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Subsurface Resource Uses in Modern Conditions for Sustainable Development

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Abstract

The relevance of the research topic lies in the emergence of new challenges, various risks and uncertainties in the current conditions for the functioning of subsoil uses are characterized. The purpose of the study is to substantiate the scientific foundations for sustainable development of subsoil use in the face of modern challenges, risks and uncertainties. As research methods, an interdisciplinary approach is used with an analysis of the flows of energy, matter and information in the environmental, economic and technological sectors of the subsoil use. An interdisciplinary model of the subsoil use system in the face of modern challenges, risks and uncertainties is proposed, and a characteristic is given of the flows of energy, matter and information in the environmental, economic and technogenic sectors of subsoil use. The essence of the concept of sustainability in the sphere of subsoil use is considered, and the main property of the sustainable development of subsoil use is substantiated - its survivability in the face of modern challenges, risks, and uncertainties. The characteristic of destructive factors of sustainable development, mechanisms of formation of sustainable development, and implementation algorithms is given.

Disciplinary: Sustainable Development

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1 Introduction

Under such conditions, providing society with mineral resources requires a transition from the general ideas about sustainable development (sustainable development is a stable state of socio-economic development) to the scientific concept and scientific principles of sustainable development of the subsoil use sector with qualitative and quantitative indicators and development criteria. The scientific concept of sustainable development in subsoil use determines the way of understanding the essence of “sustainable” development, interprets the nature of “sustainable” development, determines the main “property” of sustainable development and its destructive factors, and scientific principles based on conceptual provisions contain mechanisms for the formation and algorithms for implementing sustainable development of subsoil use.

The aim of the article – is to substantiate the scientific foundations for sustainable development of subsoil use within modern challenges, risks, and uncertainties.

The leading approach to problem research:

- an interdisciplinary approach with the analysis of energy, substance and information flows in the environmental, economic and technological sectors of the subsoil use;

- methods of convergence (synthesis of knowledge) and divergence (deepening of research in certain areas).

Difficult environmental (pollution and transformation of the natural environment), social (growth of protest activities of the population) and economic (reduction of available mineral reserves, development of remote deposits) situations and technological difficulties (depleted, complex structural, geodynamically hazardous ores with finely disseminated elements) require deep scientific analysis and substantiation of sustainable development of the sphere of subsoil use in modern conditions. At present, there is no specific generally accepted definition of sustainable development of subsoil use.

The scientific foundations for sustainable development of the subsoil use sector should include clear qualitative and quantitatively measurable ideas about the essence of the concepts "structure of the subsoil use system", "sustainability" of the subsoil use system within modern challenges, risks and uncertainties, the "main property" of the system, "destructive factors" and "responses" on them - the "mechanisms" for formation and algorithms for implementation of sustainable development. These concepts make it possible to move from general ideas (sustainable development) to the scientific concept of sustainable development in the sphere of subsoil use in modern conditions.

The purpose of the study: is to substantiate the scientific foundations for sustainable development of the sphere of subsoil use within modern challenges, risks and uncertainties.

Research objectives: to substantiate on the basis of an interdisciplinary approach a complex model of the subsoil use, to give the scientific concept of "sustainability" of the sphere of subsoil use, to substantiate the essence of the "main property" of sustainable development of the subsoil use in modern conditions, to characterize the "destructive factors" of sustainable development of the subsoil use and "mechanisms" for the formation of sustainable development and algorithms for its implementation in modern challenges, risks and uncertainties.

2 Materials and Methods

More than 120 publications in the field of mining with the phrase "sustainable development" in the titles were analyzed. Different publications present various understandings of it, from a narrow industry [1], general theoretical foundations [2, 3, 4] to the idea of a global "conspiracy" [5].

But at the same time let us note that sections of the Rio + 20 Outcome Document ("The Future We Want") do not have the word "science" in the title. Thus, science was not considered as an important component in solving the problem of sustainable development. However, the UN Secretary-General has agreed for making an international scientific advisory board that will make scientific recommendations on sustainable development (the report of the UN Secretary-General, 2017).

World science of subsoil use (Natural Resourse Charter - England, Germany, the Netherlands [6]; Technische Universitat Bergakademie Freiberg - Germany [7]; Russio-German Raw materials forum [7,9,10,11,12,13] believes that the main goal is to ensure an acceptable return from the development of natural resource potential in modern conditions. The key concept of "acceptable return" is considered from individual system positions: the role of natural resources in the economy, the study of production periods, the interaction of participants in production relations and others. The fundamental provisions in the development of mining industries are discussed in [12] (issues related to the sustainable development of mining and processing of minerals: creation of a "transparent" land, development and management of subsoil processes, minimizing the ecological footprint, protection of workers). Modak [13] prove the need for an urgent integrated approach in the formation of sustainable development - the goals of its development; consider that distortions in global material flows, low resource efficiency and uncontrolled pollution threaten the survival of the planet, and the characteristics of GDP, in their opinion, are not indicators of the growth. Datta et al. [14] suggest focusing on the theoretical and methodological foundations of rational nature management: solving the problem of environmental management from different points of view - natural sciences, business, social sciences, engineering. Kahraman and Sari [15] consider genetic and evolutionary algorithms, multi-criteria decision tools, optimization and modeling. Duglas [16] offers his own approach to assessing the "not measurable".

Some scientific studies of various objects of subsoil use [17, 18, 19, 20, 21] are characterized with an engineering approach that does not include a systematic environmental-socio-economic analysis. Such a worldview was confirmed by the topics of most reports at the 12th Russian-German Raw Materials Forum [7].

Particular fundamental provisions for sustainable development of mining production are considered in the publications [22,23,24,25,26,27] and others. The scientific journal "Sustainable Development of Mountain Territories" is published in Russia.

Many scientists are sure of the necessity of further research in the field of subsoil use. So, Puchkov [25] noted that: "From the view of the natural imperative of mineral and energy resources ... a crisis-free existence of the economy can be expected if the further development of world civilization is coordinated with the laws of nature." Kaplunov [24] believes that in the world and Russian science of subsoil use "the principles of sustainable development of subsoil use that are similar to the principles of development of biological resources have not yet found sufficient introduction."

Thus, there is no specific generally accepted definition of sustainable development of the sphere of subsoil use; in the conditions of modern challenges, risks, and uncertainties its concept includes only general provisions. The disagreement is due to the fact that the subject of discussion (the model of the subsoil use system) is not sufficiently defined, there is no clear interpretation of the concept of "sustainable development" of subsoil use, its main property, destructive factors and formation mechanisms.

When developing a model of a subsoil use system, an interdisciplinary (ecology, economics, technology) approach is used on the basis of the analysis of energy, substance and information flows.

The concept of "sustainability" of the development of subsoil use systems is substantiated by the fundamental scientific positions of natural sciences: mathematics, physics (movement of material objects), and biology (development of ecosystems).

The substantiation of the mechanisms for the formation of sustainable development in the sphere of subsoil use is carried out by studying the relationships between cause and effect (subsoil use technology and transformation of the natural environment), between the interests of subsoil use subjects (coordination of business interests and society's preferences), between action and place (definition of acceptable "corridors" of subsoil use), between action and results (innovative technologies for subsoil use and the use of profits in subsoil use), between action and place, between resources and products.

The algorithms for the formation of sustainable development in the sphere of subsoil use include multi-criteria optimization: firstly, the optimal options are determined for all particular environmental, economic and technological criteria with the disclosure of the uncertainty of single-criteria decisions. Uncertainty is disclosed by using a special “minimax risk” indicator, which is determined through a matrix of subsoil use options.

3 Results and Discussion

The results of the research are the proposed model of the subsoil use system, the substantiation of the concept of "sustainability" of the development of the subsoil use system and its main property, the characteristics of the destructive factors of sustainable development and the mechanisms of its formation, the features of the implementation of sustainable development.

Subsoil use system. The subsoil use system is a set of sites of a mineral deposit and mining industries, united by flows of energy, substance and information among them, with the natural environment and society, aimed at ensuring society's needs for mineral resources that are acceptable from an environmental, social, economic and technological position.

For a formalized presentation of the subsoil use system, the space of state parameters (X) and control parameters (Y) is used. The first ones are set, and the second ones are changed during the formation of subsoil use options.

In subsoil use systems energy flows is the link between environmental, economic, social and technological aspects. The mining industry is one of the most energy-intensive industries. The development of low-grade ores and small-scale deposits results in an increase in energy consumption in subsoil use. Non-traditional energy sources are beginning to be used: rock pressure and elastic vibrations of the rock mass, kinetic energy (bypassing filling mixtures into the mined-out space of mines), the gravity energy of heavy mining and transport equipment, etc. According to D.R. Kaplunov and M.V. Rylnikova, all the potential energy of solid, liquid and gaseous masses moving at a mining enterprise can be converted into electrical energy.

The concept of "sustainability" in the development of the subsoil use system. Sustainability is determined on the basis of fundamental scientific concepts of physics, mathematics, and biology. Mechanics, mathematics means the following: if any of the characteristics of motion under sufficiently small perturbations differs little from its motion in the unperturbed regime, then the motion of the system with respect to this characteristic is called stable.

In ecology, the sustainability of a system lies in its ability to remain relatively unchanged over a certain period of time, despite external and internal disturbances. In general, this position of sustainability corresponds to the conservation of biological diversity at the genetic, species, and ecosystem levels.

Based on the fundamental scientific provisions, *the sustainability* of the sphere of subsoil use should be understood as the ability the functioning of mining complexes without deviating from the development of the characteristics of the system under the influence of internal and external factors (environmental, economic, social, technological). That is the concept of "sustainability" of the development of the system is associated with the justification of specific characteristics; such characteristics are fundamental for the development of the system, and they determine the main feature of the sustainable development of the subsoil use.

The main feature of the sustainable development of the subsoil use system. For any system the main property is its "survival", functioning in the mode of maintaining "sustainability". For subsoil use systems, the options for the main property are the survival of nature, the survival of society, the "survival" of the economy, and the "survival" of the technological sector of the system. From a social standpoint, the main feature of the sustainable development of industrial territories is the "survival" of people in these territories. The unfavorable situation with population health in the mining areas testifies in favor of this choice.

Table 1 provides information on the levels of morbidity of the population in certain regions of the Urals. The situation indicates an increase in the morbidity of the population due to disorders of the nervous system, diseases of the circulatory system and respiratory organs. Here the negative impact of living conditions in industrial areas on the health of the population (despite their better healthcare system) is clearly observed compared to living conditions in natural landscapes.

Table 1: The morbidity of the population in the regions of the Urals (2021)

Regions	Number of inhabitants, thousand	Morbidity rate (number of patients per 10,000 people)			
		nervous system	respiratory organs	digestive organs	skin diseases
1. Yekaterinburg (metallurgy)	1386,5	21,4	313	24,1	48,3
2. Nizhny Tagil (iron ore mining, metallurgy)	361,4	23,8	342	26,3	52,6
3. Kamensk-Uralsky (non-ferrous metallurgy)	176,5	17,4	280	24,9	41,9
4. Pervouralsk (subsoil use)	149	16,0	267	23,5	43,6
5. Serov (subsoil use, metallurgy)	100,2	18,4	259	25,8	37,8
6. Asbestos (asbestos mining)	98,7	14,8	275	21,7	53,1
7. Alapaevsky district	-	8,2	157	13,4	29,0
8. Bisert city district	-	7,4	180	18,2	23,7

A similar situation in the subsoil use system was in the United States. The state was forced to close the mining of rare earth metals at the Mountain Pass deposit due to public protests about the increase in the morbidity of the population; and this was despite the critical role of rare earth metals in the industrial production of the country.

Destructive factors of sustainable development of the sphere of subsoil use. The main property of sustainable development is influenced by various destructive factors. The main environmental destructive factors in the territories of the mining sector are the destruction of natural objects and environmental pollution.

Destructive factors in the social environment: deterioration in the health of the population, stratification of the population in terms of material condition, in terms of financial security, and a decrease in employment (increase in unemployment).

In the economic sector of subsoil use, destructive factors are associated with the financial condition and financial flows. Tables 2 and 3 present data on the existing stratification of the population in terms of material condition and financial security.

Table 2: The share of national wealth concentrated in the hands of 1% of the population, according to international organizations (2021)

Country	Data source	
	Global Wealth Report (28)	Credit Suisse Group (29)
Russia	71%	74,5%
India	49%	58,4%
China	32%	43,8%
USA	37%	42,1%
UAR	44%	41,9%

Table 3: Average monthly salaries of individual group specialists and monthly remuneration of board members in state-owned companies in the Russian Federation (in rubles, as of June 2021).

Average monthly salary, rub/person		Monthly remuneration, rub/person	
Teacher's salary	24 744	Rosneft	29 200 000
Doctor's salary	37 560	Gazprom	13 300 000
Professor's salary	46 046	Bashneft	11 100 000
State Duma deputy's salary	470 000	ALROSA	5 300 000
The average salary of all ministers of the Russian Federation	589 300	Sberbank	12 300 000

Mechanisms for the formation of sustainable development. Mechanisms for the formation of sustainable development in the sphere of subsoil use include technological, environmental and socio-economic "tools", and humanitarian and institutional factors. Figure 1 shows a diagram of the technological and economic mechanisms for the formation of sustainable development in the sphere of subsoil use.

Technological mechanisms include deep processing of minerals, effective methods of physical-chemical, biochemical processing of resources, the combination of types of technology, automation and robotization of technological processes in mining production.

The literature provides data on the high efficiency of natural gas processing. Natural gas produced in Russia was sold (2019) abroad at $50 per ton. If it is processed, then ethane is obtained, after that ethylene at a cost of $600-700 per ton, which is the basic basis for the production of polyethylene and costs $1,400-1,500 per ton. Polyethylene is used to make marketable products that already cost $3,000-$5,000 per metric ton.

China's policy in the consistent development of the use of rare-earth metals (REM) deserves great attention. Initially, in the 70s, China exported mineral concentrates, and in the 80s – chemical compounds of mixed rare-earth metals (carbonates and chlorides). In the early 90s – separated rare-earth metals (oxides and metals). At the end of the 90s – recycled rare-earth metals (phosphors, magnets). And in the 2000s – products based on REM (TVs, computers, electric motors).

The economic mechanisms for implementing sustainable development in the sphere of subsoil use include the formation of budgets for the territory, regulation of the profitability of the mining and processing sectors, intensification of research and development (R&D), and growth in the share of high-tech products.

Table 4: The role of the oil sector (oil production) in the formation of budgets of different countries

Country	Share from the sale of oil to the budgets of the territory
UAE	88-91%
Nigeria	82-90%
Angola	82-88%
Norway	82%
USA	63-70%
China	59-62%
Colom	47-58%
Russia	34%

Table 4 presents data on the role of the oil sector in the formation of budgets in different countries. In the Russian Federation, only 34% of the proceeds from the sale of oil go to the country's budget; in other large oil-producing countries this most important mechanism for implementing sustainable development ranges from 70% (USA) to 82-91% (Norway, UAE)

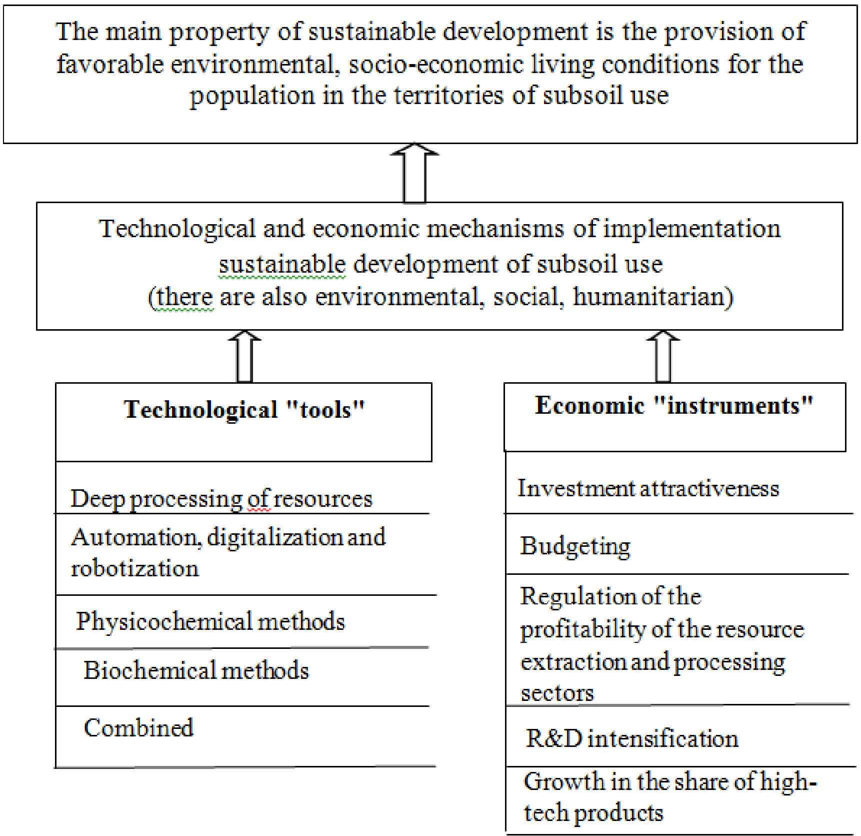

Figure 1: Schematic diagram of the implementation of the concept of sustainable development of the subsoil use sphere: basis and implementation mechanism

Table 5 shows the comparative profitability levels of ten oil companies [27]. The high profitability of current Russian companies, which is 2-3 times higher than the profitability of foreign companies, hinders the development of the oil refining complex in the country. Over the past 30 years, not a single new oil refinery has been built in the Russian Federation; only individual blocks and sections are modernized at existing enterprises.

Table 5: Profitability levels of 10 oil and gas companies

Oil company	Profitability level
ConocoPhillips	5,08
Royal Dutch Shell	6,52
Total	6,65
BP	6,84
Lukoil	7,83
Exxon Mobil	8,79
Gazprom Neft	12,1
Gazprom	13,24
Rosneft	13,54
THK-BP	14,91

An important mechanism for implementing sustainable development is spending on science (R&D), which forms an increase in the production of high-tech products.

Table 6 shows the size of R&D expenses in the world's largest oil-producing companies (Lukoil, Surgutneftegaz, Tatneft, Rosneft). Research costs in Russian companies are minimal, their share in revenue (income) is 3% (Rosneft) – 16% (Lukoil); in foreign mining companies, this figure exceeds 25% and has already reached 30% [8].

Table 6: R&D spending in major global oil companies

Oil company	R&D share in revenue, %	R&D spending, million dollars
Royal Dutch Shell	28	1280
Total	31	875
Exxon Mobil	18	870
ENI	21	180
Gazprom	15	205
GDF Suez	20	196
Lukoil	16	85
E ON Rurhgas	8	82
Surgutneftegaz	19	57
Tatneft	17	28
Rosneft	3	16

The criterion of sustainable development of the subsoil use system U is presented in vector form:

$$U = U(\max E; \max P; \max C; \min Z) \quad (1)$$

where: max E is the criterion for maximum preservation of the environment in the territory of subsoil use; max P is the criterion for the maximum use of extracted resources; max C is the criterion for maximum satisfaction of social needs in the territory of subsoil use; min Z is the criterion for the minimum total costs in the technological process of subsoil use.

After analyzing the partial criteria and determining their extreme values, after disclosing, if necessary, their "uncertainty" the values of the concessions (δ) are substantiated by analyzing the relationships between the partial criteria.

The option of truly sustainable development of subsoil use is a solution to a multi-criteria problem:

1) find max

$$E(X_1; Y_1); \quad (2),$$

2) find max $P(X_2; Y_2)$ under the condition

$$E(X2; Y2) \geqslant E(X1; Y1) - \delta 1; \quad (3),$$

3) find max C(X3; Y3) under the condition

$$E(X3; Y3) \geqslant E(X1; Y1) - \delta 1; \quad (4),$$

$$P(X3; Y3) \geqslant E (X2; Y2) - \delta 2 \quad (5),$$

4) find min $Z(X_4; Y_4)$ under the condition

$$E (X_4; Y_4) \geqslant E (X_1; Y_1) - \delta_1; \quad (6),$$

$$P(X_4; Y_4) \geqslant E (X_2; Y_2) - \delta_2; \quad (7),$$

$$C(X_3; Y_3) \geqslant E (X_3; Y_3) - \delta_3. \quad (8).$$

4 Discussion

In practice, at present, in the absence of an interdisciplinary approach (the proposed system model of the sphere of subsoil use) and ignoring the multi-criteria principle (one of the proposed algorithms for implementing the concept of sustainable development) systems of unsustainable development of subsoil use objects are usually formed. So, when organizing the development of a nickel deposit (Khopyorskoye deposit in the Voronezh region) the following situations arose.

In the event that concessions δ are equal to zero, the solution to the problem [1] will correspond to the largest value of the first particular criterion max *E*. Thus, in the process of analyzing the options for the development of the field, the value of the concession δ_1 – the decrease in the natural resource potential of the territory – was taken equal to zero (preservation of 700 hectares of soil – chernozem); and the value of the concession δ – an increase in the cost of mining and processing ore – was also taken almost equal to zero (the project did not take into account the cost of 350,000 tons of black soil in the territory). In this formulation, the solution to the problem of finding a sustainable subsoil use option corresponded to the maximum preservation of the environment (max *E*), and the criterion *Z* in this situation took on a value equal to several billion rubles, which would be unacceptable for a mining company.

In another case, when the concessions turn out to be significant, the optimal variant will correspond to the last particular criterion in the sequence [2]. So, in the considered case when the concession δ_1 to the max *E* criterion includes the complete removal of soil – chernozem, the concession δ assumes the extraction of only nickel and copper from the ore, the concession δ_3 ignores the social aspect – the elimination of traditional agricultural land use, and for the min *Z* criterion there is no concession (δ = 0), and this option reflects only the technological aspect of the subsoil use system, that is, it cannot be considered sustainable from the standpoint of a multi-criteria approach.

5 Conclusion

The scientific foundations for the sustainable development of subsoil use are clear qualitatively and quantitatively measurable ideas about the essence of the concepts “structure of the subsoil use system”, “sustainability” of the subsoil use system in the face of modern challenges, risks and uncertainties, the "main property" of the system, “destructive factors” and “answers” on them – the “mechanisms” of the formation of sustainable development and algorithms for its implementation. These concepts make it possible to move from general ideas (sustainable development) to the scientific concept of sustainable development in the sphere of subsoil use in modern conditions.

Based on the considered provisions, the sustainable development of the sphere of subsoil use should be considered such provision of society with minerals in modern and predictable future conditions under which, firstly, the natural foundation is not destroyed both in the territories of subsoil use and global ecosystems, and secondly, the created in the territories of subsoil use living conditions do not worsen the social situation (health and wages of people), and, thirdly, destructive processes in the environmental, economic and technological sectors of the subsoil use system do not develop to alarming proportions.

6 Availability of Data and Material

Data can be made available by contacting the corresponding author.

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