Prospective industrial complexes in the Russian Arctic: focus on rare-earth metals

Victoria Solovyova[1,*] and *Alina* Cherepovitsyna[2]

[1]PhD in Economics, Assistant, St. Petersburg Mining University, 199106, St. Petersburg, Russia
[2]PhD in Economics, Senior Researcher, Luzin Institute for Economic Studies – Subdivision of the Federal Research Centre, Kola Science Centre of the Russian Academy of Science, 184209, Apatity, Russia

Abstract. At present, issues related to the development of rare-earth metal industrial complexes are becoming particularly relevant for Russia. Rare-earth metals (REMs) play a vital role in high technology. Therefore, success in technological progress largely depends on the availability of these metals. However, the country's position remains uncertain – on the one hand, Russia possesses huge REM reserves, on the other hand, they are not exploited, and the existing level of import dependence of metals on supplies from foreign countries exceeds 80%. The main national REM reserves are in the Arctic region. Nevertheless, even rich deposits are still not exploited. This study aims to investigate the prospects for the development of REM industrial complexes in the Russian Arctic, taking into account both opportunities and constraints. The resource potential of REMs in the Russian Arctic is investigated, a comparative analysis of the characteristics of foreign and national REM objects is provided. The factors influencing the prospects of development of REM industrial raw material complexes are determined. Data on the main REM projects are systematized. The study makes it possible to draw some important conclusions about the current prospects for the development of rare-earth metal industrial raw materials complexes in the Russian Arctic.

1 Introduction

In recent years, the importance of rare-earth metals for the global economy has increased. This is primarily due to the intensive development of new technologies [1, 2]. Currently, these metals contribute to the climate agenda issues and to the advance of low-carbon path, as they are used in electric cars, wind turbines, and other progressive "green" technologies.

Russia, on a par with other developed countries, is trying to expand science-intensive industries, which include rocket and space, radioelectronic, aviation industries, as well as a number of industries related to information and communication technologies and medicine [3]. Currently, rare-earth metals are required in production of modern engines PD-14, PD-35, GTU (aviation industry), electronic devices and equipment, microcircuits (radio-electronic industry), etc. [1, 2].

The rare-earth crisis (2011-2012) proved the unreliability of the global supply system of REMs from China. Recently, rare-earths have become a "geopolitical tool". In this way, China as the main monopolist of the world REM market, is trying to influence the economics of other countries. Therefore, under current conditions, the need to develop national mining and processing industries to produce the required rare-earth metal products seems obvious [4]. In this context, the Arctic region is of particular interest. It is here that the largest sources of rare-earth raw materials are located – the deposits of the Khibiny massif, as well as Tomtor, Lovozero and Africanda deposits [5].

At the same time, the development of the Arctic territories is one of the most difficult directions in a view of geological features, specific natural and climatic conditions, infrastructure constraints, high level of environmental risks, etc. [6-10]. It is assumed that the Northern eco-systems are fragile and unstable. This requires strict compliance with the environmental standards and demands. The situation is aggravated by the specificity of rare-earth metal sources, imperfection of the existing system of subsoil use management, lack of experience in implementing mega projects, insufficient level of technological availability.

The "Strategy for the Development of the Arctic Zone of the Russian Federation and National Security for the period up to 2035" states the necessity to develop rare-earth metal sources (in particular, the Lovozero deposit) as one of the key priority areas of development the Arctic [11]. Meanwhile, specific measures to implement this direction have not been established. It is not clear what are the prospects for the exploitation of REM deposits in the Russian Arctic, when the planned projects will be implemented, whether the Arctic region will become the basis for the development of REM industry in the country, what is needed to create REM raw material complexes with a full technological cycle, how to ensure environmental safety. All these unresolved questions

* Corresponding author: vikasolovyova9@gmail.com

determine the relevance and the significance of the research offered.

2 Literature review and research design

There is a large volume of published research describing the role of rare-earth metal industry development. Rare-earths are among the most important and strategic minerals and have been called "vitamins of modern society". It is predicted that in the near future competition for access to these metals will be comparable to the competition in the world oil and gas market [12-15].

Russian researchers investigate key trends of the national and global REM market. Much of the current literature focuses on the identification of existing problems and barriers associated with the exploitation of the rare-earth mineral resource base. These include the high level of environmental risks, the low level of economic efficiency of REM projects, the declarative nature of legal regulation, and low indicators of domestic demand for rare-earth products [16-19]. Meanwhile, despite of all the difficulties, national researchers agree that the development of rare-earth metal industry is essential to ensure the sustainable development of high-tech industries [20]. Given the complicity of the organization of rare-earth metal industrial complexes, questions related to reliable prospects for their creation and further development remain open.

One of Russia's key advantages in the development of its rare-earth metal mineral resource base is its rich resource potential, much of which is concentrated in the Arctic region [7,9,21-22]. Domestic scientists have repeatedly emphasized the strategic importance of the Arctic territories in capacity as the main source of critically and strategically important minerals, including rare-earth metals [23-25]. According to the theses of the report by Yu. Ampilov at the 6th International Conference "Arctic 2021", in order to efficiently explore the Arctic region, it is advisable to focus not on the intensification of the exploitation of hydrocarbon resources, but on the implementation of REM projects [26]. This is explained by the changing market conditions – global trends of the energy transition, the spread of "green" technologies, etc.

The methodology of this study includes case studies, system-oriented analysis, decomposition method and comparative analysis. A content-analysis of academic literature and analytical reports on the topic was used. The paper is organized as follows: (1) the role of rare-earth metals for the Russian economy is considered and the necessity of creation of national REM production facilities (mining and refining) is shown, (2) the resource potential REMs in the Arctic region (key deposits, their characteristics) is analysed, (3) the existing environmental restrictions are discussed, (4) reliable prospects for the development of the rare-earth metal industry in the Russian Arctic according to the plans established at the state level are studied and the main factors influencing the creation and further development of the competitive industrial complexes of REMs in the Arctic region are identified.

3 Main part

3.1 Rare-earth industrial complexes: is there a need for development?

In today's world, the significance of rare-earth metals is becoming more and more prominent. These metals are successfully used in the production of catalysts, glass, metallurgical alloys, permanent magnets, etc. [1]. Recent trends related to the global energy transition have proven an overriding importance of this group of metals in terms of the production of "green" technologies [27]. According to estimates by Grand View Research, the annual growth rate of the global rare-earth market reaches 10.4%, which can be explained by the constant expansion of demand for these valuable components [28]. For many countries, rare-earth metals have become "critical" materials. This indicates the limited access to REMs, or rather to the raw sources of their mining. For example, Japan, European countries, and South Korea have no direct access to these resources. China, the main monopolist of the global REM market, cannot be considered as a reliable supplier: constant changes in the quota system, threats of sanctions, etc. This is why other countries are forced to develop long-term strategies on how to ensure their own demand for the necessary metals within the framework of growing needs for REMs [1]. China's share has fallen from 92% in 2010 to 58% in 2020, but the role of this country remains significant [28-29].

Russia, along with other world developed countries is trying to take high positions in the high-tech market [31]. However, the level of import dependence on foreign REM supplies is more than 80% [32]. This can affect the sustainability of such national industries as aircraft and engine construction, shipbuilding industry, nuclear power complex, rocket and space industry, information and communication technologies. Domestic production capacities do not allow to meet the current demand in high value-added products. Russia's share in the global market is only 1.2% [28].

The need to develop the Russian rare-earth industry is reported by the state program "Industry Development and Improving its Competitiveness", the Order of the RF Government "On Approval of the Consolidated Development Strategy of the Manufacturing Industry of the Russian Federation for the Period to 2024 and for the period until 2035" and other regulatory documents [31]. Nevertheless, the REM industry in Russia has not been properly developed.

3.2 Is the Russian Arctic a "growth point" for REM industrial complexes in Russia?

The Arctic territories are known by their abundance of mineral resources [9, 10]. There is an opinion that the Arctic will become a framework for the development of the REM industry in Russia, and it is not accidental [23]. More than 60% of national reserves rare-earth metals (categories A+B+C1) and about 90% of C2 reserves are located there. The total reserves exceed 18 000 thousand tons of ΣTR2O3. This fact allows us to consider the Arctic region as one of the most prospective sources of strategically important minerals [5]. Figure 1 shows the key rare-earth deposits and production capacity of REM products in Russia.

Industrial exploration of rare-earth metals in the Arctic region began during the existence of the USSR. However, despite the presence of a number of promising objects for development, the only source for these metals was and remains the Lovozero deposit (located in the Murmansk region) [33]. Exploitation of this deposit is provided by the Lovozersky mining and processing plant (GOK). Total reserves are estimated at 2600 thousand tons of ΣTR2O3. In 2019, Lovozersky GOK mined 2.7 thousand tons of ΣTR2O3. The concentrate produced here is sent for further processing to Solikamsk Magnesium Plant, which produces light rare-earth metal carbonates. Then, one part of the products is sent to LIT, where REMs are separated into individual components, while another part is exported (due to the limited processing capacity in the country) [5, 33].

In addition to the Lovozero deposit, the apatite-nepheline ores of the Khibiny group of deposits are also known for their reserves of rare-earths. These deposits are developed by Apatit (PhosAgro) and North-West Phosphorus Company (Akron). The commercial products are apatite concentrates and phosphate fertilizers. Rare-earth metals are not extracted into concentrate. REMs are partially transferred to fertilizers, partially to large-tonnage phosphogypsum waste. Nevertheless, a significant portion of rare-earths remains in the tailings [5].

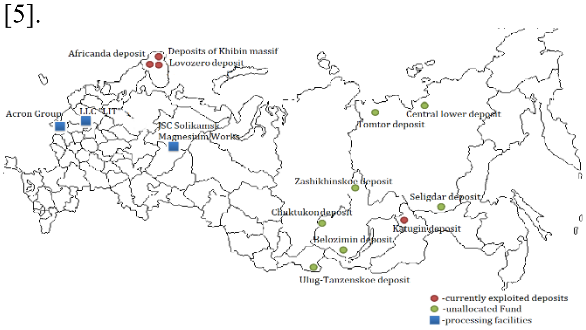
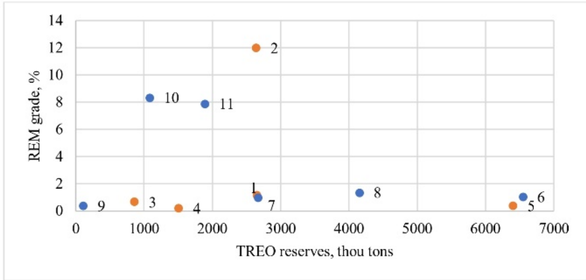


Fig. 1. Rare-earth metal deposits and processing facilities in Russia [5]

Large inferred resources of rare-earths are also located in Africanda perovskite-titanomagnetite deposit – about 860 thousand tons of ΣTR2O3 [5]. This deposit has a long history. In the 1950-s, it was put into operation. An ore processing plant was built to produce perovskite and titanomagnetite concentrates. It was planned to expand capacities for the production of various types of ferroalloys [34]. Nevertheless, later, an increased content of radionuclides in the slag was found (they did not meet the existing sanitary standards). That was the reason why the production was stopped.

The Tomtor deposit is represented by monazite-pyrochlore ores in the weathering crusts of carbonatites. In 2017, reserves of categories A+B+C1 of the Buranny site accounted only for 0.4% of the total national reserves. But the complex ores of the Tomtor deposit are metal-rich. The average content of REMs in the ores of the Tomtor deposit is higher than in the ores of the most known deposits in the world, and they contain the most valuable components in terms of the end-use opportunities – REMs of the yttrium group [5]. Figure 2 presents an overview of the comparative characteristics of Russian Arctic and foreign promising objects of rare-earth metals.



1 – Lovozero deposit (Russia), 2 – Tomtor deposit (Russia), 3 - Afrikanda deposit (Russia), 4 – Partomchorr deposit (Russia), 5 - Khibin group of deposits (Russia), 6 - Kvanefield (Greenland), 7 - Sørensen deposit (Greenland), 8 - Thor Lake (Canada), 9 - Kipawa (Canada), 10 - Mountain Pass (USA), 11 - Mt. Weld (Australia)

Fig. 2 Comparative characteristics of the Russian and foreign promising objects of rare-earth metals (foreign objects are taken selectively) [5, 35,36]

It is important to note that in terms of reserves, a number of Arctic rare-earth fields are ahead of foreign sites (considered promising). This fact creates certain prospects for their exploration. As an example, in the USA, the Mountain Pass deposit is successfully developed. However, the volume of reserves and the REM content of this deposit are lower than similar indicators of the Tomtor field and Khibiny group of deposits [5, 35, 36].

Therefore, in terms of available reserves, the Arctic territories can become a base for the development of the national rare-earth metal industry. At the same time, as practice shows, solely the availability of the resource potential in this case is not the only criterion for determining the reliable prospects for creating competitive industrial complexes for the production of REMs [37]. It is necessary to find out whether efforts are being made to develop the Arctic REM deposits, whether the implementation of rare-earth projects is planned in the near future, and what factors may influence this process.

3.3 REM production in the Arctic: environmental constraints

The development of arctic deposits is associated with certain features: severe weather conditions, infrastructure constraints (transport, telecommunications), lack of logistics systems and others [7-10, 38-40]. But one of the most important issues remains environmental one.

The increase in the extraction and processing of metals can surely affect the fragile Arctic eco-systems. The paradox is the following: on the one hand, rare-earths contribute to the "green" economy, but, on the other hand, their mining can be considered unsustainable in terms of environmental constraints [41]. This leads to a discussion about whether an energy transition based on technologies containing “dirty” metals can reduce environmental damage, emissions of CO2 and other harmful substances [41-42].

The indicator of radioactivity of rare-earth raw materials - the content of such components as thorium and uranium - is mandatory for accounting. Their neutralization is possible only with the use of special technologies for raw material purification [43]. The higher the content of these components, the higher the risk of environmental threat.

It should be noted that the apatite present in the Russian Arctic has relatively low level of radioactivity, which can be attributed to the positive characteristics of the national resource base. Nevertheless, environmental risks remain high [43]. In 2018, Russia approved the Information and Technical Handbook BAT (ITS BAT) "Mining of Rare and Rare-Earth Metals", which contains a description of production and technological processes, machinery and equipment, methods and technics of mining rare-earth elements, allowing to minimize the potential risks of negative impact on the environment and reduce the material and energy consumption of production facilities [44].

We argue that in case of the environmental factor should be taken into account as a key factor in the development of Arctic REM reserves. Current projects do not raise the question of whether or not the technologies planned for use comply with modern environmental standards, whether or not they are among the best available technologies, etc. However, without compliance with environmental restraints, the prospects of REM projects may remain uncertain.

3.4 Prospects for the development of rare-earth industrial complexes in the Russian Arctic

Extraction of rare-earth raw materials is only the first step on the way to the creation of finished REM products. This is followed by the stages of obtaining concentrates, producing oxides, isolating individual components, etc. Although the metallurgy of rare and rare-earth metals is mainly based on general principles, it differs in the use of individual chemical and metallurgical technologies [44]. Therefore, the of formation of such industrial complexes without system-oriented solutions is simply impossible.

From China’s experience, to be competitive in the global market, it is necessary to develop not only the upstream segment (extraction and production of primary concentrates), but also the downstream segment (production of oxides, individual metals, and magnets, which are widely demanded in the market). Of course, the formation of such productions is impossible without an appropriate technological base – research and development (R&D), search for new sources and possibilities for the extraction of rare-earth metals, approbation of processing technologies.

The complexity, high - science and capital-intensity nature of such multi-stage production facilities explain the reluctance of subsoil users to develop REM deposits and the lack of intentions on the part of investors to finance such projects [40]. Therefore, the state policy (mechanisms, measures and support tools) is essential in this context. In 2020, the Russian Parliament provided incentives to the development of rare-earth industry by reducing the mineral extraction tax from 8% to 4.8% [45].

Special measures to support Arctic REM projects are currently being developed. For example, in February 2020, the Order of the Ministry of Natural Resources of the Russian Federation for the Murmansk region reduced, the infrastructure coefficient for the development of solid minerals by 25% - to 1.0 [45]. This measure was considered as one of the main intensives for auctioning the right to use the subsoil plots in the central part of the Afrikanda deposit. In fact, the state support determined new prospects for the exploitation of this field. For a long period of time, the implementation of the Africanda project was considered unprofitable from an economic point of view [46].

On the example of the Africanda project, we can identify a number of other effective measures that can be applied to the development rare-earth deposits. These include tax incentives for profits, reduction of the mineral extraction tax (when creating infrastructure), and economic support for mineral processing to increase the added value of finished products [46-47]. The orientation of the proposed support measures is focused not only on the development of upstream, but also on downstream segments. It forms preconditions for advancement along the technological chain. Exceptional performance of the mining phase without implementing processing steps is economically inefficient in the case of rare-earth metals.

Based on the key features of the creation of rare-earth industrial complexes, a number of main factors that may determine the prospects for the development of such complexes in the Arctic have been identified:

(1) infrastructure (production, transport)

(2) availability of technologies (mining, processing, extraction technologies)

(3) investments (capital investments)

(4) compliance with environmental standards (best available technologies, compliance with environmental constraints)

(5) availability of plans for creation of facilities for production of rare-earth products with high added value

(6) state policy (measures implemented to support the REM industry - both general and at the level of individual regions).

Based on the analysis of the provisions of the draft "Strategy for the Development of Rare and Rare-Earth Metals Industry", the state program "Industry Development and Increasing its Competitiveness", the roadmap for the development of rare and rare-earth metals mining until 2024 (prepared by the Ministry of Industry and Trade of the Russian Federation jointly with Rosatom), it was found that in the medium and long term, two major projects that can affect the development of the national REM industry – the Afrikanda and Tomtor fields [31, 34]. The State Report "On the state and use of the Mineral Resources of the Russian Federation in 2019" states that the Partomchorr deposit is also at the stage of preparation for exploration. However, despite of the existing rare-earth potential, it has been established that there are no plans to extract rare-earth metals into commercial products. This may indicate a lack of appropriate technology [5].

Figure 3 presents characteristics of the prospective REM objects in the Russian Arctic.

Criteria	Objects		
Name of the deposit	Tomtor deposit	Africanda deposit	Partomchorr field (Khibin massif)
Main characteristics			
Location	Yakutia (Republic of Sakha)	Murmansk region	Murmansk region
Geological-industrial type	weathering crust of carbonites	perovskite-titanomagnetite ores	apatite-nepheline
REM reserves (categories A+B+C1)	2 640.4 thou. tons	860 thou. tons	1505 thou. tons
Rare-earth metal content	12%	0.67%	0.2%
Stage of implementation	Engineering	Appraisal	Appraisal
Possible production volumes			
-REM	2.4 thou. tons REM (concentrate)	8.5 thou. tons REM (concentrate)	extraction of rare-earth metals into commercial products is not planned
-other products	10 thou. tons ferroniobium; 3.5 thou. tons didim	75 thou. tons titanium dioxide 1.3 thou. tons niobium; 71 tons tantalum	phosphate raw materials
Time frames (launch of the project)	2030 year (previously planned to 2025)	2024 year	2027 year
Project operator	Triark Mining	Arkmineral	Fosagro
Key factors			
(1) Infrastructure	-	+	+
(2) The availability of technologies	+	+	-
(3) Required investments	53 bln rbl	19.4 bln rbl	NA
(4) Compliance with environmental standards	Minimizing environmental consequences (special mode of operation, abandonment of large-scale exploitation)	Effective environmental methods have been developed to organize the extraction and enrichment of ore ecological threats (Kola Scientific Centre of the Russian Academy of Sciences)	NA
(5) Plans for REM high added value products' manufacture	+	+ (production of REM oxides and individual metals)	-
(6) Support measures (the state policy)	It is planned to use the measure of state support to subsidize the interest rate of the loan.	-Reduction of the starting payment -reduction of the infrastructure coefficient for the development of solid minerals, - income tax benefits, - reduction of mineral extraction tax	State support measures are not defined

Fig. 3 Characteristics of prospective REM objects in the Russian Arctic [5, 32, 46-47]

As can be seen from the figure 3, the most "prepared" REM project in the Russian Artic is the Africanda project–availability of technology, developed infrastructure of the region. According to the proposed plans, its implementation will provide employment for about 450 residents of the region, and tax revenues to the budget after reaching production volumes are planned at more than 1.5 billion rubles per year. Thus, not only economic but also social effect is expected.

The prospects for growth of REM production are also associated with the exploitation of the Buranny site of the Tomtor field. Given the availability of appropriate technologies, the main "barrier" for the development of this deposit remains the undeveloped infrastructure of the region, which determines the high level of capital investments (53 bln rbl). Complicated logistical solutions, as well as the extremely unfavorable location of the planned facility sharply increase the cost of the finished product. Even with favorable market conditions, it is difficult to ensure the cost-effective development of these valuable components. It is no coincidence that the timing of the project was postponed - initially it was announced for 2025, however, later the terms were shifted for five years, which was explained by the impossibility of applying state support measures in the medium term.

Overall, according to the plans reviewed, the main increase in REM production in the Russian Arctic will occur only in 2030. Figure 4 shows the projected production volumes of rare-earth concentrates (on the assumption that Africanda and Lovozero projects are implemented). The production volumes of the Lovozersky GOK are taken based on the indicators for 2019.

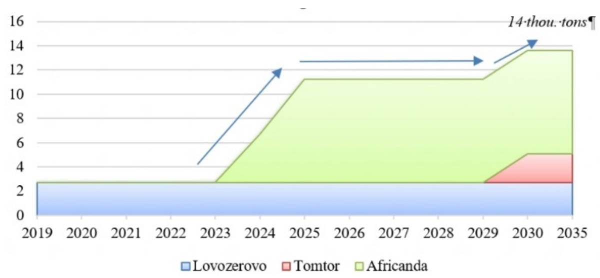


Fig. 4 Forecasting production volumes of rare-earth concentrates (on the assumption that projects planned will be implemented), thou. tons of ΣTR2O3

At the same time, this is only the first stage in the production of rare-earth goods mentioned earlier. Reliable prospects for creation and development of industrial REM complexes will be formed only if the plans for launching the production and technological chain - the creation of high added value products that are in demand on the domestic and world market - are implemented. Otherwise, the situation with the exploitation of the Lovozero field may repeat itself, when most of the products have to be exported due to the lack of opportunities (a) to use concentrates obtained, (b) to process them into finished products with high added value [5]. Therefore, the focus should be on technology. In the conditions of the Arctic region, it is technological advance that can help to reduce production costs, minimize environmental risks, and ensure the competitiveness of the finished products of the national REM.

Taking into account the high level of capital investment required to activate the creation of rare-earth industrial complexes in the Russian Arctic, it is necessary to ensure consistency in the applied measures of state support. In this case, the solution can be the use of such instruments as financial and non-financial development institutions, as well as mechanisms aimed at creating stable conditions for business functioning - signing of special project investment contracts (SPICs), inclusion in regional investment projects (RIPs), implementation of projects with special economic zones – territories of advanced development [31]. It is also necessary to revise the provisions of the current system of subsoil use in order to expand the possibilities for involvement in the production process of technogenic objects and already developed fields (reduction of one-time payments, incentives for subsoil users to increase the complex use of raw materials, etc.).

4 Conclusion

To summarize the research, we would like to underline the following points:

1. The development of the Russian rare-earth metal industry is one of the essential priorities for the national economy on the way to overcome the high level of import dependence. The success in this case can affect the possibility of the technological advance of the country.
2. The Arctic region has a large mineral base of rare-earth metals. It is established, that the main sources of REM in the country are concentrated here - Tomtor, Lovozero and Africanda and other deposits. However, having such potential, the rate of development of domestic rare-earth industry remains low: new facilities are not being developed, the available production facilities in the country are not able to provide the domestic industries with required components (both in quality and volume). This is explained by both the complexity of creation and development of REM industrial complexes and by the special features of the exploration of Arctic territories.
3. It has been established that environmental issues in REM exploitation remain particularly important. New projects must follow environmental standards and constraints to ensure sustainable mining and processing of rare-earth metals, taking into consideration the specific characteristics of raw materials.
4. Based on the study of the specifics of creation and development of REM industrial complexes, the factors that can determine their prospects in the Arctic region were determined (1) the availability of infrastructure (production, transport), (2) the availability of technology (mining, processing, extraction technologies), (3) the required amount of investment (capital investments), (4) compliance with environmental standards, (5) the availability of plans to create production facilities to produce rare-earth products with high added value, (6) state policy (implementable measures to support the REM industry).
5. Analysis of the most promising rare-earth projects in the Russian Arctic showed that the most "well-prepared" are the projects for the development of the Afrikanda and Tomtor deposits (Buranny site). They are planned to be launched in the medium term (until 2030) and will provide a significant increase in rare-earth products for the national industry. Despite the difficulties in the development of the Arctic territories, the availability of technology and the possibility to form a complete chain of technological cycle for the production of products with high added value will allow such projects to maintain an acceptable level of economic efficiency.
6. To intensify the process of creating and developing rare-earth industrial complexes in the Arctic, it is necessary to ensure the consistency of applied measures of state support, as well as to revise the provisions of the current system of subsoil management to expand the opportunities for involving in the production process of technogenic objects and already developed deposits.

References

1. D.S. Abraham, *The Elements of Power: Gadgets, Guns, and the Struggle for a Sustainable Future in the Rare Metal Age* (Paperback, Yale University Press) 336 p. (2015)
2. J. Kynický, et al., Editorial for Special Issue “Rare Earth Deposits and Challenges of World REE Demand for High-Tech and Green-Tech at the Beginning of the 3rd Millennium”, *Minerals*, **11(4)**, p. 378 (2021)
3. National report: high-tech business in the regions of Russia 2019, ed. S.P. Zemtsova (Moscow, RANEPA, 2019) 109 p (in Russian)
4. Y. Chen and B. Zheng, What Happens after the Rare Earth Crisis: A Systematic Literature Review, *Sustainability*, **11(5)**, p. 1288 (2019)
5. State report on the state and use of mineral resources Russian Federation in 2019 Ministry of Natural Resources and Environment of the Russian Federation, 494 p. (2019)
6. M. Shabalov and D. Dmitrieva, Implementation of cluster scenario approach for economic development of the arctic zone of the Russian Federation International, *Journal of Applied Business and Economic Research*, **15(2)**, pp. 281-289 (2017)
7. E. Rutenko and A. Cherepovitsyn, Strategic Planning of Oil and Gas Companies The Decarbonization Transition, *Energies*, **15(17)**, pp. 6163 (2022)
8. K.V. Matrokhina, et al., Development of methodology for scenario analysis of investment projects of enterprises of the mineral resource complex, *Journal of Mining Institute,* **259**, pp. 112-124 (2023)
9. A.E. Cherepovitsyn, et al., Innovative approach to the development of the mineral resource potential of the Arctic zone of the Russian Federation, *Journal of Mining Institute*, **232**, pp. 438-444 (2018)
10. A. Tsvetkova and E. Katysheva, Present problems of mineral and raw materials resources replenishment in Russia, *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM 2019*, **(5.3)**, pp. 573-578 (2019)
11. Strategy for Developing the Russian Arctic Zone and Ensuring National Security until 2035 Available online: http://en.kremlin.ru/acts/news/64274 (2021) (in Russian).
12. Rare earth elements – The vitamins of modern industry 2019 Chemicals Research & Analysis. HIS

Markit Available online: https://ihsmarkit.com/research-analysis/rare-earth-elements--the-vitamins-of-modern-industry.html (2019)

13. Rare earths in the energy transition: what threats are there for the "vitamins of modern society"? 2020 Energies Nouvelles Available online: https://www.ifpenergiesnouvelles.com/article/les-terres-rares-transition-energetique-quelles-menaces-les-vitamines-lere-moderne (2020)
14. C. Church and A. Crawford, Minerals and the Metals for the Energy Transition: Exploring the Conflict Implications for Mineral-Rich, Fragile States *The Geopolitics of the Global Energy Transition, Lecture Notes in Energy*, **73**, pp. 279-304 (2020)
15. E. Brennan, The Next Oil?: Rare Earth Metals The diplomat Available online: https://thediplomat.com/2013/01/the-new-prize-china-and-indias-rare-earth-scramble/ (2013)
16. Y.V. Kalashnikova, Innovative and strategic problems of the russian industry and rare earth metals, *Omsk Scientific Bulletin*, **4(121)**, pp. 61-64 (2015) (in Russian)
17. A.L. Bilin, The problem of revival of the rare earth industry in Russia Innovative geotechnologies in the development of ore and non-metal deposits, *Collection of reports of the VII International Scientific and Technical Conference in the framework of the Ural Mining Decade*, pp. 373-379 (2018)
18. V.A. Kryukov and S.A. Zubkova, Reindustrialization without REMs?, *ECO*, **46(8)**, p. 5-24 (2018) (In Russian)
19. Kryukov V A et al. Rare Earth Industry – how to take advantage of opportunities. *Russian Mining Industry*, **5**, p. 68-84 (2020) (in Russian)
20. A.A. Gasanov, et al., Some trends of the world ree market and prospects for Russia, *Izvestiya Vuzov Tsvetnaya Metallurgiya (Izvestiya. Non-Ferrous Metallurgy)*, **4**, pp. 31–44 (2018) (In Russian)
21. A.S. Buynovskiy, et al., Current state of the rare earth industry in Russia and Siberia, *1st International Symposium on Inorganic Fluorides: Chemistry and Technology, ISIF*, **11**, pp. 126-132 (2014)
22. A.V. Lalomov and A.A. Bochneva, Rare-metal potential of placer deposits and weathering crusts of the Russian Arctic Arctic: ecology and economics, **4(32)**, pp. 111-122 (2018) (in Russian)
23. V.S. Vasiltsov, On the matter of the economic development of the Russian Arctic Management of innovative development of the Arctic zone of the Russian Federation, *Collection of selected works based on materials of the All-Russian scientific and practical conference with international participation*, pp. 81-84 (2017) (in Russian)
24. In the Arctic, the mining of rare earth metals and the development of alternative energy are promising – opinion 2021 PortNews Available online: https://www.nationalgeographic.com/news/2010/10/101001-energy-rare-earth-metals/ (2021) (in Russian)
25. A.V. Volkov, et al., Deposits of strategic metals in the Arctic region, *Proceedings of the Fersmanov Scientific Session of the State Institute of the KSC RAS*, 16, pp. 80-84 (2019) (in Russian)
26. Outcomes of the 5th International Arctic Forum "Arctic – territory of dialogue" (2019) 17 p.
27. M. Paschke et al. The supply of rare earths for "green" energy and sustainable development, *Bulletin of St. Petersburg State University*, **3(5)**, pp. 56-73 (2016)
28. U.S. Geological Survey Mineral Commodity Summaries 2020: U.S. Geological Survey (2020) 200 p.
29. Rare Earth Elements Market Size, Share & Trends Analysis Report By Product (Cerium, Dysprosium, Erbium), By Application (Magnets, Catalyst), By Region, And Segment Forecasts, 2019 – 2025 Grand view research Available online: https://www.grandviewresearch.com/industry-analysis/rare-earth-elements-market (2021)
30. J. Mitchell, Can the West break China's stranglehold on rare earth supply chains? Available online: https://www.investmentmonitor.ai/business-activities/extractive-industries/china-rare-earths-supply-chain-west (2021)
31. Ministry of Industry and Trade of the Russian Federation Available online: http://government.ru/en/department/54/events/ (2021) (in Russian)
32. S.Yu. Scripachev, Current state and prospects for the development of rare earth industry, *Federal State unitary Enterprise All-Russian scientific research Institute of aviation materials Presentation*, 15 p. (2018) (in Russian)
33. G. Meleniev Russian rare earth priorities Available online: http://rareearth.ru/ru/pub/20150420/01578.html (2015) (in Russian)
34. Afrikanda: the beginning of history Available online: http://discoverkola.com/afrikanda-nachalo-istorii (2021) (in Russian)
35. J. Dostal, Rare Earth Element Deposits of Alkaline Igneous Rocks, Resources, **6(3)**, p. 34 (2016)
36. J. Snow, et al., The Value of REEs Presentation IAMGOLD Corporation, 24 p. (2012)
37. With rhenium never seen before. How Russia plans to become a leader in the production of rare metals 2020 Available online: https://www.kommersant.ru/doc/4596106 (2020) (in Russian)
38. M.A. Nevskaya and O.A. Marinina, Challenges and opportunities of state regulation of the innovation process in the russian mineral resource sector, *Mining waste products in the mineral resources sector of the Russian Federation*, **16(1)**, pp. 149-159 (2017)

39. T. Ponomarenko and I. Sergeev, Problems and opportunities of mining company's strategic development, *Management Theory and Studies for Rural Business and Infrastructure*, **39(4)**, pp. 453-464 (2017)
40. A.O. Nedosekin, et al., Strategic Approach to Assessing Economic Sustainability Objects of Mineral Resources Sector of Russia, *Journal of Mining Institute*, **237**, pp. 354-360 (2019)
41. G. Pitron, The Rare Metals War: The Dark Side of Clean Energy and Digital Technologies Scribe, 284 p. (2020)
42. C. Blumenthal, The dirty side of clean energy technologies: a call for action Available online: https://www.cleanenergyleaders.org/celi/the-dirty-side-of-clean-energy-technologies-a-call-to-action (2016)
43. Rare earth minerals and the geochemistry: the implications of their respective uranium and thorium contents. Thesis for: BSc Applied GeologyAdvisor: Frances Wall Jonathan O'Callaghan (2012)
44. Best Available Technology Information Technology Handbook 24-2020 Production of rare and rare earth metals Moscow: Russian BAT Bureau, p. 338 (in Russian)
45. Tax Code of the Russian Federation (part two) - CIS Legislation Available online: https://cis-legislation.com/document.fwx?rgn=1717 (2022)
46. Heading to the North: why the Murmansk region is interesting for investors Available online: https://plus.rbc.ru/news/5f887c6a7a8aa9d7d5ef6673 (2020) (in Russian)
47. A.A. Zlobin, New history of development of the Africanda perovskite ores deposit of the Murmansk region Modern science: current issues, achievements and innovations, *XV International Scientific and Practical Conference*, pp. 102-107 (2020) (in Russian)