Systemization of Indicators for Assessing the Impact of Power Engineering Facilities on the Environment of the Arctic Zone in Yakutia

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Abstract. The development of mineral resources in the Arctic zone of Yakutia is followed by a progressively increasing impact on the environment. Under these conditions, it is necessary to develop such directions for reducing the negative consequences of industrial development that could support the entire ecosystem of the North in a balanced state in strict accordance with the laws of structure, processes and changes in the landscape structure. This can provide a complex geoeological approach that involves a systematic study of the relationships between both natural and man-made objects. In general, this approach is based on the study of the impact processes of anthropogenic activities on the environment, changes in the environment and consequences that affect natural and social conditions. Under conditions of extremely low resistance of natural landscapes to any impacts, it is necessary to assess and search for directions reducing the consequences of industrial development. In this regard, a schematic model of indicators systematization of environmental and socio-economic consequences of the functioning of energy supply facilities is developed on the example of the Yana, Indigirka and Kolyma river basins in accordance with the laws of structure, processes and changes in the landscape structure.

1. Introduction

Currently, one of the most priority state directions is the development of the huge potential of mineral resources in the North-East of Russia, including the Arctic zone of the Republic of Sakha (Yakutia), which occurs under extreme natural and climatic conditions. The mining industry of the zone has a limited distribution but its importance for the economic and national security of the country is undeniable. Thus, gold production is carried out in the Ust-Yansky, Monsky and Verkhoyansky districts. The largest is the Kyuchus deposit among them [1] and in the southern part of the Yana river basin Prognoz, Vertikalnoye, Mangazeyskoye silver deposits are developed. In addition, the richest shelf marginal-marine (Lyakhovskiy, Chokurdakshoye) and alluvial (Tirekhtyakhskoye) deposits of tin have been explored [2].

The function of the mining industry and the construction of necessary infrastructure, including energy production, entail negative changes in the environment of the North. In this regard, priority attention is paid to the tasks of scientific support for sustainable socio-economic development of the Arctic, taking into account the peculiarities of ecosystem transformation to ensure the necessary conditions for the population safe life [3]. At the same time, the basis of scientific research results should be the analysis of the interaction of power engineering facilities with the environment. Such analysis
can provide a geoecological approach that ensures the complexity and consistency of the study and has the methods of landscape analysis and the concept of geotechnical systems [4-6]. It also allows adequately justifying the choice of areas of geographically differentiated environmental measures, strictly linking them to a specific environmental situation. In general, this approach is based on the study of the processes of economic activity impact on the environment, changes in the environment and consequences that affect natural and social conditions. Due to the large variety of interaction process of technical structures with the environment in the composition of geotechnical systems, there is a need to systematize all the processes of impacts, changes and consequences.

2. The current state of the studied territory energy system and its projection

The Arctic zone as a whole occupies 52.2% of the Republic territory and includes 13 administrative districts. In the studied part of the Arctic territory of Yakutia, which includes the basins of the Yana, Indigirka and Kolyma rivers, there are 9 administrative districts: Abysky, Momsky, Allaikhovsky, Verkhoyansky, Ust-Yansky, Eveno-Bytantaysky, Verkhnekolymsky, Srednekolymsky and Nizhnekolymsky [7].

The energy system of the region is a decentralized power supply zone represented by local energy, which is under control of Sakhaenergo JSC. Features of the energy system due to natural and socio-economic features are severe climatic conditions, remoteness and isolation of small consumers, a large service area, dispersed population, small power plant capacity and a low degree of landscape stability [8].

The main part of the Arctic zone is occupied by the basins of the Yana, Indigirka and Kolyma rivers, where energy production facilities are mostly represented by diesel power plants (DPP) in the amount of 67 units and 323 units of generator equipment. Their share of the territory accounts for about 97% of the installed power of all energy sources. The power generators of the studied territory are also represented by one mini combined heat and power unit (CHPU) and a coal-fired boiler house in the village of Deputatsky in the Ust-Yansky district and 7 solar power stations (SPS) [9] (Figure 1):

![Figure 1](image)

Figure 1. Structure of installed electrical capacity of power generators in the Yana, Kolyma, and Indigirka river basins.

In addition, a large number of autonomous energy sources belonging to various mining, geological exploration and other companies of subsurface users with electricity consumption for technological needs are located in this zone.

The energy system of the territory under study has significant problems, the main of which are: heavy wear and technologic state of DPP and network infrastructure; high fuel consumption; high electricity tariffs; undeveloped territorial transport infrastructure; significant losses of electricity in electric networks.
The energy forecast is based on the data of Sakhaenergo JSC (Table 1). In most areas, there is a stagnation or negative dynamics of population size, while the increase in electricity consumption is associated with plans to improve the living standard reflected in the construction of water treatment and sewage treatment plants, new social facilities, as well as new boiler houses with the connection of a significant part of the private sector.

Table 1. Forecast of electricity consumption in Arctic regions in the service area of Sakhaenergo JSC, million kWh.

| Region            | Year | 2016   | 2017   | 2018   | 2019   | 2020   | 2021   | 2022   |
|-------------------|------|--------|--------|--------|--------|--------|--------|--------|
| Abyisky           |      | 9,3    | 9,67   | 9,97   | 10,33  | 10,61  | 10,8   | 11,01  |
| Allaikhovsky      |      | 8,9    | 9,13   | 9,35   | 9,52   | 9,63   | 9,73   | 9,83   |
| Verkhnekyolymysky |      | 19,05  | 19,37  | 19,51  | 19,55  | 19,7   | 19,8   | 19,9   |
| Verkhoyansky      |      | 28,2   | 29,48  | 30,48  | 31,6   | 33,09  | 34,33  | 35,53  |
| Momsky            |      | 9,8    | 11,13  | 11,74  | 12,21  | 13,22  | 13,53  | 13,85  |
| Nizhnekolymsky    |      | 14,21  | 14,55  | 14,88  | 15,34  | 15,96  | 16,46  | 17,28  |
| Srednekolymsky    |      | 16,99  | 17,63  | 18,12  | 18,58  | 19,19  | 19,61  | 20,05  |
| Ust-Yansky        |      | 21,4   | 21,71  | 22,24  | 22,82  | 23,19  | 23,91  | 24,38  |
| Eveno-Bytantaisky |      | 4,1    | 4,72   | 5,11   | 5,27   | 5,53   | 5,79   | 5,94   |
| **Total**         |      | 191,55 | 201,49 | 206,86 | 212,23 | 218,45 | 223,81 | 228,89 |
water from various sources, volumes and composition of pollutants entering the nature from the fluttering of waste, dumps, sludge depositories).

To obtain a comprehensive environmental assessment, it is necessary to perform intermediate stages – local assessments of the impact levels, landscape disturbances, and consequences in the natural and socio-economic environments. The latter should be expressed in the form of indicators of economic damage, reflecting the degree of unfavorability of changes in natural conditions for human economic activity.

**Figure 2.** Scheme of indicators systematization for a comprehensive assessment of the energy facilities impact on the environment of the Arctic area of Yakutia.

To collect indicators of changes in natural complexes and components, data on changes in air and water environments, the earth’s surface including soil and vegetation cover and the permafrost, were analyzed and compared with the indicators of their regulatory states of maximum permissible emissions, concentrations of normalized substances which reflects deviations from these standards. The degree of change in nature is determined by comparing it with the base or background state.

Indicators of consequences affecting nature, the economy and population, aim to establish a link between natural phenomena and the consequences in the economy and to zone the territory according to the degree of environmental consequences. The main types of negative consequences can be related to groups that reflect the deterioration of indicators of the quality and quantity of natural resources; living conditions of people; conditions of economic development of the economy.

Based on the results of degree evaluation of the impact, changes in the environment, and the stability of landscapes, an ecological map of the landscape provinces of the Arctic zone of the Yana, Indigirka, and Kolyma river basins was compiled. It can be used both in the further intensification of the studied
region utilization and the choice of environmental measures to reduce the ecological impact of the Arctic energy sources (Figure 3).

The impact indicators are the pollution emissions into the air in the Yana, Indigirka and Kolyma river basins from the operation of DPP and mini-CHPU plants.

Diesel power units (DPU) have a local impact on the environment. The calculation of the maximum and gross emissions of pollutants into the atmosphere from DPU was carried out in accordance with the methodology requirements [11]. The total data on the emissions of pollutants were analyzed on the basis of Sakhaenergo JSC data for 2000-2005 and 2014-2018. With the increase in diesel fuel consumption, the emissions of pollutants into the atmosphere also gradually increase.

The dynamics analysis of the surface water quality for 2005-2019 is based on the statistical processing of data from the hydrochemical observation network of the Federal State Budgetary Institution "Yakut Department of Hydrometeorology and Environmental Monitoring" on the most characteristic indicators for each water body [12].

![Figure 3. Map of the ecological state of landscape provinces of the Arctic zone in the Yana, Indigirka and Kolyma river basins.](image)

The characteristic pollutants are organic substances according to COD and BOD5, compounds of copper, iron, zinc, manganese, phenols, and petroleum products.

The degree evaluation of surface water pollution was carried out on the basis of SCIWP (the specific combinatorial index of water pollution) values [13] which allows dividing the quality of surface water into 5 main classes and 6 categories depending on the degree of their pollution. At the same time, the criteria of harmful substances for the water of fishing reservoirs were used.

Due to the fact that the stability of natural complexes to human impact is their fixed property, the degree of stability of the landscapes in the Yana, Indigirka and Kolyma river basins was evaluated [14-
on the basis of the permafrost landscape map of Yakutia [16]. For this purpose, the method of the landscape-ecological approach was applied [17].

It is determined that the landscapes of the studied territory have different variants of a low degree of resistance to man-made load depending on the complex of permafrost and biohydroclimatic indicators: extremely unstable peculiar to tundra landscapes; unstable, sensitive and relatively unstable for mountain tundra and mountain sparsely wooded and relatively stable in north taiga landscapes.

4. Conclusion
As a result of the development of a schematic model in the indicators systemization of environmental and socio-economic consequences of the facilities energy production functioning on the example of the Yana, Indigirka and Kolyma river basins, the following conclusions are made:

1. The level of changes in the main components of landscapes – water and air environments from man-made factors depends both on the level of impact, power and intensity of emissions and discharges, and on the natural stability of landscapes themselves.

2. The emission of pollutants into the atmosphere from diesel power plants in the Arctic area of the Sakha Republic (Yakutia) is generally insignificant, does not exceed the regulated properties and does not significantly affect the state of the air environment in the studied territory of the Yana, Indigirka and Kolyma river basins.

3. Wastewater discharges from diesel power plants in the Arctic zone of Yakutia are not a significant factor of anthropogenic impact on water bodies.

In general, the environmental impact of power generators is negligible. However, under extreme climatic conditions, they are hotbeds of direct and indirect impact on all components of landscapes due to the existing horizontal and vertical relationships. The main risk factor is the extremely low degree of resistance of the northern landscapes to man-made load which determines the importance of scientific study of the impact of energy facilities on the state of the Arctic natural landscapes.

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