia of an effective system for stimulating the innovation activity of enterprises including mining a procedure for each enterprise to develop its own strategy of innovation development in order to activate their innovation activity is proposed. The formation of such strategies will show on the one hand to identify the possibilities of enterprises to achieve high values of target indicators but on the other hand will determine the expediency and possibility of state financial support.

Key words: the North and the Arctic, mining enterprises, innovative activity, innovative development strategy, stimulation.

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1. Introduction

Mining enterprises are the basis of the economy of the most regions of the North and Arctic that are subjects of the Federation, therefore their development determines the further growth of the gross regional product (GRP) [1]. At the same time, mining enterprises have a negative impact on the environment [2]. Herewith rich ore deposits decrease forcing to exploit poor ore deposits. At the same time the amount of hazardous production waste containing a number of toxic elements will increase. Accordingly, to prevent such tendency it is necessary to develop and implement innovation technologies that allow to ensure the "green revolution" [3—5].

In this regard, it is necessary to conduct a quantitative analysis of the innovation activity level of the mining enterprises from the point of view of the technological innovations to decrease the level of their impact on the environment which is the purpose of the work.

2. Materials and methods

The concept of innovation activity in the scientific literature does not have an unambiguous definition [6], since for this it is necessary, first of all, to formulate self-consistent indicators (one or more interconnected), the change in the values of which will show how innovatively or non-innovatively a particular enterprise has developed. If innovatively then what is the degree of innovation activity that characterizes the rate of change in the values of indicators used for such an assessment.

In [7] it is shown that in the economic literature two approaches to determining the innovation activity of enterprises are considered. In the first approach, an enterprise that implements any innovations in the appropriate period of time is considered to be innovatively active. In accordance with the second approach, innovatively active enterprises will include any enterprise that has R&D costs. It is used more often, but in [7] this approach is rightly criticized, since the volume of R&D costs does not correlate with sales revenue. At the same time, the authors of the work propose their own approach based on an expert assessment of the significance of three blocks of indicators, however, firstly, such an assessment is always subjective. Secondly, each block includes many different indicators, and some of them are absent in the public reporting of enterprises. As a result, a comparative assessment of the innovation activity of different enterprises becomes impossible.

It is proposed a new approach to measuring the innovation activity of industrial enterprises and industrial sectors of the economy of the regions — subjects of the Russian Federation and the country as whole. Its basis is the proposed by authors a new type of the economic analysis of the activities of enterprises and industries — an economic analysis of the technological renewal of production. In accordance with this method technological development of enterprise or industry depending on the economic efficiency of using the main types of production resources (material, including energy, labor and physical capital in the form of fixed assets) is determined by its life cycle which includes six stages [8].At the same time, an indicator of the transition of an enterprise to the corresponding stage is a change of the value in one direction or another of one of three interrelated indicators: coefficient of the production manufacturability level (CPML), material efficiency (ME) and efficiency of capital (EC). First of these indicators is defining one since the growth rates of its values show in authors' opinion the degree of innovation activity of enterprises and industries and the absolute value of CPML in the corresponding period of time indicates the level of their innovation technological development. Quantitatively CPML is calculated by the ratio of the value of the capital intensiveness of production to the material intensity of products or by the ratio of the value of material efficiency to the efficiency of capital and its essence lies in the fact that the technological renewal of the active part of fixed assets (machinery, equipment and vehicles), that is according to the classification of G. Chesbro [9] open innovations in the form of materialized ("bodily") knowledge, has a direct impact on reducing the material intensity of manufactured products, that is, on increasing the level of material efficiency. This theoretical assumption which results from the theory of endogenous economic growth is confirmed by numerous calculations of the proportional relationship between the values of material intensity and capital intensiveness carried out according to the data of the activities of many industrial enterprises primarily located in the regions of the North and the Arctic over a long (more than 15 years) period of time [10].

Of the six stages of the life cycle of technological development of enterprises and industries mentioned above only one stage shows the possibility of a simultaneous increase of the values of all three indicators. Accordingly, in order to maximize the efficiency of use of basic economic resources each enterprise should strive to achieve production activities precisely at this stage but then the question arises — how can it make such a transition and whether it possible based on its current or prospective financial capabilities?

3. Results and discussions

Decree of the President of the Russian Federation of May 7, 2018 No. 204 set the task to increase the number of organizations implementing technological innovations to 50% of their total amount by 2024. To determine the innovation activity of the northern industrial enterprises in terms of introducing technological innovations 19 mining companies that provide information in the public access on websites and in the annual reports as well as in scientific publications for the period 2013 — 2020 were chosen.

Companies that have implemented technological innovations:

Kirovsk branch of JSC “Apatit” PJSC “PhosAgro”.

In 2017 the enterprise developed and implemented a technology for cyclical-flow transportation of overburden with the participation of Thyssen Krupp Industrial Solutions (Germany), which made it possible to increase ore production by 10%.

In 2018 the enterprise developed and implemented a fine screening technology using high-frequency Landsky screens, manufactured by Beijing Screen Technology Co., Ltd. (China), which allowed to increase the efficiency of ore separation by size classes and process lean and off-balance ores (with a P2O5 content from 4 to 6%).

In 2019 the enterprise together with PLC Epiroc RUS developed and implemented a technology for remote control of drilling equipment for underground ore mining which made it possible to increase the drilling efficiency by 20%.

JSC Kola MMC is a subsidiary of PJSC MMC Norilsk Nickel

In 2017 the enterprise together with PLC Gipronickel developed and implemented a technology for briquetting copper-nickel concentrate which allowed to reduce sulfur dioxide emissions by 35 — 40 thousand tons per year.

In 2018, the enterprise developed and implemented a technology for controlling finished products in the briquetting section using artificial intelligence and machine vision which made it possible to improve quality control of finished products.

In 2019 the enterprise together with LLC Gipronickel developed a technology for producing electrolytic nickel from solutions of chlorine dissolution of nickel powder of tube furnaces which makes it possible to increase the production of electrolytic nickel from 120 thousand to 145 thousand tons per year and to increase the level of nickel extraction into concentrate by 1%.

JSC North-Western Phosphorous Company is a subsidiary of PJSC Acron.

In 2020 the company introduced a water accumulation technology allowing to reduce the load on the pumping equipment of the mine and the industrial site of the mining and processing plant.

JSC Olkon part of the Severstal Resources division of PJSC Severstal.

In 2015 the enterprise together with PLC SPB-Giproshakht introduced the technology of cyclical-flow delivery of ore using a steeply inclined conveyor which made it possible to reduce transportation costs by 2 times [11].

In 2019, the enterprise together with scientists from the MI FRC KSC RAS introduced the technology of magnetic-gravity separation which allowed to increase the iron content in the concentrate to 68.46%.

In 2020, the enterprise together with the FRC KSC RAS introduced a screw separation technology which made it possible to obtain hematite concentrate at a level of 62%.

PLC Mayskoye Gold Mining Company is a subsidiary of JSC Polymetal.

In 2018 the enterprise together with the company “SGS” (Russia) implemented a technology for processing oxidized ore in a combined way allowing to increase the share of gold in concentrate by 24%.

Polar Division of PJSC MMC Norilsk Nickel.

In 2017 the enterprise together with JSC Mekhanobr Engineering at the Talnakh enrichment plant introduced a technology for enrichment of a charge of rich and cuprous ores which made it possible to process low-nickel pyrrhotite [12].

Thus for only 13 out of 19 (30%) considered enterprises have implemented technological innovations. Including JSC Karelsky Okatysh and JSC Vorkutaugol (as part of the Severstal Resources division of PJSC Severstal), JSC Kovdorskiy GOK, MCC PJSC Eurochem, PLC Lovozersky GOK, Rusal Kandalaksha — a branch of JSC Rusal Ural UC Rusal.

Thus, one can state that the innovation activity of the majority of Russian mining enterprises in the North and the Arctic is relatively low but this is a very generalized conclusion characterizing only the introduction of new production technologies which is usually rarely carried out at Russian enterprises unlike, for example, the Scandinavian countries located mainly in the North. Many Russian mining enterprises are engaged in improving existing production technologies, however, in accordance with the approach mentioned above they are not considered to be innovatively active [13—15].

In authors' opinion a more accurate classification of mining enterprises as innovatively active can be obtained using the calculation of the absolute values of the coefficient of the production manufacturability level and the rate of their change. To substantiate this conclusion, the technical and economic indicators of activities of two mining and processing enterprises that have approximately the same production technology and are part of the same holding of PJSC Severstal: JSC Olkon and JSC Karelsky Okatysh for ten years (2011—2020) (tables 1 and 2) were considered. Sales revenue of products at each enterprise during this period increased equally by 71 percent [16].

The mentioned above calculated data show that, first, for the analyzed period

Table 1

Technical and economic indicators of activities of JSC Olcon[1]

Indicators	2011	2012	2013	2018	2019	2020	growth rate for the period (%)
ME	4,27	2,89	2,88	2,71	3,54	3,69	86,5
EC	3,36	2,24	1,92	2,64	2,87	2,87	85,4
CPML	1,27	1,29	1,50	1,02	1,23	1,29	101,6

Table 2

Technical and economic indicators of activities of JSC Karelsky Okatysh[1]

Indicators	2011	2012	2013	2018	2019	2020	growth rate for the period (%)
ME	4,27	2,89	2,88	2,71	3,54	3,69	86,5
EC	3,36	2,24	1,92	2,64	2,87	2,87	85,4
CPML	1,27	1,29	1,50	1,02	1,23	1,29	101,6

[1]Calculated by the authors based on the data of annual reports on the activities of enterprises [16], where ME — material efficiency of manufactured products;

EC — efficiency of capital of production by the residual value of fixed assets at the end of the year;

CPML — coefficient of the production manufacturability level.

Indicators corresponding to the best stage of the technological development life cycle are marked in bold.

of time, the rates of change in the values of the coefficient of the production manufacturability level at the two enterprises are almost the same. At the same time JSC Karelsky Okatysh was actively engaged in improving production technology, which allowed it in 2020 to only slightly reduce material efficiency and efficiency of capital compared to 2010. Accordingly, this enterprise can also be considered innovatively active.

Second, due to the introduction of new production technologies in 2018—2020, JSC Olcon managed to significantly increase the level of material efficiency and, accordingly, reduce the specific consumption of materials and energy per ruble of manufactured products, although the level of 2011 was not reached. However, without the activation of such type of innovation activity the decrease of the values of material efficiency would be more significant.

Third, JSC Olcon over the past two years has developed as efficiently as possible in terms of increasing resource efficiency, that is, at the best stage of the life cycle of technological development of enterprises. At the same time, JSC Karelsky Okatysh reached the best stage of technological development only in 2019. This shows that in the future this enterprise will not be able to reach the maximum possible resource efficiency of production only by improving the production technology.

Compared to mining and processing enterprises, mining and metallurgical enterprises have a more significant environmental pollution. In this regard, it is of interest to compare the level of their innovation activity, and it is especially important to compare the results of innovation activity and the corresponding change of the volume of pollutant emissions of Russian and foreign enterprises.

To perform a comparative analysis, two non-ferrous metallurgy enterprises — PJSC MMC Norilsk Nickel (Russia) and Boliden Croup (Sweden) (tables 3 and 4) for the period of their activity of 2011—2020 were selected. Each of them produces copper and nickel among the group of metals. In addition, they are relatively comparable in scale of production (in 2011, the volumes of sales revenue of these companies in US dollars were the same, however, in 2020, the Russian enterprise increased its sales volume three times, and the Swedish — only one and a half times, mainly due to for lower rates of growth in prices for zinc and lead compared to prices for cobalt and palladium).

The main conclusion from the data obtained is that the innovation activity of the Russian company was mainly aimed at improving the existing production technology, when in the Swedish one — at the introduction of new technological processes, since over ten years the value of the coefficient of the production manufacturability level for PJSC MMC Norilsk Nickel has increased only by 20%, and the Boliden Group by 70%. At the same time, the Swedish company showed a steady growth trend of the CPML values, and the sharp increase of the values of this indicator at the Russian company in 2012—2017 is mainly due to the change in the organizational structure of PJSC MMC Norilsk Nickel and the corresponding changes in the data on the volume of material costs. The obtained conclusion is confirmed by the fact that R&D expenditures of the Boliden Group in relation to sales revenue are more than 1.3% and have doubled in absolute expression over ten years. At the same time, such costs for the Russian company are ten times less and, according to scattered data from annual reports, amount to about 0.02% of sales revenue.

Table 3
Results of production and innovation activities of PJSC MMC Norilsk Nickel[1] [17,18]

Indicators	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
ME	5,16	8,23	7,60	9,71	10,28	9,53	6,95	7,09	7,09	4,96
EC	3,03	2,48	2,12	2,57	1,31	1,23	1,26	1,63	2,46	2,34
CPML	1,70	3,32	3,59	3,77	7,86	7,74	5,52	4,35	2,88	2,12
Air emission of SO_2, thousand tons	2016	2044	2033	1948	2009	1878	1785	1870	1898	1911
Air emission of solids, thousand tons	21,0	19,0	20,0	21,5	19,6	13,6	13,0	13,1	11,2	10,2
Wastewater discharge, million m^3	139	147	146	146	141	144	148	164	142	202,5

Table 4
Results of production and innovation activities of Boliden Group[1] [19]

Indicators	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
ME	1,59	1,59	1,57	1,64	1,66	2,00	2,04	1,99	2,06	1,97
EC	1,76	1,59	1,26	1,29	1,42	1,16	1,36	1,35	1,14	1,29
CPML	0,90	1,00	1,25	1,27	1,17	1,72	1,50	1,47	1,81	1,53
Air emission of CO_2, thousand tons	924	1008	1000	1001	889	1052	1024	971	917	897
Air emission of SO_2, tons	7410	8240	6410	7320	7210	7060	7360	7720	6240	6310
Air emission of metals, tons	23	92	75	126	88	100	109	92	69	60
Metal discharge into water, tons	14	21	23	21	18	13	9	8	51	37
Share of R&D expenditures in revenue, %	0,89	1,07	1,18	1,07	1,23	1,31	1,33	1,34	1,48	1,33

[1]*Data on* environmental pollution are given from the annual reports of companies, and the other values of indicators are calculated by the authors based on the data of these reports.

As a result of such innovation activities in 2020 compared to 2011 the material efficiency of the Russian company decreased by 4.5% and in the Swedish company is increased by 23.9% that is the consumption of natural capital (raw materials, materials and fuel) decreased significantly per unit of production value.

It should be noted that each company carries out significant targeted activities to reduce environmental pollution by production waste but even so for example a Russian company has even increased wastewater discharge over ten years while a Swedish company has more than doubled its metal emissions into the atmosphere and water.

The problem of utilization of sulfurous gases deserves special attention. The Boliden Group has practically solved it since less than ten thousand tons of SO_2 are emitted into the atmosphere and there is a tendency for a further decrease. At PJSC MMC Norilsk Nickel the problem of utilizing sulfur dioxide is much more complicated since the volume of SO_2 emissions is about two million tons that is more than 200 times higher than the emissions of the Swedish company. It should be noted that the Russian company uses more high-sulfur ore but its processing technology has been used for several decades without significant changes. The current situation will change significantly for the better only after the full implementation of the “sulfur project” in the coming years.

The low level of innovation activity of Russian mining industrial enterprises is largely determined by the fact that in Russia unlike for example the subarctic countries the system of stimulating the introduction of innovations is poorly functioning [20, 21]. The state policy in the field of innovation activities is reduced only to the formation of various Strategies and Development Programs but their implementation turns out to be ineffective including due to the lack of federal bodies (organizations) existing in all Scandinavian countries which main tasks are to coordinate innovation policy in the country, information and advisory support of innovation activities and selection of highly effective projects and financing of investments in such innovation projects (directly or through various funds).

The proposed industrial policy for increasing resource efficiency by transferring enterprises to the best available technologies (BAT) [22] will not solve the problem of a significant reduction in the material intensity of production and reduction of the impact of enterprises on the environment since in general such technologies will allow only to improve the technological processes existing in production.

Each enterprise including mining one with an increase of the level and degree of its innovation activity especially when transition to new innovation production technologies may experience a great risk of failure to reach the required technological, technical and economic results including from ineffective implementation of relevant investment projects. In this regard any enterprise in order to determine the need for and the possibility of enhancing innovation activities in order to increase resource efficiency should, in authors’ opinion, develop its own strategy for innovation development based on the possibility of using not only its own financial resources but also attracting borrowed capital from various external sources however subject to compliance the required level of financial stability.

The primary basis of such a strategy should be a preliminary determination of the prospective values of the mentioned above target indicators that is CPML, ME, EC and the amount of investments from various sources required to reach them. Then through iterative calculations the real possibility of reaching the target values is checked and if necessary they are adjusted downward..

4. Conclusions

1. The performed analysis based on a new methodological approach of the level of innovation activity of Russian northern mining enterprises showed a low level of implementation of innovation technologies for the exploitation and processing of mineral resource, which could reduce the material intensity of production and reduce the negative impact on the environment.

2. A comparative analysis of the level of innovation activity of four enterprises (JSC Olcon, JSC Karelsky Okatysh, PJSC MMC Norilsk Nickel,

Boliden Group (Sweden)) for the period 2011 — 2020 was carried out. The analysis showed that an increase of the production manufacturability level is typical only for enterprises of the Boliden Group where a significant increase of material efficiency and accordingly a decrease of the level of natural capital use and hence the impact on the environment is ensured.

3. With the absence in Russia of an effective system for stimulating the innovation activity of enterprises, including mining, in order to activate innovation activities, the procedure for developing each enterprise's own strategy for innovation development is considered where the coefficient of the production manufacturability level and the interrelated with it indicators of the level of material efficiency and efficiency of capital are proposed as target indicators. Formation of such strategies will show on the one hand the ability of enterprises to achieve high values of target indicators and on the other hand will determine the expediency and possibility of state financial support.

REFERENCES

1. Kozlov, A. V. (2016). Complex development of the economic space of the Arctic zone of the Russian Federation. Saints-Petersburg: Publishing house of Polytechnic University, 315.

2. Druzhinin, P. V., Shkiperova, G. T., Potasheva, O. V. (2017). The Assessment of the impact of the economy on the environment (spatial aspects). North and market: formation of economic order, 3(54), 228–237. DOI: 10.15838/esc.2020.2.68.8.

3. Tsukerman, V. A. (2019). Management of innovation development of industry of the Arctic zone of the Russian Federation. Apatity: KSC RAS, 219.

4. Tcvetkov, P., Cherepovitsyn, A., & Fedoseev, S. (2019). The Changing Role of CO2 in the Transition to a Circular Economy: Review of Carbon Sequestration Projects. Sustainability, 11(20), 5834. DOI: 10.3390/su11205834.

5. Zhukovskiy, Y., Tsvetkov, P., Buldysko, A., et al. (2021). Scenario modeling of sustainable development of energy supply in the Arctic. Resources, 10(12), 124. DOI: 10.3390/resources10120124.

6. Vertakova, Yu. V., Grechenuk, O. N. (2018). Assessment of the performance of the region innovative activity in the sectoral-industrial section. Theory and practice of the service: economy, social sphere, technology, 4 (38), 18–26.

7. Zaernyuk, V. M., Zabaikin, Yu. V., Skryabin, M. S. (2020). Formation of a methodological approach to the economic assessment of the innovation activity of a mining enterprise. Economics: Yesterday, Today and Tomorrow, 10(1A), 68–77. DOI: 10.34670/AR.2020.91.1.008.

8. Zharov, V. S. (2018). The interrelation of technological and economic development of production systems. St. Petersburg State Polytechnical University Journal. Economics, 11(3), 32–44. DOI: 10.18721/JE.11303.

9. Chesbrough, H. (2003). Open innovation: the new imperative for creating and profiting from technology. Boston: Harvard Business Press, 227.

10. Zharov, V. S. (2016). The system of stimulating innovative activities of industrial enterprises of the Russian arctic zone. North and market: creating an economic order, 2(49), 105–114.

11. Semenyuk, A. A. (2015). Innovative iron ore delivery using high angle conveyor at Olenegorsky open pit. MIAB. Mining Inf. Anal. Bull., S56, 413–420.

12. Lesnikova, L. S. (2018). Implementation of the technology of the charge enrichment of rich and cuprous ores at the Talnakh enrichment plant. Non-ferrous metals, 6, 32–37. DOI:10.17580/tsm.2018.06.04.

13. Romasheva, N., Dmitrieva, D. (2021). Energy Resources Exploitation in the Russian Arctic:Challenges and Prospects for the Sustainable Development of the Ecosystem, Energies, 14(24). DOI: 10.3390/en14248300.

14. Dmitrieva, D., Romasheva, N. (2020). Sustainable Development of Oil and Gas Potential of the Arctic and Its Shelf Zone: The Role of Innovations Journal of Marine Science and Engineering, 8(12), 1–18. DOI: 10.3390/jmse8121003.

15. Litvinova T. E., Suchkov D. V. Comprehensive approach to the utilisation of technogenic waste from the mineral resource complex. *MIAB. Mining Inf. Anal. Bull.* 2022;(6–1):331–348. [In Russ]. DOI: 10.25018/0236_1493_2022_61_0_331.

16. Annual reports of PJSC Severstal. URL: http://severstal.com (Access date: 10.02. 2022).

17. Annual reports of PJSC MMC Norilsk Nickel. URL: http://nornickel.ru (Access date: 10.02.2022).

18. Tsukerman V. A., Ivanov S. V. Environmental policy of resource corporations in commercial mineral production in the Arctic Zone of Russia. *MIAB. Mining Inf. Anal. Bull.* 2020;(10):56–66. [In Russ]. DOI: 10.25018/0236-1493-2020-10-0-56-66.

19. Annual reports of Boliden Group. URL: http://boliden.com (Access date: 10.02.2022).

20. Bondarenko, N. Y., Dubovik, M. V. Gubarev, R. V. (2018). «Triple helix» as the basis of the creation of innovative systems. Bulletin of the Russian Economic University named after G. V. Plekhanov, 2 (98), 3–15. DOI: 10.21686/2413–2829–2018–2-3–15.

21. Shkodinsky, S. V., Nazarov, A. G. (2019). Attracting investment in the development of industrial enterprises using the Triple helix (Triple Helix) model. The Eurasian Scientific Journal, 2(11).

22. Skobelev, D. O. (2020). Best available techniques: experience in increasing resource and environmental efficiency of production. Moscow: ASMS, 250. ГИАБ

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ТРАНСФОРМАЦИЯ РОЛИ ДОБЫВАЮЩИХ КОМПАНИЙ В УСТОЙЧИВОМ РАЗВИТИИ СЕВЕРНЫХ РЕГИОНОВ КАК УСЛОВИЕ СТАНОВЛЕНИЯ «ЗЕЛЕНОЙ ЭКОНОМИКИ»

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Аннотация: рассмотрено управленческие аспекты обеспечения устойчивого развития северных территорий, в ней проанализированы подходы к роли добывающих компаний в становлении основ «зелёной экономики» и определены периоды в трансформации этой роли. При этом рассмотрены основные составляющие компоненты устойчивого развития в деятельности компаний. Авторами представлены основные направления изменений в экономической, экологической и социальной роли добывающих компаний, которые вносят существенный вклад в повышение потенциала устойчивого развития территорий: осуществление инвестиций в экологические, социальные и научно- инновационные проекты, переход к ответственной политике устойчивого развития компаний, расширение спектра получателей выгод от корпоративной социальной политики. Показана необходимость учета региональных особенностей Севера при выборе направлений и составляющих компонентов устойчивого развития, а также пересмотра роли и места заинтересованных сторон и участников в процессах управления таким развитием, необходимость переосмысления сдвига от органов государственного и муниципального управления к компаниям работающим на северных территориях, то есть достижения такого компромисса между интересами всех сторон (власти, бизнеса, населения), который не ограничивал бы возможности будущих поколений в устойчивом развитии. Позитивный аспект в таком управленческом тренде состоит в том, что компании, локализованные на северных территориях, начинают принимать на себя ответственность за устойчивость развития этих территорий, за сохранение окружающей среды и за привлекательность для жизни на них.

Ключевые слова: добывающие компании, Север, устойчивое развитие, корпоративная социальная ответственность, экологическая экономика.

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Transformation of the role of mining companies in sustainable development of northern regions as a driver of green economy

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Abstract: the article examines approaches in management science to the role of mining companies in achieving the Sustainable Development Goals and the formation of green economy in northern regions, identifies periods in the transformation of the corporate role and reviews the activities of companies in the context of the main components of sustainable development. The authors identify the main changes in the economic, environmental and social role of mining companies, which make a significant contribution to achieving sustainable development in the regions: investment in environmental, social, scientific and innovative projects, transition to a new corporate policy aimed at taking responsibility for sustainable development, expansion of the number of potential beneficiaries from corporate social policy. The article shows the importance of taking into account regional characteristics of the North when choosing the directions and components of sustainable development, as well as revising the role and place of stakeholders in the management of such development: the transition from state and municipal authorities to companies operating in the northern territories. Such transformation requires a compromise between the interests of all actors (state, business, local residents) that would not limit the opportunities of future generations in sustainable development sustainable development of the northern territories can be achieved when the enterprises of the major industries in the region grow steadily. companies take responsibility for the preservation of the environment and the attractiveness of life in the northern regions. This leads to the achievement of the Sustainable Development Goals and the formation of a "green economy". Theoretical framework.

Key words: mining industry, the North, sustainable development, corporate social responsibility, green economy.

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Most researchers of problems and trends of sustainable development of northern regions note that there is a need to rethink the role of such areas in the development of Russia and recognize their significant specific features. These features include, first of all, climatic conditions that create discomfort for the population and increase the risks of injury in these regions, rise vulnerability of environmental systems and other additional risks associated with, for example, soil structure or permafrost [1, 2, 3, 4]. Management processes in the transition to sustainable development should be focused not only on determining the responsible parties for economic growth, but also on environmental safety, preservation of the environment, development of a "green" economy, as well as on improving the quality of life of the population. Most studies by Russian scientists have developed the notion that state or regional authorities should bear the responsibility for the implementation of the principles of sustainable development, and the main focus should be made on economic and social components of sustainable development. The social component of sustainable development could be embodied through introduction the green curricula in the bachelor and master programs to train highly qualified and responsible labor force for the North [5, 6].

P. M. Ivanov [7] in his monograph described the model of sustainable development management in the context of relations in the system "Center — Periphery". In this system, the main actors are the authorities, and then the problem of sustainable development is considered only in two aspects — economic and national-territorial (ethno-environmental). Moreover, the thesis that "the ethnic aspect of the environment also manifests itself" was formulated by the author, but not analyzed in detail. T. V. Uskova [8] investigated the management system of sustainable development of the territory, including the collaborative activities of the authorities at the federal, regional and local levels. Another omission in the studies of sustainable development is that the authors [9,10,11,12] consider in detail the relationship between sustainable development and environmental problems, analyze various industrial problems (energy, bioeconomics and others), but do not highlight managerial aspects, with the exception of the research of various regulatory legal acts, declarations, strategies and programs.

Studies of foreign scientists mainly focus on the analysis of the weight of the environmental and social components in sustainable development and skip the economic component. The process of implementation of sustainable development is frequently considered with the engagement of corporations [13,14,15]. G. Hilson and B. Murck in their work "Sustainable development in the mining industry: clarifying the corporate perspective" provided guidance for companies for the engagement of sustainable development principles and emphasized the minimization of negative impacts. The corporate contribution to sustainable development in the context of environmental aspect can be achieved by applying environmentally friendly goals, annual monitoring and publication of results in Sustainability reports, modeling the negative outcomes of production activities, implementation and modernization of cleaner production, conducting training sessions, interaction with stakeholders [13].

D. Rondinelli, M. Berry, L. Shen, K. Muduli and A. Brave focused on determining the place of corporations in sustainable development with an emphasis on the environmental component. In particular, L. Shen, K. Muduli and A. Brave analyzed the processes of green supply chain management, and D. Rondinelli and M. A. Berry highlighted a set of corporate measures to preserve biodiversity (conservation of renewable and non-renewable resources and energy, implemention of environmental accounting system) [14,15]. V. S. Litvinenko, P. S. Tsvetkov, K. V. Molodtsov considered corporate social responsibility as a way to reach internal corporate sustainability [16].

Neither Russian nor foreign researchers see steps or a mechanism for the implementation of principles of sustainable development, because their point of view can be divided into two opposing approaches. On the one hand, "environment" is an independent component of sustainable development and should be considered separately from other components. On the other hand, "environment " can be seen as part of the economy and be integrated into economic development (for example, in an environmentally sound economy). Then, according to the first approach, the implementation of the principles of sustainable development in the region can take place in several stages:

1. Obtaining financial well-being or "financial security cushion";
2. Integration of the economic system with elements of the environmental system: for example, the use of indicators to describe the environmental system
3. Solving social problems
4. Solving environmental problems, but with emphasis on those that threaten the existence of life
5. Implementing the concept of weak sustainability [17].

The above-mentioned stages of implementing sustainability principles are partly similar to the process of corporate role transformation in sustainable development. The process of corporate role transformation implies changing of the share of spending on social issues from achieving internal production goals to the Sustainable Development Goals. Such corporate role transformation consists of five successive stages, which can be defined by the share of company spending on the Sustainable Development Goals. Depending on the stage, such expenditures can be 1) unallowed, 2) undesirable, 3) possible, 4) desirable, and 5) necessary.

For companies starting out in the Nordic region, spending on social and environmental issues is not allowed for the reason that regular production costs have already exceeded the industry average. This leads to the risk of non-competitiveness. Spending on social and environmental issues then moves to the "undesirable" category and more ercently becomes "possible". When costs move to into the "possible" or "desirable" category, it means that the company is actively involved in the sustainable development of the region.

The transformation of the corporate role in achieving the Sustainable Development Goals is reflected in its role in the three major components of sustainable development: economic, social and environmental. Therefore, the aim of the study is to determine the stage of the process of transformation of the corporate transformation role (mining industries) in the context of the three aspects of sustainable development. The scope of study is mining companies operating in the Arctic zone and North of the Russian Federation. The research method is content analysis, and the main source of information is secondary data from corporate reports and official websites of companies.

Transformation of the economic role of mining companies

Economic and population growth increases pressure on ecosystems and natural resources. The future demand for reliable, affordable and sustainable energy requires from companies significant and timely investments in resource-efficient and climate-friendly activities. Changes in the investment profile of mining companies are the first sign of their commitment to sustainable development. Two directions of changes can be distinguished: in terms of amount or scope of investment, such as addressing environmental issues and supporting advanced scientific innovation. Mining companies in the Arkhangelsk region (part of the northern regions of Russia) are analyzed as an example of such changes.

In May 2019, eight investment projects were approved by the regional government, but two of them account for 61.8% of the total investment volume. These projects are developed by mining and primary processing enterprises: Mining and Processing Plant (MPP) at the Lomonosov diamond deposit of PJSC Severalmaz, MPP at the Pavlovskoye lead-zinc ore deposit and the port complex of JSC First Ore Mining Company. Another project of JSC AGD DIAMONDS, worth nearly 20 million rubles, aims at technical re-equipment of the concentrating plant at the V.Grib MPP, including the construction of a drainage system and a reservoir [18].

Mining companies show good examples of R&D investment profile. For instance, JSC AGD DIAMONDS is implementing a project worth 307.2 million rubles. The idea of the project is the organization of high-tech production for synthesis of diamond mono crystals by the temperature gradient method and manufacture of monocrystalline diamond plates with specified characteristics for research and development in the field of quantum sensing, X-ray optics and other promising areas of scientific and technological development. And JSC First Ore Mining Company launched a project for 19 million rubles, taking into account the needs of its employees. The project focuses on a software and hardware solution based on robotics and virtual reality for telemedicine, which allows to automatically collect anamnesis of employees (patients) and organize virtual online consultations in healthcare [19].

PJSC Lukoil also responds to all modern trends in the digitalization of the economy and started operating a comprehensive large-scale digital model of the Vatyeganskoye oil field, which is part of the "Intelligent Field" corporate project. Digital twins have been created for more than 3,000 wells and 12 production facilities, covering the entire production chain [20].

The above cases provide arguments about the transformation of the economic role of mining companies. Corporations invests not only in increased production and profits, but also in programs that contribute to sustainable development of northern territories.

Transformation of the environmental role of mining companies

The transformation of the corporate environmental role of mining companies in the context of sustainable development is also determined by the transition from passive and rather formal activities to active and responsible policies. This translates into a shift from compliance with minimum environmental requirements and emission limits to the implementation of preventive environmental actions to reduce environmental risks. These methods of reducing and transforming environmental risks include:

– active monitoring based on indicators

– attracting scientists for research on the corporate impact on the environment

– supplementing additional initiatives or policy briefs to existing development strategies

– implementation of specific projects to increase biodiversity, save resources, waste recycling, etc.

As an example, changes in the structure of Sakhalin Energy Investment Company Ltd.'s (Sakhalin Energy) operations were examined. Sakhalin Energy is the major operator of the Sakhalin-2 Project and has been in operation for more than 9 years. The company is a leader in the Environmental transparency rating of oil and gas companies operating in Russia in 2019 [21]. Analysis of sustainable development reports of Sakhalin Energy shows that the main environmental activities in 2012 correspond to management control functions, such as standards for air emissions, water use, water discharge, waste disposal, and monitoring performance in the mentioned fields. And only a few activities are related to the monitoring of flora and fauna in the areas where the company operates. For instance, in 2012, Sakhalin Energy conducted environmental inspections at 21 tested areas in the Prigorodnoye Production Complex (PPC) and at 35 sites in the zone of potential impact of the integrated onshore technological complex near PPC [22]. But in 2016, Sakhalin Energy officially announced that the company is participating in the implementation of all Sustainable Development Goals [23]. In 2020, electric and gas-powered vehicles were purchased for cargo and passenger transportation to reduce emissions, which is part of the corporate policy of switching to an environmentally friendly vehicle fleet. Moreover, Sakhalin Energy conducted acoustic monitoring of gray whale feeding to measure the level of anthropogenic noise from the company's offshore facilities as part of the development of an ecological biodiversity monitoring program [24].

Another case of the corporate environmental role transformation demonstrates LLC Lukoil-Komi. The transformation implies a transition from mere compliance with environmental legislation to restoration of biodiversity of northern water bodies and compensatory reforestation projects in the Komi Republic as part of the National Projects in Russia [25].

The dissemination of the practice of participation mining companies in various environmental activities contributes not only to the implementation of the Sustainable Development Goals, but also the strategic goals and priorities of socio-economic policy of the Russian Federation at the state and regional levels, the formation of a "green" economy.

Transformation of the social role of mining companies

In the last decade, the focus on sustainable development has led to a transformation of corporate policies in the region where the company operates. In particular, mining companies that have adopted a social responsibility policy have begun to more active in publishing data about conducted social events in the region. For instance, LUKOIL Group has been publishing its Sustainability Report once every two years since 2003, and annually since 2015. The Sustainability Report of LUKOIL Group consolidates the information on the activities of all companies in the Group. The first Sustainability Report was rather formal and general in nature, covered such issues as economic contribution, interaction with local authorities, personnel support activities and environmental issues. [26]. LUKOIL Group focused on disclosing the approaches and principles of operating in the regions, confirming the information with aggregated statistical data. The 2020 Sustainability Report contains detailed and in-depth information on the ongoing activities. The Corporation discloses the issues of building the entire management system with the main focus on reducing negative impacts, energy conservation, occupational health and safety. The document includes analytics on a wide range of safety aspects, with a strong focus on the development of local communities and Indigenous Peoples of the North [27]. Quality education, gender equality and partnerships could be the further priorities for the company in achieving the Sustainable Development Goals [28]

We can conclude that the entire policy of goal-setting of mining companies has changed . At the start of the corporation's activity, the goal of social activity was "gaining trust". Lately, it had been transformed to "corporate citizenship" (Fig. 1). Corporate citizenship means that companies take over some of the social functions of the state. This leads to significant investment by companies in the construction of social infrastructure facilities, which significantly increases the social potential of the region and strengthens protection against social risks. It should be noted that in the Northern regions there is a lack of social infrastructure facilities, their high wear and tear, old technical equipment and lack of modern technology. Another problem is also the excessive concentration of social facilities in the largest settlements (e.g., cities), which, in fact, sharply limits their use by part of the population living in rural areas. Initially, the target audience for corporate social activity was only the company's personnel, and, in part, the Indigenous Peoples of the North. Currently, corporate social activity has extended to schoolchildren, youth and the elderly. This indicates the transformation of the corporate policy to an understanding of the idea that the harsh climatic conditions of the North must be compensated. In short, the attractiveness of the territory for living becomes the

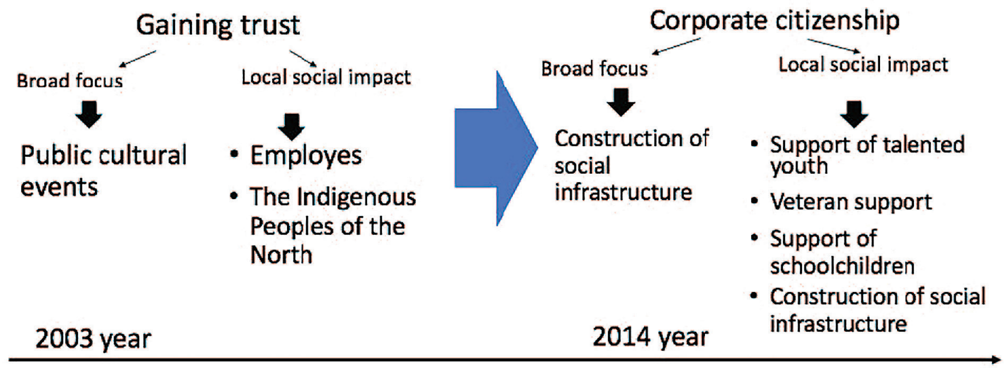

Fig. 1. The transformation of the social role of mining companies in achieving the Sustainable Development Goals
Source: developed by the authors

most important component of social and economic development.

At the present stage of transformation the social role of mining companies is focused on eleven of the seventeen Sustainable Development Goals, includes being a responsible partner in addressing a wide range of social issues, and complies with the principles of the Arctic Investment Protocol [29].

Main research results

The Arctic and the northern regions have become one of the key priorities of the country's policy, despite the specific features of their settlement and development, the challenges and risks of sustainable development in these areas. It can be explained by the fact that in the context of climate change the Arctic and the northern regions are the most important drivers of increasing geopolitical and socio-economic positions of Russia in the global economy.

In view of this fact, the role of all stakeholders in the sustainable development of mentioned area has changed. The responsibility for sustainable development management has partially shifted from the authorities to the companies that operate in the northern regions. The corporate role in achieving the Sustainable Development Goals has changed. Spending on "sustainable development" programs were "unallowed" for companies in the early days of resources production in northern regions. Then the companies came to understanding the value of sustainability and their responsibility for ensuring it, implemented corporate sustainable development policies and became involved in the management of sustainable development in northern regions.

The role transformation of mining companies includes three components of sustainable development: economic, environmental and social.

The economic aspect of the transformation covers changes in the priorities and spheres of corporate investment activity. Investment projects have become more complex and necessarily include environmental (green financing) and social sections and subprojects. Also, the volume of investment in scientific and innovative projects has increased significantly. As a result, not only economic growth takes place, but also environmental safety and the quality of life increases.

The transformation of corporate environmental responsibility includes a transition from compliance with environmental legislation and pollution control to environmental, remediation and ensuring preventive action. These activities are implemented in such projects as increasing biodiversity, resource conservation, waste recycling, clean energy and etc.

The transformation of the corporate role in the social sphere occurred in the awareness of responsibility for ensuring the quality of life not only for the company's employees, but also of the entire population living in region where company operates. And if initially the Indigenous Peoples of the North were the main target group, now the sphere of corporate responsibility extends to schoolchildren, students, the elderly and other people who require special care.

The transformation of the role of corporations in the sustainable development of northern regions is so obvious that not only the leaders and management of the companies but also scientists and other actors are paying more and more attention to this issue. This can be confirmed by the emergence of the Polar Index project created by Project Office for Arctic Development (the PORA Expert Center) and the Faculty of Economics of Lomonosov Moscow State University [30]. The Polar Index project was presented by its developers [31], but so far this work is the first attempt to assess the role of companies in sustainable development of northern regions.

Thus, the study shows that the stages of transformation in the corporate contribution to sustainable development are a possible or desirable. Based on the analysis of corporate policies, as well as investments in environmental goals or additional financing for environmental and social activities, we can state a new positive trend in the processes of sustainable development management: the subjects of such management are now not the state and municipal authorities, but corporate structures and their stakeholders. The direction of further fundamental and applied research should be focused on the assessment of the potential, level and obstacles in the sustainable development of the northern regions, the analysis of participation of mining companies in achieving the Sustainable Development Goals in order to improve the managerial decision-making process at the national, regional and local levels. Such scientific approaches and assessments will help to develop the principles of sustainable development for northern territories and form various elements of the "green economy" based on new management approaches and technologies.

REFERENCES

1. Bedritsky, A. (2018). Sustainable development of the Russian Arctic zone and climatic aspects of environmental and hydrometeorological security. Energy Policy. 4, 3–10.

2. Nilolaev, A. (2021). Model for Assessing Sustainable Development Potential of the Russian Arctic Territories Economics and Management, 3, 109–113.

3. Gendler, S., Prokhorova, E. (2021). Risk-based methodology for determining priority directions for improving occupational safety in the mining industry of the Arctic zone Resources, 21100808642, 10, 1–14. DOI: 10.3390/resources10030020.

4. Rybak, Y. (2021). Resource-saving technologies for development of mineral deposits, Sustainable Development of Mountain Territories, 13(3), 405–415. DOI: 10.21177/1998–4502–2021–13–3-406–415.

5. Rybak, J. (2017). Some remarks on experience based geotechnical education. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 17(12), 1003–1012. DOI: 10.5593/sgem2017/12/S02.127.

6. Myaskov, A. V. (2018) The future of mining engineers: interdisciplinary and digitization work. *Gornyi Zhurnal*, 2, 13–17.
7. Ivanov, P. (2016) Sustainable development of the region: concept, management model, strategy: monograph. (Moscow: Ltd «EKZ «Proffesor»), 254.
8. Uskova, T. V. (2020). Territories' Sustainable Development and Modern Management Methods Problems of territory's development, 2(106), 7–18. DOI: 10.15838/ptd.2020.2.106.1.
9. Bobylev, S. N. (2019). Green Economy and Sustainable Development Goals for Russia: Collective Monograph (Moscow, Economics Faculty of Lomonosov Moscow State University), 284.
10. Tcvetkov, P., Cherepovitsyn, A., & Fedoseev, S. (2019). The Changing Role of CO2 in the Transition to a Circular Economy: Review of Carbon Sequestration Projects. Sustainability, 11(20), 5834. DOI: 10.3390/su11205834.
11. Yurak, V. V. (2020). Vs sustainable development: scenarios for the future, *Journal of Mining Institute*, 242, 242–247. DOI: 10.31897/pmi.2020.2.242.
12. Dmitrieva, D., Romasheva, N. (2020). Sustainable development of oil and gas potential of the arctic and its shelf zone: The role of innovations, Journal of Marine Science and Engineering, 21100830140, 8, 1–18. DOI: 10.3390/jmse8121003.
13. Hilson, G., Murck, B. (2000). Sustainable development in the mining industry: clarifying the corporate perspective. Resources Policy, 26, 227–238. DOI:10.1016/S0301–4207(00)00041–6.
14. Rondinelli, D., Berry, M. (2000). Environmental citizenship in multinational corporations: Social responsibility and sustainable development. European Management Journal, 18, 70–84.DOI:10.1016/S0263–2373(99)00070–5.
15. Shen, L., Kamalakanta, M., Akhilesh, B. (2013). Developing a Sustainable Development Framework in the Context of Indian Mining Industries: AHP approach, Resource Policy, 46(1), 15–26. DOI: 10.1016/j.resourpol.2013.10.006.
16. Litvinenko, V. S. (2020). The social and market mechanism of sustainable development of public companies in the mineral resource sector. Eurasian Mining(Business and International Management), 1, 36–41. DOI:10.17580/em.2020.01.07.
17. Turner, R. (1993). Environmental Economics: An Elementary Introduction (The John Hopkins University Press), 54–62.
18. The register of priority investment projects of the Arkhangelsk region, approved by the order of the Ministry of Economic Development of the Arkhangelsk region dated May 21, 2019 no. 42-r. URL: https://dvinainvest.ru/upload/dok/%D0%A0%D0%B5%D0%B5%D1%81%D1%82%D1%80%20%D0%9F%D0%98%D0%9F_01.12.2020.pdf (Access date: 10.02.2022).
19. Investment Portal of the Arkhangelsk Region 2021 Official web-page. URL: https://dvinainvest.ru/en/ (Access date: 10.02.2022).
20. LUKOIL Group 2021 Official web-page LUKOIL — Company. URL: https://www.lukoil.com/Company (Access date: 10.02.2022).
21. Knizhnikov, A. et. al. Environmental Transparency Rating of Oil and Gas Companies Operating in Russia WWF report, 28.
22. Sakhalin Energy Investment Company Ltd. (2012). Sustainable Development Report, 117.
23. Sakhalin Energy Investment Company Ltd. (2016). Sustainable Development Policy, 16.
24. Sakhalin Energy Investment Company Ltd. (2020). Sustainable Development Report, 300.
25. LUKOIL — Komi. (2021). Official web-page. URL: https://komi.lukoil.ru/ru/ (Access date: 10.02.2022).
26. LUKOIL Group. (2004). Sustainability Report for operations in the Russian Federation, 102.
27. LUKOIL Group. (2020). Sustainability Report, 214.
28. LUKOIL Group. (2021). Our contribution to the UN sustainable development goals Official web-page. URL: https://www.lukoil.com/Sustainability/sustainabledevelopmentmanagement/ (Access date: 10.02.2022).

29. World Economic Forum. (2015). Arctic Investment Protocol Guidelines for Responsible Investment in the Arctic (CH-1223 Cologny/Geneva Switzerland), 10.
30. The Expert Center Project Office for Arctic Development. (2021). Polar Index Official web-page. URL: https://porarctic.ru/en/projects/p-index/ (Access date: 10.02.2022).
31. Nikonorov, C., Papenov, K., (2019). Conceptual approaches to building a sustainable development rating for constituent entities of the Russian Federation and companies in the Arctic zone of Russia. The Spatial Development Potential of Russia: Unlearned Lessons and Challenges for the Future. Collection of scientific papers of the participants of the International Scientific Conference XXVI, 278–285. ГИАБ

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ЭКОЛОГИЧЕСКАЯ ПОЛИТИКА ДОБЫВАЮЩИХ КОМПАНИЙ В АРКТИКЕ

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Аннотация: дано описание экологической политике крупных добывающих компаний, осуществляющих деятельность в российской Арктике. Внедрение обязательных требований по представлению экологической отчетности напрямую связано с корпоративной социальной ответственностью, с которой не могут не считаться добывающие компании, просчитывающие риски, связанные с негативным воздействием промышленности на окружающую среду и учетом интересов заинтересованных сторон в Арктике.

Ключевые слова: добывающие компании, Арктика, устойчивое развитие, публичная нефинансовая отчетность, корпоративная социальная ответственность, экологическая политика, стандарт ответственности.

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Environmental policy of mining companies in the Arctic

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Abstract: The article deals with the environmental policies of large mining companies operating in the Russian Arctic. The introduction of mandatory requirements for the submission of environmental reporting is directly related to corporate social responsibility, which cannot be ignored by mining companies that calculate the risks associated with the negative impact of industry on the environment and take into account the interests of stakeholders in the Arctic.

Key words: mining companies, the Arctic, sustainable development, public non-financial reporting, corporate social responsibility, environmental policy, responsibility standard.

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1. Introduction

Today, Russian mining companies are faced with the need to provide open information about their activities, the importance and impact of a particular company on the region' economy, the environment, and relations with the local population and authorities. This is especially true for the Russian Arctic, where there has recently been active exploration of the subsoil [1].

First of all, partners of companies, public authorities and local community are interested in what policy is being pursued in the field of environmental protection related to sustainable development of the company, its impact on natural components [2]. Large companies with state participation, state corporations, since the beginning of 2000, have been annually publishing social, environmental and sustainable development reports on their websites. The non-financial indicators reflected in these reports characterize the company in three areas, which are called ESG-factors (environmental, social and governance). This is information about the company's strategy in the field of ethical business conduct, taking into account the interests of all parties in relations with which they enter — counterparties, government and local authorities, the local community. As a rule, the reports contain indicators of the effectiveness of corporate governance, industrial safety and labor protection, quality of products and services, contribution to environmental protection, information on social policy and support of local communities, including indigenous peoples of the North.

These factors act as criteria for the selection of companies in order to invest in their activities. At the same time, the investment community is increasingly paying attention to the long-term sustainability of mining companies, their policies of managing social and environmental risks, that is, their sustainable development in the future.

Thus, the topic of sustainable development has become relevant not only in the world, but also for the Russian mining industry [3, 4, 5]. This is evidenced by the decisions of state authorities and the requirements of financial institutions, including global stock exchanges. Cost-effectiveness is increasingly viewed through the lens of environmental performance indicators and governance [6].

2. Regulatory requirements in EU member states

The requirements for disclosure of information on performance have been introduced into national legislation most consistently since the adoption of Council of Europe directives 2013/34 / UE of June 26, 2013 and 2014/95 / UE of October 22, 2014.

The directives provide for the publication of off-budget reports by large enterprises and require a description of their environmental and social policies, major risks, problems associated with commercial activities, and information on the management of these risks. This extra-budgetary reporting is annual. According to Article 4 of Directive 2014/95/UE, Member States must implement its provisions from 2017.

The next step was the adoption of a resolution on sustainable enterprise management by the European Parliament on December 17, 2020. On March 10, 2021, MEPs voted in favor of a resolution containing recommendations on the duty of diligence and responsibility of enterprises. In its turn, the European Commission presented a draft directive replacing Directive 2014/95/UE, which provides for clarification of transmitted data of non-financial reporting, the expansion of enterprises concerned with reporting (for EU member states from January 1, 2026), and the analysis of reporting data within the framework of independent control [7]. New trends in the expansion of liability for non-financial reporting will also directly apply to companies in the extractive industries.

3. Requirements of the environmental policy of companies in Russia

Mining in the Arctic is one of the problematic sectors of the economy that has a significant negative impact on the environment. To ensure the competitiveness of industrial companies, society needs to have open, accessible information about their activities and the policies of responsibility adopted by the companies [8].

In this regard, it is necessary to create more effective mechanisms that can reduce the negative impact of mining companies on the environment and the conflicts arising on this basis.

This is facilitated by the approaches of companies to the formation of public non-financial reporting in accordance with international norms and standards (for example, GRI, SASB). But as N. V. Dyadik and A. N. Chapargin note [9], many large Russian holdings practice the development of environmental policies based on the GRI standard, despite the fact that it is not always possible to determine the stated objectives of the company by these standards.

The Russian Federation has also integrated European Directive 2014/95/EU into its legislation. At present, attention is paid to the development of normative regulation of the formation of public non-financial reporting. So, the first such document is the Concept for the development of public non-financial reporting and an action plan for its implementation, approved by the order of the Government of the Russian Federation dated 05.05.2017 No. 876-r [10] (hereinafter — the Concept).

The Concept applies to state-owned companies and corporations, public companies, state unitary enterprises with revenues of 10 billion rubles and more, business entities with state participation of at least 50 percent.

Thus, the provision of non-financial reporting is mandatory for large companies, for the rest it is voluntary, depending on their competitiveness.

The Russian Union of Industrialists and Entrepreneurs (RSPP) publishes analytical reviews and, based on the analysis, identifies leaders of large Russian companies. RSPN has developed indices for the Moscow Stock Exchange "Responsibility and Openness" and "Vector of Sustainable Development" [11]. These RSPP indices are used to evaluate Russian companies in the international market and still remain an independent tool for their promotion. In addition, the RSPP publishes collections of corporate practices "Russian Business and Human Rights", reflecting the role of companies in actively promoting the SDG-2030 sustainable development goals.

RSPP on its website places information on non-financial statements of companies. So, as of October 11, 2021, 197 companies have posted non-financial reports. In total, 1163 reports have been registered since 2000: social reports (374), environmental reports (101), reports in the field of sustainable development (415), integrated reports (273) [12].

These reports can be found on the websites of such companies as

Table 1
Non-financial reporting of Arctic mining companies by year*

Extractive companies	Sustainable Development Reports	Social reports	Environmental reports	Integrated reports
PAO Gazprom Neft	2007–2020	2002–2004		
PAO Lukoil	2003–2020			
PAO NK Rosneft	2006–2019			
Gazprom Energoholding Group	2012–2019			
OAO Severneftegazprom			2012–2014 2017–2019	2015–2020
OAO Surgutneftegas			2011–2019	
AO NOVATEK	2004–2020			
PAO Gazprom	2008–2020		2001–2008 2017–2019	
PAO Severstal	2012–2020	2004–2006 2010–2011		
PAO MMC Norilsk Nickel	2008–2011 2017–2020	2003–2007 2012–2016		
PAO ALROSA	2019–2020	2011–2018		2018–2019

* Compiled from the library of corporate non-financial reports [13].

GAZPROM, ROSNEFT, ALROSA, LUKOIL, NOVATEK, NORILSK NIKEL, engaged in exploration and production of gas, oil, diamonds and other mineral resources in the Arctic zone of the Russian Federation. As a rule, public non-financial reporting is placed in the sections "Investors", "Information disclosure", "Sustainable development", "Environmental protection".

In the Russian Federation, on March 15, 2013, the national standard, the analogue of the international standard, GOST. R. ISO 26000–2012 "Guidance on Social Responsibility" [14] was put into effect. The standard is intended for all organizations and is aimed at introducing the principles of social responsibility, respect for human rights, interaction with stakeholders. In accordance with GOST. R. ISO 26000–2012, the development of public non-financial reporting should take into account seven key areas of social responsibility:

1) organizational management
2) human rights
3) labor practices
4) environment
5) good business practices
6) protection of interests and interaction with consumers
7) involvement and development of communities.

Following international standards of corporate social and environmental responsibility, Russian mining companies voluntarily commit themselves to mitigate potential risks and negative consequences in the development of mineral deposits. In this regard, the policy of the companies was based on the World Wildlife Fund (WWF) of Russia in 2009 "Basic provisions of the policy of environmental and social responsibility of mining companies" developed by the World Wildlife Fund (WWF) of Russia in 2009 [15]. The document was supported by a group of non-governmental environmental organizations of Russia.

As for oil and gas companies, the formation of companies in the Russian oil and gas sector is quite specific — the companies have largely operated and operate not in the environmentally sensitive end-consumer market, but in the market of a “seller of scarce goods”. Nevertheless, there remains competition for the end consumer between companies for access to “longer and cheaper” financial resources to implement new projects.

World Wildlife Fund (WWF) of Russia and the CREON group, based on the “Joint Environmental Requirements of Public Environmental Organizations for Oil and Gas Companies” [16], have been annually conducting ratings of openness of environmental and corporate information since 2014. In general, the ratings are aimed at encouraging companies to efficiently use hydrocarbon resources, protect the environment and conduct socially responsible business in Russia.

All the companies listed in Table 1, mining in the Arctic, are leaders in the RSPN indices, participants in the Social Charter of Russian Business and strive to comply with the principles of sustainable development in their activities.

3.1. PAO “Gazprom”

As the world leader in natural gas production (12% in the world and 68% in Russia), Gazprom must meet international standards for producing companies [17]. Currently, the company is actively implementing large-scale projects to develop gas resources of the Yamal Peninsula and the Arctic shelf.

Environmental reports are published annually on the company’s website in the section “For Shareholders and Investors — Information Disclosure” and, since 2008, reports on sustainable development activities.

3.2. PAO Lukoil

The company has been present in the Arctic since 2000 is the Yamal-Nenets Autonomous District (Nakhodkinskoye, Pyakyakhinskoye and Yuzhno-Messoyakhskoye fields), the Komi Republic (Usinskoye and Vozeyskoye fields, Denisovsky license area), and the Khanty-Mansiysk Autonomous District.

In 2005 — 2007, the company entered into agreements on social and economic cooperation with the Governments of Yugra and the Yamalo-Nenets Autonomous District, which have been extended till 2024 [18].

3.3. AO NOVATEK

The main fields of NOVATEK are located in the Yamalo-Nenets Autonomous District. The company is engaged in the exploration, production, processing and sale of natural gas and liquid hydrocarbons and has more than twenty years of experience in the Russian oil and gas industry [19]. In total, it owns 72 licenses for exploration and production of hydrocarbons, mainly in the Yamalo-Nenets Autonomous District with total proven reserves of 16.4 billion barrels. NOVATEK is known for its projects to process natural gas into liquefied Yamal LNG, Arctic LNG 2 and ambitious climate goals to reduce specific pollutant emissions by 20% by 2030, greenhouse gases in the production segment by 6% [20].

3.4. PAO ALROSA

ALROSA is a large Russian state-owned mining company, the leader in the global diamond mining industry. The main production region is the Republic of Sakha (Yakutia). Since 2009, the company has been steadily increasing its production of rough diamonds, which in 2019 reached 41 million carats [21]. Since diamond mining is currently carried out in remote areas, such as Olenek, Anabar uluses, the company is transitioning to a new model of social responsibility.

Although the company declares its commitment to environmental principles and is ISO 14001 certified, from time to time environmental accidents occur as a result of the company’s operations.

Thus, in August 2018, four dredge pits at the Irelyakh placer deposit of the PAO ALROSA's Mirninsky Mining and Processing Division were breached, , which caused large-scale pollution of water bodies in the Irelyakh, Malaya Botuobuya and Vilyui rivers. The l calculation of the damage according to preliminary data amounted to 5 billion rubles [22].

In July 2021, a leak occurred during the breakthrough of the dam of the mining waste storage facility at the Catoca mine, which is a joint venture between Alrosa and Endiama. Toxic substances leaked into the tributaries of the Congo River — the Chikapa and Kasai rivers, the water in them turned red. As a result of the poisoning, 12 people died, more than 4 thousand were injured. At the same time, the company stated that it has no control over the mine [23], although the company undertakes obligations to protect the environment not only in the regions of its presence, but also at the international level.

3.5. PAO MMC Norilsk Nickel

Within the framework of the rating of openness of environmental information, since 2019, the monitoring of accidents and conflicts of oil and gas companies began for the first time [24]. Today, there is an acute environmental problem in the Arctic in connection with the expansion of activity on the Russian shelf — these are oil spills, which pose a particular danger, since the elimination of their consequences can take several decades.

An example is the spill of oil products in May 2020 in Norilsk (Krasnoyarsk Territory) at the facility of NTEK JSC, a subsidiary of MMC Norilsk Nickel.

The assessments of leading experts unambiguously show that the accidental spill at CHPP-3 occurred due to serious miscalculations in the corporate governance system of MMC Norilsk Nickel in terms of assessing environmental risks and ensuring environmental safety. According to the results of an audit conducted by Rosprirodnadzor in September 2020, the company revealed 139 violations of mandatory requirements in the field of industrial and environmental safety [25]. The main production facilities from the 1940—1960s were morally and technically obsolete, while no reconstructions and major repairs were carried out.

At the suit of the supervisory authority, an unprecedented decision was made by the Arbitration Court dated February 12, 2021 in case No. A33—27273/2020 to recover from the Norilsk-Taimyr Energy Company Joint Stock Company the damage caused to the environment (its components) in the amount of 146 177 467 227, 96 rubles [26].

The degree of closeness of Norilsk Nickel is well read in the company's profile, prepared as part of the calculation of the ratings of openness in the field of environmental responsibility. The experts also found out that MMC Norilsk Nickel has no voluntary insurance against environmental risks; moreover, the company does not publish documentation on environmental impact assessment in the public domain, nor does it provide emergency response plans. This is convincingly demonstrated by the company's dynamics in the rating itself: from 7th place in 2017, Norilsk Nickel moved down to 12th place by 2019 in terms of openness in environmental responsibility [27]. Using the example of this company, which was considered one of the best mining companies in the Arctic, but as a result of the accident showed ineffective risk management, it is likely that the criteria for analyzing data transmitted in the framework of non-financial reporting should be changed.

4. Conclusion

July 13, 2020 President of the Russian Federation V. V. Putin signed a package of laws on the creation of a special economic zone in the Arctic. The fundamental concept of the Federal Law N 193-FZ "On State Support of Entrepreneurship in the Arctic Zone of the Russian Federation" [28] is the provision of state preferences and benefits in exchange for investments by private companies in the development of the Arctic region.

The law provides for the adoption of the standard of responsibility for the residents of the Arctic zone in relations with the indigenous peoples of the Russian Federation, state authorities and local self-government bodies. The implementation of the responsibility standard by signing the agreement is the key to the successful social and economic policy of residents in relations with the stakeholders in the Arctic region, and primarily with the indigenous minorities living in the Arctic.

With active progress in the Arctic, it is necessary to create more effective mechanisms that can reduce the negative impact of mining companies on the environment. The practice of introducing environmental reporting supports the pursuit of this goal, as it aims to increase the transparency of the industry and supports the efforts of companies to prevent harm to the environment, including minimizing carbon dioxide emissions.

Environmental reporting of companies in general makes it possible to analyze the quality of environmental risk management in the extraction, transportation and processing of solid minerals and hydrocarbons. It should be noted that reducing the negative impact on the environment, in addition to the direct environmental effect, also has an important social result: reducing the negative impact on the health of personnel and local communities, preventing conflicts associated with the restriction of territories of traditional use. In addition, this policy is a significant incentive to increase the transparency of companies, develop interaction with stakeholders (civil society, local communities and indigenous peoples) and ensure openness when discussing future projects.

Therefore, it seems necessary to extend the action of the Concept approved by the Order of the Government of the Russian Federation dated 05.05.2017 No. 876-r to all mining companies and to submit to the State Duma of the Russian Federation a bill "On public non-financial reporting", according to which companies must submit annual reports on the results of the social and environmental responsibility parts. Thus, the introduction of a responsible environmental policy, the standard for environmental responsibility of mining companies at the level of federal legislation, is now becoming a priority task for the development of socially responsible business in Russia [29].

It is necessary to support the process of further development of systems of independent external evaluation of mining companies, development of indicators and criteria for this evaluation, including taking into account the experience of the EU countries and modern approaches in this area. The role and influence in this process of various public institutions, media, all-Russian associations of employers and business associations will be substantially strengthened.

REFERENCES

1. Ilinova, A., Solovyova, V., Yudin, S. (2020). Scenario-based forecasting of Russian Arctic energy shelf development, Energy Reports, 21100389511, 6, 1349–1355. DOI: 10.1016/j.egyr.2020.11.022.

2. Rybak J., Adigamov, A., Kongar-syuryun C., Khayrutdinov M., Tyulyaeva Y. Renewable-resource technologies in mining and metallurgical enterprises providing environmental safety.Minerals. 2021, 11–10, 1145. DOI: 10.3390/min11101145.

3. Zhukovskiy, Y., Tsvetkov, P., Buldysko, A., et al. (2021). Scenario modeling of sustainable development of energy supply in the Arctic. Resources, 10(12), 124. DOI: 10.3390/resources10120124.

4. Tcvetkov, P., Cherepovitsyn, A., & Fedoseev, S. (2019). The Changing Role of CO2 in the Transition to a Circular Economy: Review of Carbon Sequestration Projects. Sustainability, 11(20), 5834. DOI: 10.3390/su11205834.

5. Krasyukova, E., Aynbinder, I., Ivannikov, A. (2021). A rational approach to the management of underground mining in complex hydrogeological and geomechanical conditions based on a risk assessment. IOP Conf. Series: Earth and Environmental Science, 684, 012006. DOI: 10.1088/1755–1315/684/1/012006.

6. Dvoynikov, M., Buslaev, G., Kunshin, A., Sidorov, D., Kraslawski, A., & Budovskaya, M. (2021). New Concepts of Hydrogen Production and Storage in Arctic Region. Resources, 10(1), 3. DOI: 10.3390/resources10010003.

7. Buisine, O. (2021). RSE et comptabilité environnementale. Bulletin Joly Sociétés Septembre, 59.

8. Romasheva, N., Dmitrieva, D. (2021). Energy resources exploitation in the russian arctic: Challenges and prospects for the sustainable development of the ecosystem, Energies, 62932, 14(21), 8300. DOI: 10.3390/en14248300.

9. Dyadik, N. V., Chapargina, A. N. (2020). Business and government: environmental and economic responsibility in the Russian Arctic. Arctic. Arktika i Sever [Arctic and North], 41, 45. DOI: 10.37482/issn2221–2698.2020.41.38.

10. On approval of the Concept for the development of public non-financial reporting and an action plan for its implementation 2017 Order of the Government of the Russian Federation dated 05.05.2017 no. 876-r. URL: http://www.pravo.gov.ru (Access date: 10.02.2022).

11. Feoktistova, E. N. (2019). Analytical review of corporate non-financial reports: 2017–2018, 5.

12. National Register of corporate non-financial reports. URL: https://www.rspp.ru/activity/social/registr/ (Access date: 10.02.2022).

13. Table of the Library of corporate non-financial reports. URL: https://rspp.ru/tables/non-financial-reports-library/ (Access date: 10.02.2022).

14. GOST R ISO 26000–2012 Guidelines on social responsibility Available from: https://standartgost.ru/g/%D0%93%D0%9E%D0%A1%D0%A2_%D0%A0_%D0%98 % D0% A1% D0% 9E_26000–2012 (Access date: 10.02.2022).

15. The main provisions of the policy of environmental and social responsibility of mining companies. URL: https://wwf.ru/resources/publications/booklets/basic-principles-for-environmentally-and-socially-responsible-policy-of-mining-companies / (Access date: 10.02.2022).

16. Joint environmental requirements of public environmental organizations to oil and gas companies. URL: https://wwf.ru/upload/iblock/4ac/oil_demands.pdf/ (Access date: 10.02.2022).

17. Reports 2020 GAZPROM. URL: https://www.gazprom.ru/investors/disclosure/reports/2020/ (Access date: 10.02.2022).

18. Yamalo-Nenets Autonomous District LUKOIL. URL: https://lukoil.ru/Company/BusinessOperation/GeographicReach/Russia/yamalo-nenetsautonomousokrug (Access date: 10.02.2022).

19. Our assets NOVATEK. URL : https://www.novatek.ru/ru/business/assets/ (Access date: 10.02.2022).

20. Sustainability Report NOVATEK Available from: https://www.novatek.ru/ru/development/ (Access date: 10.02.2022).

21. Strategy ALROSA. URL: http://www.alrosa.ru/%D0%BF%D1%80%D0%BE%D0%B8%D0%B7%D0%B2%D0%BE%D0%B4%D1%81%D1%82%D0%B2%D0%BE/%D1%

81%D1%82%D1%80%D0%B0%D1%82%D0%B5%D0%B3%D0%B8%D1%8F/ (Access date: 10.02.2022).
22. Tikhonova S. A., Struchkova G. P., Kapitonova T. A. Manmade pollution assessment in water bodies in Yakutia using color response curves and satellite images. *MIAB. Mining Inf. Anal.* Bull. 2021;(12–1):213-222. [In Russ]. DOI: 10.25018/0236_1493_2021_121_0_213.
23. DR Congo seeks compensation for the mine accident from Catoca. This is a joint venture between Alrosa and Endiama. URL: https://www.bfm.ru/news/480686 (Access date: 10.02.2022).
24. 2019 Rating of openness of oil and gas companies in Russia in the field of environmental responsibility (Moscow: WWF Russia) 5, 7. URL: https://f71246df-863f-4eb1–93c4–6f5d32358c4e.filesusr.com/ugd/d526f3_edc9d9180ad849f79b7d82606858658c.pdf.
25. Rosprirodnadzor revealed numerous violations in the activities of AONorilsk-Taimyr Energy Company. URL: https://rpn.gov.ru/news/rosprirodnadzor_vyyavil_mnogochislennye_narusheniya_v_deyatelnosti_ao_norilsko_taymyrskaya_energetich/ (Access date: 10.02.2022).
26. The decision of the Arbitration Court of the Krasnoyarsk Territory dated February 12, 2021. URL: https://kad.arbitr.ru/Card/4490905b-aec9–472e-a30a-c384e1679527 (Access date: 10.02.2022).
27. WWF DID NOT RECEIVE A RESPONSE TO ITS LETTERS FROM NORNIKEL AND URGES THE COMPANY FOR A QUICK RESPONSE. URL: https://wwf.ru/resources/news/zelenaya-ekonomika/wwf-ne-poluchil-ot-nornikelya-otveta-na-svoi-pisma-i-prizyvaet-kompaniyu-k-operativnoy-reaktsii/ (Access date: 10.02.2022).
28. On state support for entrepreneurial activity in the Arctic zone of the Russian Federation Federal Law of July 13, 2020 N 193-FZ. URL: http://www.pravo.gov.ru (Access date: 10.02.2022).
29. Filatova, I., Nikolaichuk, L., Zakaev, D., & Ilin, I. (2021). Public-Private Partnership as a Tool of Sustainable Development in the Oil-Refining Sector: Russian Case. Sustainability, 13(9), 5153. DOI: 10.3390/su13095153 ГИАБ

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РАЙОНИРОВАНИЕ ТЕРРИТОРИИ ТРАСС ТРУБОПРОВОДОВ ПО СТЕПЕНИ ОПАСНОСТИ ВОЗНИКНОВЕНИЯ АВАРИЙ СРЕДСТВАМИ ГЕОИНФОРМАЦИОННЫХ СИСТЕМ И ИСКУССТВЕННЫХ НЕЙРОННЫХ СЕТЕЙ

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Аннотация: описан метод районирования территории вдоль трассы трубопровода по степени потенциальной опасности возникновения аварий. Прогноз основан на многофакторном анализе, выполненном в интегрированной системе: ГИС и искусственных нейронных сетей (ANN) (программный комплекс «Advangeo»). В качестве объекта исследования был взят трубопровод на Северном Урале (Россия). В результате обработки исходных данных и обучения нейронных сетей была получена карта мест потенциальных аварий по трассе многофакторном анализе а. Результаты были сопоставлены с итогами математико-картографического моделирования в среде ГИС MapInfo.

Ключевые слова: районирование территории трубопровод, многофакторный анализ, прогноз, искусственные нейронные сети.

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Zoning pipeline routes according to the degree of danger of accidents using geoinformation systems and artificial neural networks

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Abstract: The article describes a method of zoning the territory along the pipeline route according to the degree of potential danger of accidents. The forecast is based on a multivariate analysis performed in an integrated system: GIS and artificial neural networks (ANN) (software package Advangeo). The pipeline in the Northern Urals (Russia) was taken as an object of research. As a result of initial data processing and neural network training, a map of potential accidents along the pipeline route was obtained. The results were compared with the results of mathematical and cartographic modeling in the GIS MapInfo.

Key words: zoning of the pipeline territory, multivariate analysis, forecast, artificial neural networks.

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Introduction

Pipeline logistics is the most efficient way of transportation at all stages of mining production. In the extraction of solid minerals, pipeline transport is used for the delivery of laying mixtures [23] to the place of laying [21], and in the extraction of hydrocarbon raw materials for its transportation to the place of processing [22]. Accidents at pipelines are one of the most serious economic and environmental problems of the gas industry [14], [18]. The most general analysis shows uneven distribution of pipeline accidents [4],[13]. Damage of a main pipeline is caused by two groups of factors. The first group is caused by a decrease of pipeline bearing capacity, the second –by increase of loads and impacts. Decrease of bearing capacity of oil pipelines occurs due to defects in the pipe wall, metal aging, and corrosion [1], [11], [17], [21]. Factors of the second group are caused by pressure, stress from the temperature effects of the pumped oil and the surrounding soil, the pressure of the soil layer above the pipe, various static and dynamic loads, earth surface deformations, seismic impacts [5], [20], [22]. Factors of the second group, listed above, are characterized by spatial reference and the need to process large volumes of different types of data in their evaluation [7]. For this reason, the analysis of this kind data requires the use of computer technology. A significant number of works are devoted to this aspect, considering from different points of view the problem of zoning pipeline routes territory according to the degree of accident risk by means of geoinformation systems and artificial neural networks. In particular L. A. Strokova and A. L. Ermolaeva [15] on the basis of GIS-technologies analyzed the main loads and impacts on the main gas pipeline from the influence of land surface subsidence caused by karst and thermokarst processes, and built schemes of territory zoning by degree of danger. However, this work did not take into account the degree of influence of individual factors on the results. In the work of V. A. Chikharev [19], the stages of creating a spatial database of the pipeline condition are considered and recommendations on optimization of geotechnical monitoring are given. However, the question about the degree of influence of each of the factors was not considered. In the work of A. N. Rasputin, V. A. Zhelobetsky, S. N. Kuimov and K. V. Postautov [12], solutions to optimize the system of diagnostics and control, technical and forecasting state of the main gas pipeline using GIS based on geological and geophysical information are presented. However, the issue of territory zoning was not considered. S. I. Bidenko [3] showed the possibilities of artificial neural networks (ANN) for processing and analysis of large arrays of geospatial data with obtaining testing errors depending on the accuracy and quality of training sets. However, this experience was obtained for specific coastal conditions and is not relevant to pipeline systems. S. A. Terekhov, N. N. Mukhamadieva, N. N. Fedotova, et al. [16] presented an approach to building an ANN for modeling a multi-parameter pipeline system, but the article lacks spatial reference of the object itself. The article by A. G. Osipov, V. V. Dmitriev, S. A. Maslennikov [10] describes scientific and methodological approaches to GIS-mapping modeling of pipelines based on spatial multiparametric analysis of the territory in order to choose the route of pipeline system in the model territory in the Arctic zone of Siberia. In the study the ranking of landscape properties according to their influence on the territory suitability, qualimetric estimations of suitability classes of natural systems and graph theory for determination of the optimal pipeline route based on the Dijkstra algorithm were used. However, the values of the weighting coefficients are subjective. Article by N. E. Mohammed [8] developed a framework for the integration of GIS and ANN for forecasting the development of social objects. GIS is used to collect, manage and query spatial data, and ANN is used for modeling. However, how this approach can be used for the zoning of the territory according to the degree of danger along the pipeline route is not clear. The above review of sources devoted to the problem under consideration confirms that the identification of hazardous areas of pipeline routes by means of GIS and ANN is relevant.

Methods of research

The Krasnoturyinsky district of the Northern Urals served as an example of integrated use of GIS and ANN technologies for zoning the territory of pipeline routes according to the degree of danger of accidents. The specified area is characterized by massive manifestations of accidents on the main gas pipeline. Within its limits, on the area of about 200 km2 in different years there were about 10 major accidents and more than thirty incidents , including repeated ruptures of pipes during their hydraulic tests. The area under consideration is intersected by a complex system of the largest geodynamically active faults, which separates hypsometrically contrasting differently leveled regions — the Ural Mountains and the West Siberian Plain [9]. The area is located within the ore node of non-ferrous metals, as a result of which an area alternating sulfidization of Paleozoic strata is observed. In addition, the presence of sedimentary hematite-limonite, sideronite and manganese ores in the marginal part of the Meso-Cenozoic cover of platform deposits is established. The area has a well-developed energy supply system, which includes long lines of powerful and heavy-duty power lines, which determine the electrolyte characteristics of geochemically saturated groundwater.

The following digital cartographic materials served as a working basis for zoning the territory: maps of power lines, highways and railoads, hydrography (Fig. 1, *a*); maps of active fault zones with indication of places of recorded pipeline accidents (Fig. 1, *b*); map of quaternary formations (soils) (Fig. 1, *c*); geological map and information on ore occurrences, allowing to judge about types of groundwater mineralization in different-age structural and formation complexes of ore areas (Fig. 1, *d*).

Identification of active faults and making a geodynamic map for their classification was carried out by special interpretation of a satellite image of scale 1:200,000. The revealed system of faults was compared with the hypsometric map of scale 1:50,000 and the results of morphometric analysis of the territory. The faults were divided into 5 categories according to their actual width on the ground: up to 50 m; from 50 to 100 m; from 100 to 150 m; from 150 to 200 m; and from 200 to 300 m. classification of faults according to their activity was carried out based on the visible vertical amplitude of the relative relief-forming spaces separated by geodynamic blocks. According to this feature, active faults of 5 categories are distinguished: with an amplitude of less

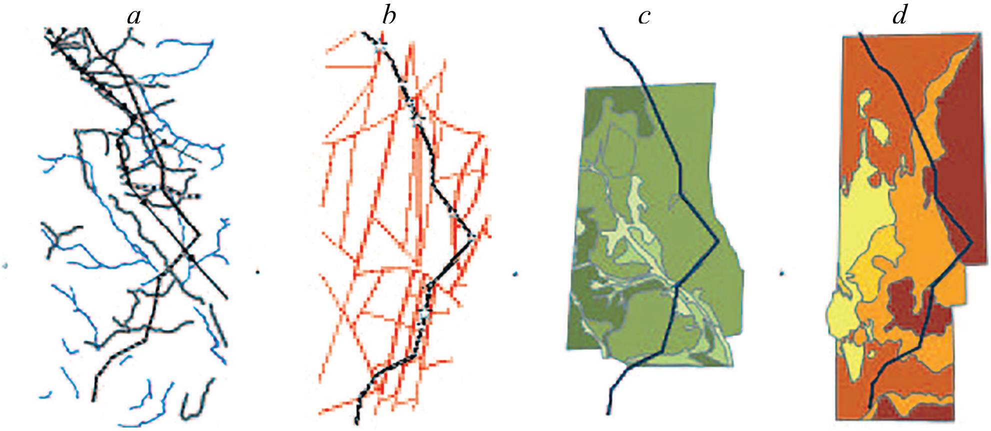

Fig. 1. Source materials: a — network of roads, power lines and hydrography; *b* — zones of active faults with indication of places of registered accidents on the pipeline; *c* — quaternary deposits (soils); *d* — rocks

than 10 m (within a block), 10 m, up to 20 m, up to 30 and more than 30 m (interblock). Each group of these values was assigned points of potential danger. The values of the specified parameters and their corresponding scores were entered into the GIS attribute tables. Based on the obtained results, a thematic map was created (see Fig. 1, *b*). The probable geochemical assessment of groundwater aggressiveness in zones of active faults consists of three factors. The first is the presence and type of ore mineralization in the geological complexes intersected by such faults. The second is the granulometric composition and genesis of loose quaternary formations containing pipelines. These soils contribute to maintaining the level of groundwater mineralization in the zones of in active faults or, on the contrary, cause its dilution. The third one is the proximity to power lines of different capacity. To account for the first factor, on the basis of the map presented in Fig. 1, *d*, the classification of rocks on the degree of their geochemical aggressiveness was carried out. The least dangerous in the area, apparently, are those of Paleozoic age. The type of rocks and the values of these points were entered into the GIS attribute table. Similar operations were performed to account for the second factor. The compiled digital map of Quaternary formations reflected the spatial distribution of individual differences. Based on the obtained map, classification of vertical sediments according to the degree of dilution of a level of mineralization of groundwater in zones of active faults was carried out. In total, taking into account the granulometric composition and the degree of saturation with surface water, four categories were identified, each of which was assigned a certain value of the potential hazard score. The type of quaternary formations and the values of these scores were entered into the corresponding GIS attribute table.

The software package Advangeo [2] was used to determine the location of potentially dangerous geodynamic zones. The complex was developed for modeling and analysis of spatial data using artificial intelligence. It consists of databases (DB) and GIS. Neural network model database parameters and metadata are stored in Microsoft SQL Server. The GIS component is an add-on to ESRI ArcGIS software.

The artificial neuron is the main component of the ANN. Neurons are organized in such a way as to facilitate data reception and processing (multilayer perceptron) from layer to layer. Through this process, the data is simultaneously evaluated and weighed. This is done in order to find the best fit to the data on which the network was trained, and which will give an accurate forecast. To calculate the output value, the weight (wi) may differ for each input signal (ai) and each activation function (g) (Fig. 2, *a*). Activation functions are often determined by a sigmoidal curve (Fig. 2, *b*).

The output signal of each neuron of the previous layer is the input signal of each neuron of the next layer. All inputs

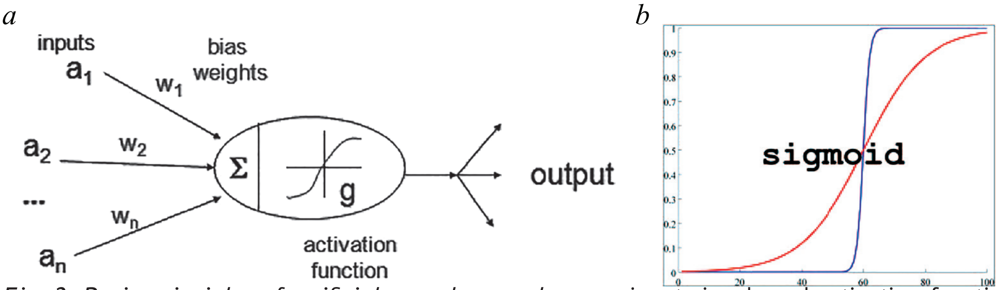

Fig. 2. Basic principles of artificial neural networks: a — input signals and activation function; *b —* sigmoidal curve

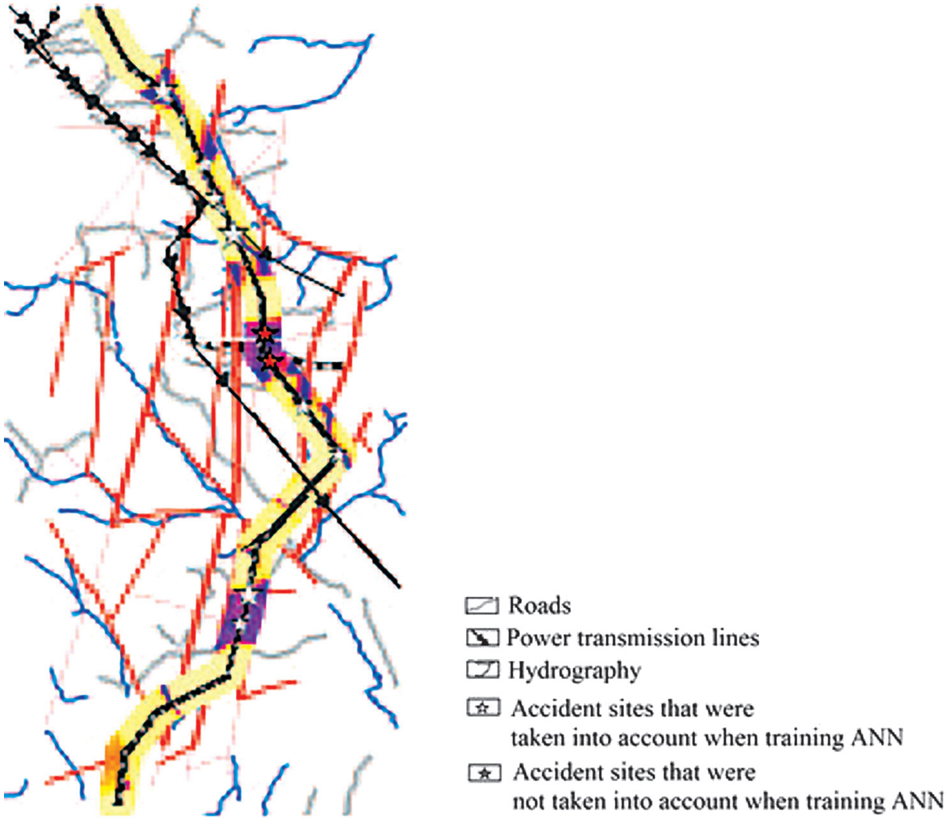

Fig. 3. Map of pipeline route zoning by accident hazard

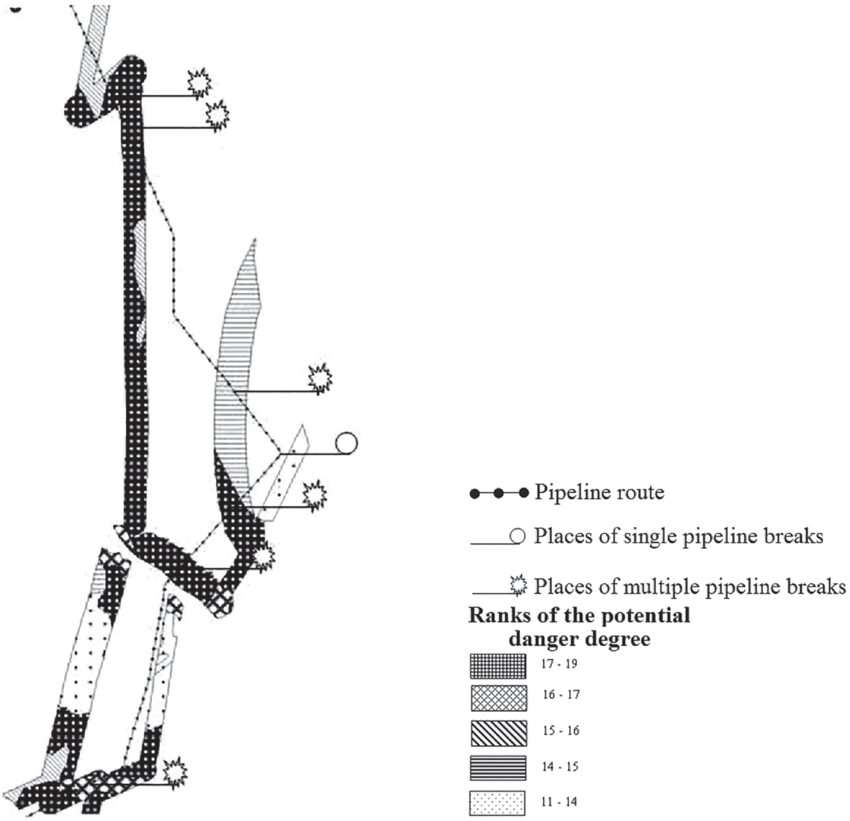

Fig. 4. Map of potentially hazardous zones in the vicinity of the pipeline route, built using GIS MapInfo

of one neuron are weighted and used to calculate the output signal. The number of layers and neurons in a layer can vary for each scenario. This type of network is called a multilayer perceptron. The results of Advangeo are: maps of the probability of occurrence of an event of interest (e.g., a pipeline accident) or maps illustrating a quantitative forecast of the parameter in question (e e.g., mineral content in rocks).

Results and discussion

As a result of overlay operations, a map of potentially dangerous zones is obtained (Fig. 3).

The obtained results fairly well agree with the recorded pipeline breaks, which which were not involved in the ANN training process (red stars in Fig. 3). In addition, the obtained results were compared with the results of mathematical cartographic modeling of similar zones of the same object using the GIS MapInfo. The results are shown in Fig. 4.

Conclusions

The results obtained show that the integration of GIS and ANN in the form of the Advance software package makes it possible to predict the zones of possible pipeline accidents and to differentiate the degree of danger within these zones. The approach presented above for identifying environmentally hazardous zones serves as the basis for zoning the territory through which the pipeline is supposed to be laid. The list of factors taken into account may be changed depending on the degree of importance of objects, their length, availability of necessary information, etc. Zoning of the territory along the pipeline route according to the degree of accident risk allows to tmake a decision on additional measures to protect the pipeline or make changes in the position of the future route in this section in advance, at the design stage.

REFERENCES

1. Askarov, R. M. et al. (2017). Features of stress corrosion cracking at the present stage of operation of magi-stralny gas pipelines Gas Industry, 10, 40–45.

2. Official site of the company Advangeo Beak Consultants. URL: https://www.beak.de/advangeo/advangeo_prediction/home (Access date: 10.02.2022).

3. Bidenko, S. I. et al. (2019). Assessment of the territorial situation with the use of artificial neural networks. Scientific Notes of the Russian State Hydrometeorological University (RSMU), 54, 109–123.

4. Grebenyuk, G. N. et al. (2011). Trunk oil pipelines and their impact on the environment. Izvestiya Samara Scientific Center of the Russian Academy of Sciences, 13 1(5), 1260–1263.

5. Gumerov, A. G. et al. (1998). Emergency repair of trunk oil pipelines. Moscow: Nedra — Businesscenter LLC, 271.

6. Kasyanova, N. A., Kuzmin, Yu. O. (1996). Modern anomalous geodynamics of the subsurface and its impact on the objects of the oil and gas complex. Moscow: Geoinformmark, 55.

7. Melnikov, E. K., Shabarov, A. N. (2010). Assessment of the role of geodynamic factor in accidents-news of pipeline systems. *Journal of Mining Institute*, 188, 203–206.

8. Mohammed N. E. et al. (2010). Framework for integration between Artificial Neural Network & Geographical Information System. Slum prediction as the case study. International Journal of Electrical & Computer Sciences IJECS-IJENS, 10(1), 25–39.

9. Orlova, A. V. (1975). Block structures and relief. Moscow: Nedra, 230.

10. Osipov, A. G., Dmitriev, V. V., Maslennikov, S. A., Plastinin, L. A., & Plyusnin, V. M. (2017). Cartographic modeling of pipeline routes in the arctic zone of siberia. Geography and Natural Resources, 38(1), 12–19. doi:10.1134/S1875372817010024.

11. Pimakhin, A. N. et al. (2003) Accidents at oil fields and main gas pipelines. On the state of the environment of the Khanty-Mansi Autonomous Okrug (inform. byul.) Yugra in 2003. Khanty-Mansiysk: Polygraphist, 104.

12. Rasputin, A. N. et al (2009) Application of geo-information systems for assessing the influence of natural factors on the technical condition of the main gas pipelines of Gazprom Transgaz Yekaterinburg LLC. Gas Industry, 11, 81–83.

13. Solodovnikov, A. Yu. (2007). The impact of oil and gas pipelines on the environment in the Tyumen region: factors and consequences. Bulletin of St. Petersburg State University, 7(4), 85–95.

14. Dvoynikov, M., Buslaev, G., Kunshin, A., Sidorov, D., Kraslawski, A., & Budovskaya, M. (2021). New Concepts of Hydrogen Production and Storage in Arctic Region. Resources, 10(1), 3. DOI: 10.3390/resources10010003.

15. Strokova, L. A., & Ermolaeva, A. V. (2016). Zoning according to the hazard level of earth surface subsidence when designing the main gas pipeline in south yakutia. Bulletin of the Tomsk Polytechnic University, Geo Assets Engineering, 327(10), 59–68.

16. Terekhov, S. A. et al. (2000). An approach to modeling elements of the main gas pipeline based on artificial neural networks. Radioelectronics, informatics, management, 1(3), 116–122.

17. Khizhnyakov, V. I. et al. (2011). Corrosion cracking — deformed pipeline transportation of oil and gas. Bulletin of Tomsk Polytechnic University, 319(3), 84–89.

18. Hill, R. T., Catmur, J. R. (1995). Risks from Hazardous Pipelines in the United Kingdom. HSE Contract Research Report no. 82/1994.
19. Chikharev, V. A. (2012). The use of geoinformation technologies in conducting geotechnical monitoring of pipeline transport. Pipeline transport. Monitoring and transport, 4(32), 1–6.
20. Egorov, A. S., Prischepa, O. M., Nefedov, Y. V., Kontorovich, V. A., & Vinokurov, I. Y. (2021). Deep structure, tectonics and petroleum potential of the western sector of the Russian Arctic. Journal of Marine Science and Engineering, 9(3), 1–26. doi:10.3390/jmse9030258.
21. Dumitrescu, A., Minescu, M., Dinita, A., & Lambrescu, I. (2021). Corrosion repair of pipelines using modern composite materials systems: A numerical performance evaluation. Energies, 14(3). doi:10.3390/en14030615.
22. Yannikov A. M., Yannikova S. A., Korepanov A. Yu. Influence of tectonic faults on the projected advanced water reduction systems on the example of the "Yubileynaya" pipe. *MIAB. Mining Inf. Anal. Bull.* 2022;(5–2):174—186. [In Russ]. DOI: 10.25018/0236_1493_2022_52_0_174 ГИАБ

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ЭНЕРГЕТИЧЕСКАЯ ОСНОВА ОСВОЕНИЯ МИНЕРАЛЬНО-СЫРЬЕВЫХ РЕСУРСОВ АРКТИЧЕСКИХ РАЙОНОВ ЯКУТИИ

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Аннотация: обозначена необходимость поиска и разведки углеводородных энергоресурсов для эффективного освоения богатых минерально-сырьевых ресурсов Арктической зоны Республики Саха (Якутия). Построена схема размещения основных объектов минерально-сырьевой базы арктических районов Республики Саха (Якутия) и перспективных на нефть и газ территорий. На западном секторе Арктической зоны Республики Саха (Якутия) в качестве первоочередного объекта выделено Южно-Тигянское месторождение тяжелой нефти. Сделан вывод о большом потенциале наращивания сырьевой базы месторождения, который можно реализовать в краткосрочной перспективе. Оленекское месторождение природного битума предлагается рассмотреть, как перспективный объект добычи нефтепродуктов в долгосрочной перспективе. На восточном секторе Арктической зоны Республики Саха (Якутия) предложено заложить глубокую поисково-оценочную скважину в пределах Тастахского прогиба, расположенного в непосредственной близости от Северного морского пути. Отмечена необходимость проведения тематических исследований по перспективам нефтегазоносности Индигиро-Зырянского прогиба с учетом всех возможных причин получения отрицательных результатов бурения. Для освоения остальных отдаленных районов восточного сектора Арктической зоны Республики Саха (Якутия) предложено рассмотреть вопрос получения моторного топлива из бурых углей.

Ключевые слова: освоение ресурсов Арктической зоны, минерально-сырьевая база, месторождение, нефтегазоность, энергообеспечение, уголь, моторное топливо.

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The energy basis for the development of mineral resources in the Arctic regions of Yakutia

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Abstract: The necessity of search and exploration of hydrocarbon energy resources for effective development of rich mineral resources of the Arctic zone of the Republic of Sakha (Yakutia) is outlined. The layout of the main sites of the mineral resource base of the Arctic regions of the Republic of Sakha (Yakutia) and promising oil and gas territories was constructed. In the western sector of the Arctic zone of the Republic of Sakha (Yakutia), the Yuzhno-Tigyanskoye field of heavy oils is identified as a priority object. The conclusion is made about the great potential of increasing the raw material base of the field, which can be implemented in the short term. Olenek natural bitumen field is proposed to be considered as a promising object of oil products production in the long term. In the eastern sector of the Arctic zone of the Republic of Sakha (Yakutia) it is proposed to lay a deep exploration and appraisal well within the Tastakh trough, located in close proximity to the Northern Sea Route. The necessity of carrying out thematic studies on the prospects of oil and gas content in the Indigiro-Zyryansky Trough was noted, taking into account all possible reasons for the negative results of drilling. For the development of other remote areas in the eastern sector of the Arctic zone of the Republic of Sakha (Yakutia), it is proposed to consider the issue of obtaining motor fuel from lignite.

Key words: development of resources of the Arctic zone, mineral resource base, deposit occurrence, oil-and-gas-bearing capacity, energy supply, coal, motor fuel.

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Introduction

The Arctic zone of the Republic of Sakha (Yakutia) covers the territory of 13 districts and occupies more than half of the entire territory of the republic. Only 67674 people lived on this vast territory as of 01.01.2019 [1]. Extreme climatic conditions causing long heating seasons, absence of reliable year-round transportation system, high cost of imported life-supporting cargoes, low income level of population and expensive decentralized power supply make the Arctic regions extremely depressive for human habitation.

The basis for qualitative improvement of human life in the Arctic regions can only be full-scale effective development of rich mineral resources of the territory [2, 3]. There are large and unique deposits of diamonds, gold, non-ferrous and rare-earth metals, coal, fossil mammoth bone, etc. The effective development of the extractive industry is impossible without solving the issue of energy supply and, above all, affordable motor fuel.

Currently, the most convenient and reliable fossil raw materials for energy supply and motor fuel production are hydrocarbons. For allocation of potential clusters on development of Arctic regions it is necessary to consider comprehensively a condition of a mineral-raw-material base and prospects of oil-and-gas bearing capacity of northern territories.

Major mineral and raw material projects

The Arctic regions of the Republic of Sakha (Yakutia) are notable for their poor geological and geophysical knowledge due to their complex natural and climatic conditions and lack of reliable transport infrastructure. At the same time, even the existing mineral resource base, prepared mainly in the Soviet era, makes it possible to outline large investment projects (Fig. 1).

On August 14, 2020, the Strategy of socio-economic development of the Arctic zone of the Republic of Sakha (Yakutia) for the period up to 2035 was approved [1]. The baseline scenario involves the implementation of priority measures for the development and exploitation of the mineral resource base, as well as transport and energy.

Thus, extensive development and exploitation of the mineral resource base is expected in the Anabar and Olenek districts. In the short term, the development of the world's largest deposit of rare-earth metals (niobium, terbium, yttrium and scandium) will begin. As

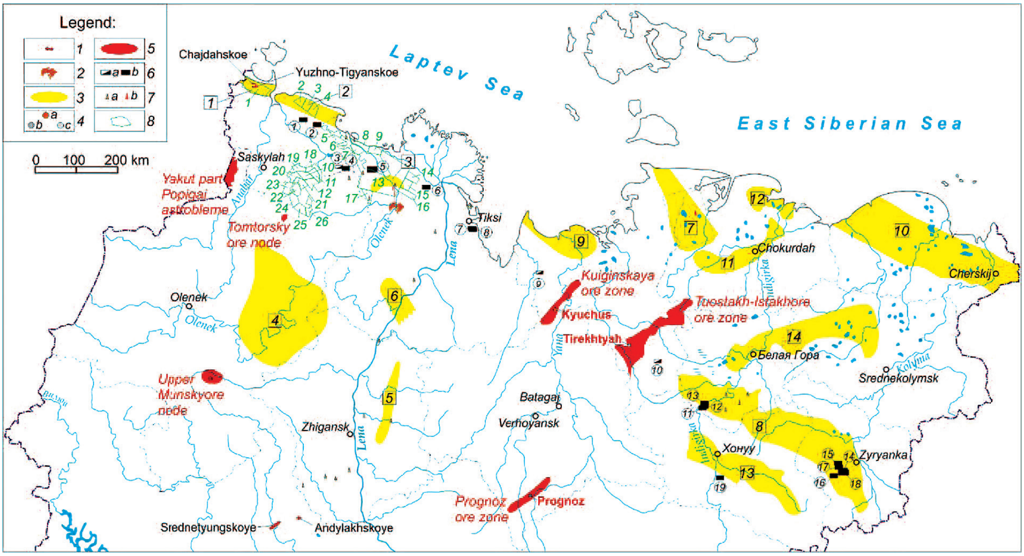

Fig. 1. Layout of the main objects of the mineral and raw material base of the Arctic regions and promising oil and gas areas.

Legend: *1* — oil and gas fields; *2* — Olenekskoye deposit of natural bitumen; *3* — promising areas for oil and gas: *4* — deposits: a — gold, 6 — silver, *3* — tin; *5* — ore zones; *6* — coal deposits: a — lignite coal, 6 — hard coal; *7* — wells: a — drilled, 6 — recommended; *8* — hydrocarbon feedstock

Promising territories for oil and gas (Fig.s in the square): *1* — Yuzhno-Tigyanskoye field, *2* — Pronchishchevsky swell, *3* — Tyumetinsky protrusion, *4* — Sukhonskaya depression, *5* — Sobolokh-Mayan swell, *6* — Kyutyungdik block, *7* — Tastakh trough, *8* — Indigiro-Zyryansky trough, *9* — Nizhneyansky trough, *10* — South Anyu suture zone, *11* — Berelekhsky trough, *12* — Goose depression, *13* — Momsky trough, *14* — The Alazeian-Indigir system of depressions.

Coal deposits (Fig.s in circles): *1* — Salga, *2* — Chaidakh, *3* — Kumakh-Yuryakh, *4* — Buolkalaakh, *5* — Taymylyr, *6* — Chay-Tumus, *7* — Soyginskoye (Northern), *8* — Soyginskoye (Southern), *9* — Kularskoe, *10* — Uyandinskoe, *11* — Krasnorechenskoye (Sogolokh), *12* — Krasnorechenskoye (Shakhtnoye), *13* — Krasnorechenskoye (Razrez), *14* — Erozionnoe (Buor-Kemyusskoy), *15* — Sibik -2, *16* — Kharanga, *17* — Erozionnoe (Zyryanskij), *18* — Buor-Kemyusskoy, *19* — Tikhonskoe.

List of subsoil areas on hydrocarbons (green numbers): *1*. Zapadno-Anabrsky (Anabarneftegaz LLC), *2*. Punchischevsky Western (ARKTika LLC), *3*. Pronchischevsky Central (ARKTika LLC), *4*. Pronchischevsky Eastern (LLC ARKTika), *5*. Tirekhtyakhsky (LLC Taimylyrneftegaz), *6*. Ust-Buolkalaakhsky (LLC Taimylyrneftegaz),*7*. Bulunsky (LLC Yakutskneftegaz), *8*. Bysarsky (OOO Yakutskneftegaz), *9*. Yurdyuksky (OOO Yakutskneftegaz), *10*. Khastyrsky (OOO Olenekneftegaz), *11*. Nuorakhtakhsky (LLC Olenekneftegaz), *12*. Surtakhsky (LLC Olenekneftegaz), *13*. Tyumyatinsky (Surgutneftegaz), *14* Ulakhan-Yuryakhsky (Olonkho Mining LLC), *15*. Kuogastakhsky (Dezhnev Mining LLC), *16*. Kelimersky (Olonkho Mining LLC), *17*. Kyup-Chopkinskiy (Olonkho Mining LLC), *18*. Verkhnekhatygynsky (Dyuglyuneftegaz LLC), *19*. Arakh-Bilirsky, *20*. Verkhne-Balagannakhsky, *21*. Nizhne-Balagannakhsky (LLC Bilirneftegaz), *22*. Bilirsky (LLC Bilirneftegaz), *23*. Grigorievsky (LLC Bilirneftegaz), *24*. Nizhneonnekhoysky (Udyakanneftegaz LLC), *25*. Udyakansky (Udyakanneftegaz LLC), *26*. Verkhneudyakanskiy (LLC Tamalakanneftegaz).

of 01.01.2019, there are 86.4 thousand tons of niobium, 0.43 thousand tons of scandium and 139 thousand tons of rare earths under categories C1 and C2 in the State Balance of the Russian Federation for the Tomtor ore cluster. According to an independent assessment, according to the JORC Code (2012), Tomtor deposit contains 700 thousand tons of niobium and 1.7 million tons of rare earth oxides, which makes it the world's third largest deposit of rare earth metals [4].

In the Yano-Indigirskiy and Kolyma regions, it is planned to resume and expand mining of ore and alluvial gold, silver, and tin.

The Kyuchus gold ore deposit is located in the lower reaches of the Kyuchus River, a left tributary of the Yana River in the Verkhoyanskiy district. On the state balance sheet as of 01.01.2019, the reserves of the Kyuchus deposit by categories $A+B+C_1+C_2$ are 175.262 tons of gold with an average grade of 7—9 g/t.

'Prognoz' silver deposit. The deposit contains large reserves of rich ore. As of 01.01.2019, 9748.6 tons of silver in categories C_1+C_2. by category at an average grade of 560 g per ton of ore. Inferred resources are estimated at 2,320 tons of silver. Expected annual production of silver is 420 tons.

'Tirekhtyakh' alluvial tin deposit is located in the North-Yan tin-bearing district in the territory of the Ust-Yan district. The state balance sheet of the Russian Federation takes into account the reserves for open-pit mining in the amount of 74 268 tons by categories $A+B+C_1+C_2$. Average tin content is 814.13 g/m^3. Expected annual tin production is 3,500 tons.

In addition to the major projects outlined in the Strategy, the Verkhnemunskoye diamond mining enterprise will reach its design capacity of 3 million tons of ore per year in the Oleneksky district with reserves until 2041. There are plans to develop the Popigayskoye field of impact diamonds, which is located on the border of the Krasnoyarsk region and Yakutia in the area of Popigayskaya astroblem — a hundred-kilometer meteorite crater. Reliable reserves and inferred resources of impact diamonds in high-diamond-bearing primary rocks on a total area of about 120 km^2 in Popigaysky area are up to 212 billion carats [5]. In addition to this volume in the 50 m layer of impactites on the rest of the area (about 1020 km^2), in addition to the areas of deposits and promising sites, is about 150 billion carats (with a confidence coefficient of 0.5) [6].

All the mentioned large projects have a high investment capacity, which could be significantly reduced if there were available raw materials for energy resources, including motor fuel. In addition, in the Arctic zone of Yakutia 94% of the installed capacity of decentralized energy systems are diesel power plants, 4.5% — mini-CHPs and only 1.3% — renewable energy sources (solar panels and wind installations) [7]. Taking into account the low rates of modernization of remote low-power energy systems, diesel fuel will remain the only source of energy for a long time.

In connection with the above and the planned in the Energy Strategy of the Russian Federation for the period up to 2035 [8] global projects of development of the Arctic, the search for oil and gas fields for the formation of new oil and gas mineral centers becomes an urgent task.

Prospects of oil and gas potential

Western sector

Virtually the entire western part of the Arctic zone of the republic, which belongs in tectonic terms to the northeastern part of the Siberian platform, is in one way or another promising for oil and gas. In this regard, Fig. 1 highlights only the areas where accelerated preparation of raw materials for energy resources is possible. The most promising appears to be the Anabar-Khatanga saddle, where in the 40—50s of the last century 5 non-industrial (in our opinion, due to their underexplored) oil fields were discovered — Nordvik, Ilya, Kozhevnikovskoe, Chaidakhskoe and Yuzhno-Tigyanskoe. The last two are

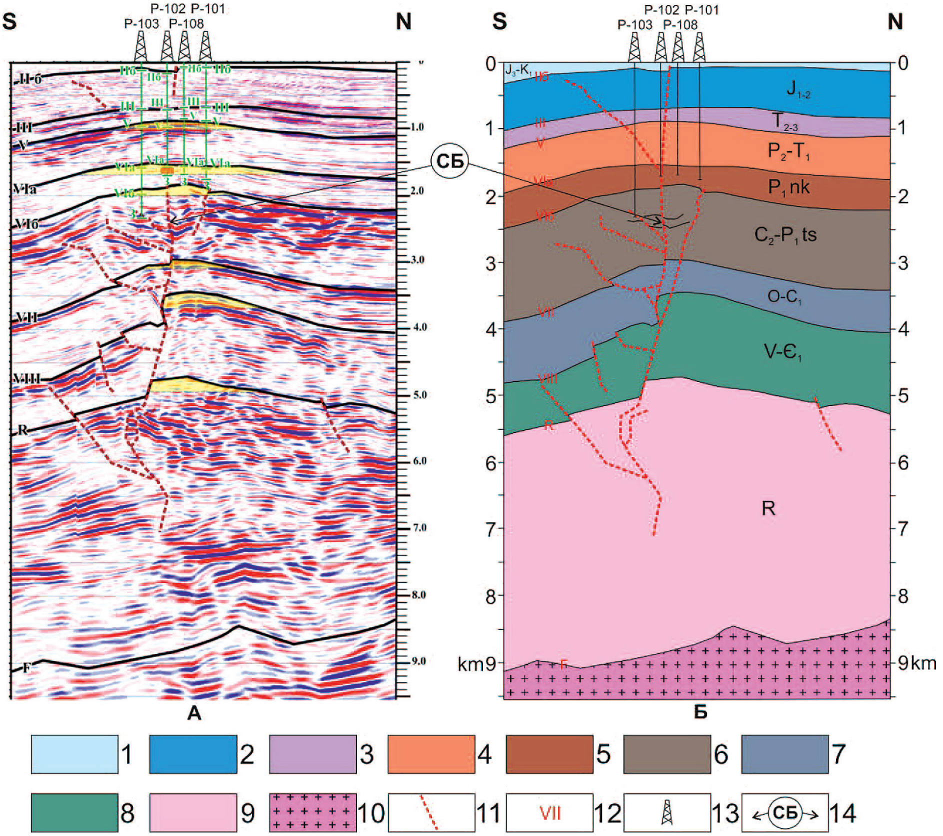

Fig. 2. Seismogeological section along the section of profile 050311 on the Western dome of the South Tigyan structure [8, 9].

Legend: deposits: 1 — upper Jurassic-lower Cretaceous, *2* — lower — middle Jurassic, *3*–, mediumverkhnetarasovka, *4* — upper Permian-lower Triassic, *5* — Nizhnetagilsky Suite lower Permian, *6* — section of upper Carboniferous-lower Permian (custosa Suite), *7* — Ordovician-lower Carboniferous, *8* — Vendian-lower Cambrian, *9* — Riphean; *10* — basement; *11* — faults; *12* — indices of the reflecting horizons; *13* — borehole; *14* — area of transition fault on reset.

located on the territory of the republic within the Zapadno-Anabarsky license area. The only well (No. 102-R) which gives commercial oil flow is located in the Yuzhno-Tigyanskaya area (oil flow rate is up to 15.3 m^3/day and gas flow rate is up to 1,455 m^3/day). Author's estimate of geological reserves of oil from horizon XI was 1.448 million tons by category C_1 [9].

Recent studies [10, 11] have proposed a new model for the structure of the Yuzhno-Tigyan field, suggesting the presence of a major producing accumulation in the lower part of the section (Fig. 2). It is recommended to drill a prospecting and appraisal well with a design depth of 5000 m, which, if successful, will significantly increase the reserves, and if negative, will put the existing reserves on the State balance. The fact that in 2017 Rosneft discovered the Tsentralno-Olginskoye field in Khatanga Bay, which is large in terms of reserves, testifies to the high prospects of the area.

A number of parametric and prospecting wells were drilled within

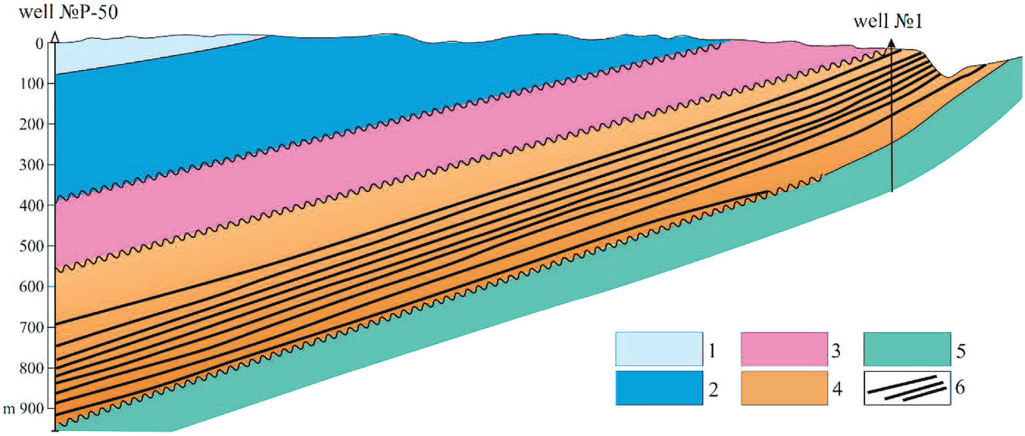

Fig. 3. Schematic profile section of the Olenek natural bitumen field.
Legend: 1 — Middle Jurassic deposits, *2* — Lower Jurassic deposits, *3* — Lower Triassic deposits, *4* — Permian deposits, *5* — Upper Cambrian deposits, *6* — bituminous layers

the Lena-Anabar trough and the adjacent territory of the Predverkhoyanskiy trough in the second half of the 20th century (Fig. 1). Only indications of the oil and gas content of the section (bituminous and gas showings) were recorded. In the short term on these territories of oil and gas deposits discovery is not expected. General characteristics of oil-and-gas bearing capacity of these territories is reflected in work [12].

Under a certain situation in the world market of hydrocarbons the organization of heavy oil production from the Olenek natural bitumen field may be of interest. It is located in the lower reaches of the Olenek river and is a relic of a giant oil field [13], confined to the zone of wedging of Permian deposits on the northern slope of the Olenek uplift (Fig. 3). According to the results of NIIGA (1966—1967) the bitumen resources of the Olenek field are estimated at a total of 3.5 billion tons. Explored reserves by category C_2 in the Ust-Bur area of 16 km^2 amount to 15.2 million tons [14].

Eastern sector

According to a number of geological assumptions, some territories within the limits of North-Eastern Yakutia are potentially oil and gas-bearing as well (Fig. 1) [15]. These are, first of all, the Indigiro-Zyryansky trough, made by carbonaceous terrigenous-volcanogenic deposits of Jurassic, Cretaceous and Cenozoic age. Four prospecting and appraisal wells were drilled in the western part of the Indigiro-Zyryansky trough. The actual depth of the wells was 1066—1611 m and the total penetration was 5126 meters. No oil and gas discoveries were made upon completion of drilling operations. For the Indigiro-Zyryanskiy Trough, additional case studies should be carried out, taking into account all possible reasons for the negative drilling results. Very likely, gas deposits were missed [16].

Also promising and to some extent prepared for deep drilling in the eastern sector of the Arctic zone is the Tastakh Trough (Fig. 1). Discovery of weakly oxidized oils in the Omulevsk block [17] and high bituminosity of the Selenniakh block [18] give reason to be optimistic about the prospects of oil and gas content of the predicted Middle Paleozoic deposits within the Tastakh Trough as well. This issue will remain open until deep parametric and exploratory drilling. In [19], it was recommended to make a parametric borehole on the northeastern side of the trough with a depth of up to 4000 m. Here, special prospects are associated with the Middle Paleozoic Domanikoid sediments, which may contain oil deposits. The proximity of the Tastakh Trough to the route of the Northern Sea Route is an important favorable infrastructural and investment factor.

Taking into account the duration of oil and gas prospecting and exploration processes, as well as their preparation for industrial development (15 — 20 years) in the short and medium term it is necessary to consider options of using alternative sources of energy resources and motor fuel. Currently, in the Arctic zone of the Republic of Sakha (Yakutia) the only traditional available raw materials for energy is hard coal (Fig. 1). However, the high environmental requirements in the Arctic [20, 21] and the policy of decarbonization supported at the state level, taking into account the quality indicators of coals [22, 23], are unlikely to allow the use of coal as a direct fuel for mini-cogeneration plants.

At the same time, domestic and world practice has accumulated considerable experience in obtaining liquid fuels from coals [24, 25, 26]. The most acceptable raw material for obtaining synthetic fuel is lignite, which is widespread in the Arctic zone of the republic. The increase in prices of petroleum products due to the increase in the cost of oil production and high transportation costs in the absence of stable transportation schemes can make coal a promising raw material for the production of liquid fuels in remote areas of the Arctic.

Conclusion

In the harsh natural and climatic conditions of the Arctic, energy is becoming a basic indicator of the quality of human life. The energy crisis of autumn 2021 in Europe showed the dominant role of traditional energy sources and the need for a smoother transition to renewable energy sources [27, 28].

For accelerated and integrated development of mineral resources in the Arctic zone of the Republic of Sakha (Yakutia), it is necessary to involve local energy resources. In the short term, the Anabaro-Olenek industrial cluster may become the main point of growth. Here there is an opportunity of accelerated build-up of raw hydrocarbon base — as an energy basis for implementation of major projects. In Yano-Indigirskiy and Kolyma districts it is necessary to carry out priority exploration for oil and gas at the expense of federal funds. Until large deposits of oil and gas are identified, it is advisable to consider options for the use of hard coal as a basis for energy.

REFERENCES

1. 2020 On the Fundamentals of State Policy of the Russian Federation in the Arctic for the p 2035 Deeriod up tocree of the President of the Russian Federation from 05.03.2020 no.164. URL: http://www.pravo.gov.ru (Access date: 10.02.2022).

2. Romasheva, N., Dmitrieva, D. (2021). Energy resources exploitation in the russian arctic: Challenges and prospects for the sustainable development of the ecosystem, Energies, 62932, 14 (24):8300. DOI: 10.3390/en14248300.

3. Ilinova, A., Solovyova, V., Yudin, S. (2020). Scenario-based forecasting of Russian Arctic energy shelf development, Energy Reports, 21100389511, 6:1349–1355. DOI: 10.1016/j.egyr.2020.11.022.

4. 2021 Initial estimation of Tomtor Ore Reserves Polymetal International plc press release. URL: https://www.polymetalinternational.com/ru/investors-and-media/news/press-releases/19–04–2021/?month=&q=&year=2021&current=2 (Access date: 10.02.2022).

5. Simonov, O. N. (2004). Efficiency of prediction and search for impact diamonds in the Popigai Astrobleme: a retrospective view. Materials of the scientific-practical conference dedicated to the 50th anniversary of the discovery of the first diamondiferous kimberlite pipe «Zarnitsa» (St. Petersburg: VSEGEI Publishing House), 323–326.
6. Masaitis, V. L. (2013). Indigenous deposits and placers of impact diamonds of the Popigai region (Northern Siberia), Regional geology and metallogeny, 54, 89–98.
7. Ivanov, A. V. (2021). Development of Electric Power Industry in the Arctic Regions of the Russian Federation with Regard to the Use of Renewable Energy Sources. Russian Arctic, 13, 62–80. DOI: 10.24412/2658–4255–2021–2-62–80.
8. 2020 Energy Strategy of the Russian Federation for the period until 2035 Decree of the Government of the Russian Federation of June 9, 2020 no. 1523-r. URL: http://www.pravo.gov.ru (Access date: 10.02.2022).
9. Safronov, A. F. (1996). Yuzhno-Tigyan oil field Reports of the First International Conference of the Northern Forum Academy (Yakutsk: Izd. Severoved), 167–169.
10. Sivtzev, A. I. (2017). Model of the South-Tegyansky field of heavy oil. Georesursy, 19(3), 279–283. DOI: 10.18599/grs.19.3.20.
11. Lemeshev, Ya. (2021). On the Issue of Isolated Well Productivity in a Number of Areas of the Republic of Sakha (Yakutia). IOP Conf. Series: Earth and Environmental Science, 720, 012099. DOI: 10.1088/1755–1315/720/1/012099.
12. Sivtsev, A. I., Aleksandrov, A. R. (2017). Prospects of oil and gas bearing capacity of Lena-Anabar trough Proceedings of the VII All-Russian scientific and practical conference dedicated to the 60th anniversary of the Institute of Geology of Diamond and Noble Metals, Siberian Branch of the Russian Academy of Sciences, April 5–7, Yakutsk 228–233.
13. Safronov, A. F., Sivtsev, A. I. (2018). History of the formation of the Olenek natural bitumens field. Geology of Oil and Gas, 1, 115–120.
14. Kosachuk, G. P. (2014). Development of natural bitumen accumulations as a prospect of fuel and energy resources development in the Republic of Sakha (Yakutia). Vesti gazovoy nauki, 4(20), 50–58.
15. Sitnikov, V. S. (2017). On the structure and prospects of oil and gas content of the shelf arctic territories of Eastern Yakutia. Science and Education, 4, 50–59. DOI: 10.23670/IRJ.2020.102.12.037.
16. Petrov, D. M., Sivtsev, A. I. (2021). Causes of negative results in structural-parametric drilling within the Indigiro-Zyryanskiy trough Proceedings of the XV International Scientific and Practical Conference «New Ideas in the Earth Sciences» (Moscow: Publishing house of Russian State University named after Sergo Ordzhonikidze), 69–71.
17. Shishkin, V. A., Ganov, A. P. (2010). Prospects of oil and gas bearing capacity of the southern part of the Taskan structural zone of the Omulevsk uplift Bulletin of the North-Eastern Scientific Center of FEB RAS, 2, 8–13.
18. Sivtsev, A. I. (2020). Selennyakh block: geological position and issues of oil and gas bearing capacity of Eastern Yakutia Materials of X All-Russian scientific and practical conference with international participation (Yakutsk : Publishing house of NEFU) 294–297.
19. Sivtsev, A. I, Aleksandrov, A. R. (2018). Inferred section of the Tastakh trough In the collection: Geology and mineral resources of the North-East of Russia. Proceedings of the VIII All-Russian scientific and practical conference, 326–330.
20. Zhukovskiy, Y., Tsvetkov, P., Buldysko, A., et al. (2021). Scenario modeling of sustainable development of energy supply in the Arctic. Resources, 10(12), 124. DOI: 10.3390/resources10120124.
21. Pesterev A. P. Assessment of the impact of mining activities on the environment of arctic north taiga landscapes. *MIAB. Mining Inf. Anal. Bull.* 2022;(5–2):187-197. [In Russ]. DOI: 10.25018/0236_1493_2022_52_0_187.

22. 2020 On the approval of the Energy Strategy of the Russian Federation for the period up to 2035 Decree of the Government of the Russian Federation of 09.06.2020 no. 1523-r. URL: http://www.pravo.gov.ru (Access date: 10.02.2022).
23. Epshtein S. A., Shinkin V. K. Quality indices of coals for different directions of use. *MIAB. Mining Inf. Anal. Bull.* 2022;(4):5-16. [In Russ]. DOI: 10.25018/0236_1493_2022_4_0_5.
24. Kreinin, E. V. (2011). Prospects of Synthetic Motor Fuels Production from Coal by its Underground Gasification Gas Industry, 3(657), 65–67.
25. Nabiev, M. (2015). Gasification of coal and gas production for synthesis of motor fuels Innovations in Science, 51–1, 150–155.
26. Tsarkov, A. N. (2007). Development of technology for obtaining synthetic motor fuels from lignite. Proceedings of the Institute of Engineering Physics, 4(6), 59–63.
27. Dvoynikov, M., Buslaev, G., Kunshin, A., Sidorov, D., Kraslawski, A., & Budovskaya, M. (2021). New Concepts of Hydrogen Production and Storage in Arctic Region. Resources, 10(1), 3. DOI: 10.3390/resources10010003.
28. Tcvetkov, P., Cherepovitsyn, A., & Fedoseev, S. (2019). The Changing Role of CO2 in the Transition to a Circular Economy: Review of Carbon Sequestration Projects. Sustainability, 11(20), 5834. DOI: 10.3390/su11205834 ГИАБ

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