Transforming Structure of Generating Capacities in the Eastern Arctic with Large-Scale Development of Resources

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***Abstract* — The paper presents estimates of the electric power required for the implementation of projects for the development of deposits of mineral resources in the Eastern Arctic. The creation of new industrial load centers or expansion of existing ones will call for significant changes in the energy infrastructure. The estimates presented indicate that the demand for electricity for promising projects in the Taimyr-Turukhan zone is commensurate with current consumption; in the North Yakutsk zone, the demand exceeds the consumption by almost 6 times, and in the Chukotka zone, it is larger by more than 3 times. The paper considers changes in the structure of generating capacities in the territorial zones of the Eastern Arctic for two possible development scenarios: the creation of a low-capacity nuclear power industry and the development of an Arctic liquefied natural gas infrastructure. The provided types of energy sources are rational and substantiated by the conducted modeling studies.**

***Index Terms*: centralized and autonomous power supply, promising projects, power consumption, low power nuclear power plants, liquefied natural gas.**

I. Introduction

The strategic priorities and main objectives of the state policy in the Arctic are defined in the state program documents, where a significant number of projects for the development of mineral resources are declared as priority areas [1, 2]. Given the focal nature of the development of the territory, the implementation of these projects is impossible without the expansion of transport and industrial infrastructure. The demand for electricity in the Eastern Arctic is 6 billion kWh only for priority projects with a high degree of exploration of mineral reserves included in the state balance sheet [3]. According to our estimates, the power consumption in these territories can more than double due to the projects that were developed in 2017–2020.

The absence of the necessary industrial infrastructure and, primarily, free generating capacities is a serious limitation for the large-scale development of the resources of the eastern Arctic. The implementation of the projects for the development of mineral resources will require a significant expansion of existing electricity sources and construction of new ones.

The Eastern Arctic territories are isolated from the Unified Energy System of the Russian Federation, and most of the projects are located in the decentralized power supply zone, therefore, the central objective is to substantiate feasible power supply schemes for Arctic projects. The study presented in the paper aims mainly to assess the possible transformations in the structure of generating capacities for each of the territorial zones of the Eastern Arctic in comparison with the current state.

II. Current Structure of Generating Capacities

The zones of the Eastern Arctic (Taimyr-Turukhan zone, North-Yakutsk zone, and Chukotka zone) differ significantly in the level of energy infrastructure development. The total capacity of power plants in the Arctic areas of the Krasnoyarsk Territory, the Republic of Sakha (Yakutia), and the Chukotka Autonomous District is currently 3 178 MW [4].

The energy supply in these areas is represented by five isolated energy areas: two in the Taimyr-Turukhan zone and three in the Chukotka zone, which is a result of historical industrial and economic development. The North Yakutsk zone consists of 13 districts where consumers are supplied with electricity from autonomous energy sources. Remoteness and lack of necessary transport infrastructure have led to the energy isolation.

More than 80% of the total capacity of power plants in the Eastern Arctic operates in the Taimyr-Turukhan zone. The energy structure of this zone is as follows: the

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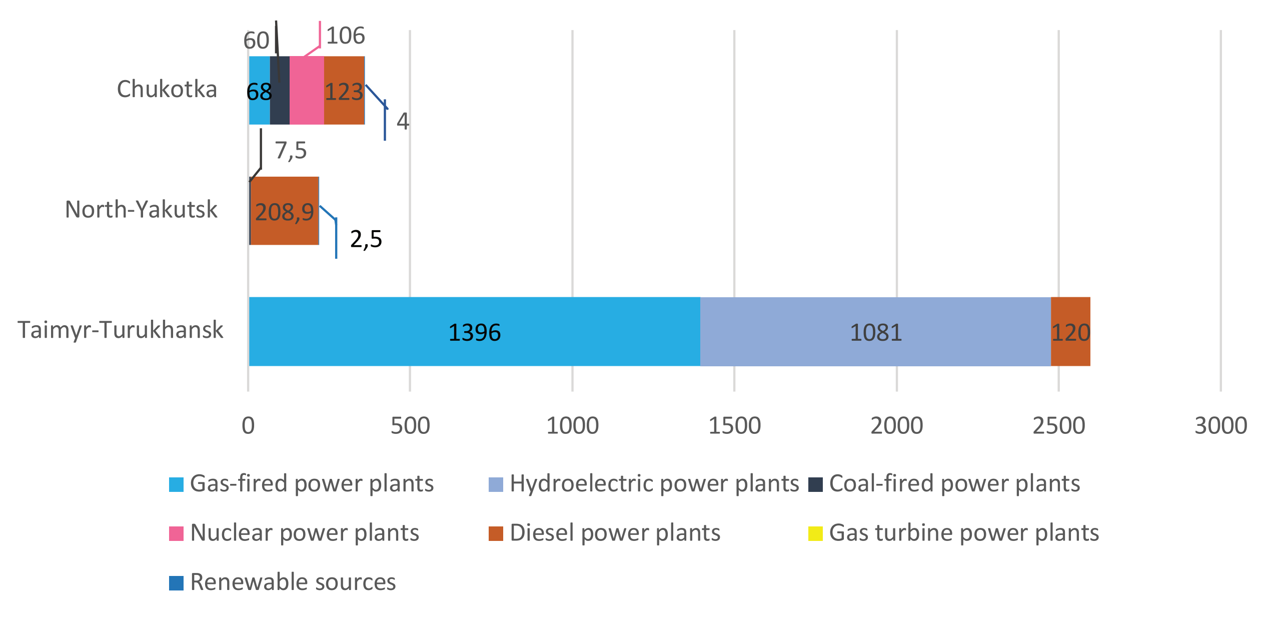


Fig. 1. The structure of the installed capacity of power plants in the Eastern Arctic (Based on the forms of Rosstat "Information on the heat and electricity production by generation facilities (power plants)" for 2019, given data from companies and expert assessments of the authors).

gas-fired power plants of the Norilsk and Vankor energy areas account for about 53%, the Ust-Khantayskaya hydro power plant (HPP) and the Kureyskaya HPP make up more than 40%, and the proportion of diesel power plants is 5% only (Fig. 1).

The Vankor energy area has electrical connections with the Northern energy area of the Tyumen energy system, which is part of the Unified National Electric Grid of Russia. Since 2015, the Vankor energy area has been included in the Krasnoyarsk energy system.

Centralized power supply in the territory of the Chukotka Autonomous Area is provided in three isolated load centers: Anadyr, Egvekinot, and Chaun-Bilibinsky. In the capacity structure in this zone, diesel power plants and nuclear power plants account for 30% each, given the decommissioning of one unit at the Bilibino NPP in 2019 and the commissioning of the floating nuclear power plant "Akademician Lomonosov." Almost 20% is provided by coal-fired power plants (Chaunskaya and Egvekinotskaya) and another 20% – by the Anadyr power plants (Anadyr TPP and Anadyr gas-fired TPP) burning natural gas from the Zapadno-Ozernoye field.

In the capacity structure of power plants in the North Yakutsk zone, utility power plants of JSC Sakhaenergo account for 80%. Relatively large power plants of LLC Yakutsk Generating Company operate at the Verkhnyaya Muna and Ebelyakh diamond deposits.

Due to the vast territory and poor development of the Eastern Arctic of Russia, decentralized energy supply is widespread. Almost 40% of the capacity of autonomous utility power plants in the Asian regions of the Russian Federation operates here. The main problems are complex logistics and seasonality of fuel delivery [4, 5].

III Promising projects for the development of mineral resources

The priority projects in the Eastern Arctic involve the development of the following deposits and fields:

- in the Taimyr-Turukhan zone: Chernogorskoe and Norilsk-1 deposits (rare-earth metals); Suzunskoe, Tagulskoe and Lodochnoe fields of the Vankor area (oil and gas); Syradasay and Malaya Lemberova deposits (coking coal); Popigai deposit (diamond); Payakhskoe field (oil) [6–8];
- in the North Yakutsk zone: Tomtor deposit (rare-earth metals); Ruchey Tirekhtyakh deposit (placer tin); Verkhne-Munskoye deposit (diamond); Kyuchus deposit (gold ore); Prognoz deposit (silver); West Anabar area field (oil and gas) [7, 8];
- in the Chukotka zone: Kekura and Klen deposits (ore gold); Peshchanka deposit (copper); Pyrkakay stockworks (tin and tungsten); Amaam and Alkatvaam deposits of the Bering coal basin (coking coal) [8–10].

The total demand of these projects for power is estimated at 13.7 billion kWh/year [3]. At the same time, the comparison between the growth in demand for electricity and the current indicators of generation in these zones indicates that in the Taimyr-Turukhan zone, the growth in demand is commensurate with generation; in the North Yakutsk zone, it exceeds 5.8 times; in the Chukotka zone, it exceeds 3.3 times. The need for electric power in the projects in the Eastern Arctic is more than 2.5 GW [3].

IV Research methods

The paper proposes a new methodological multi-stage approach developed to conduct feasibility study of energy supply options for new enterprises to be engaged in the

Table 1. Change in the Installed Capacity of Energy Sources, MW

State/Scenario	Gas-fired TPP	Coal-fired TPP	HPP	DPP	GTPP	Total
Current state	1 396	-	1 081	120	-	2 597
Nuclear scenario	2 841	227	1 081	189	-	4 338
Gas scenario	2 841	227	1 081	120	69	4 338

development of mineral deposits. The main stages of the approach are implemented as a set of simulation economic-mathematical and production-financial models that allow multifactor assessment of the performance of energy supply options for consumers located in off-grid areas [11, 12].

The feasible energy supply options for new enterprises were selected based on the findings of the research that determined:

- the competitiveness conditions for the centralized and autonomous power supply from diesel, thermal, and nuclear power plants [13];
- the competitive prices for liquefied natural gas to replace coal, crude oil in boiler houses, and diesel fuel at power plants [14].

V. Prerequisites for structural changes

The substantiation of feasible power supply schemes for new enterprises to be engaged in the development of promising fields involved building two scenarios for the development of energy infrastructure in the Russian Arctic:

- Creation of the low-capacity nuclear industry;
- Development of a liquefied natural gas infrastructure.

Both nuclear and gas scenarios suggest the same increase in the total installed capacity of energy sources compared to the current state.

The implementation of the most power-intensive projects (100–200 MW) will require the development of generating capacities and power grid infrastructure for the load centers in the Taimyr-Turukhan and Chukotka zones:

- Norilsk load center for Chernogorskoye and Norilsk-1 rare-earth metals deposits;
- Vankor load center for Suzunskoye, Tagulskoye and Lodochnoye oil and gas fields;
- Chaun-Bilibinsky load center for Peshchanka (copper) and Kekura (gold) deposits.

New less power-intensive production facilities (20–30 MW) can be connected to the generation centers if they are located in close proximity to them and the mechanism for equalizing electricity tariffs is maintained in the Far East of Russia [13].

Projects in the North Yakutsk zone can only be focused on autonomous power supply, since centralized power supply from the Yakutsk energy system in this territory is hardly possible even in the long term.

An important point in substantiating a preferable energy supply scheme for the enterprises in new development areas is selection of the type of fuel and its rational logistics. The projects for the extraction of fuel resources will naturally use their resources to supply power to the production facilities. In addition to the above deposits and fields (expansion of the Norilsk and Vankor load centers), it is planned to build power plants that use associated gas to power the enterprises of the Payakhskoye and the West Anabar fields and coal-fired power plants - to develop the Syradasay, Malaya Lemberova, the Amaam and Alkatvaam fields.

Ensuring the efficiency of projects for the development of metal ore deposits encounters the problem of choosing a fuel supply option for autonomous power plants. The studies presented in [14] prove the effectiveness of the use of liquefied natural gas in the coastal regions of the Arctic territories. A similar conclusion for the Arctic territories of the Russian Federation is made in [15]. In this regard, the gas scenario assumes the use of gas turbine power plants when developing the Peshchanka and Kekura deposits (when they are connected to the Chaun-Bilibinsky load center) and the Popigai, Tomtor, Kyuchus, Ruchey Tirekhtyakh, and Pyrkakay stockworks.

The nuclear scenario assumes that there is no liquefied natural gas infrastructure. This scenario also considers construction of low-capacity nuclear power plants in the Chaun-Bilibinsky load center to develop the Peshchanka and Kekura deposits, and in the Verkhoyansk area of the Republic of Sakha (Yakutia) – for Kyuchus deposits. The rest of the enterprises involved in the development of remote hard-to-reach deposits are powered by diesel power plants.

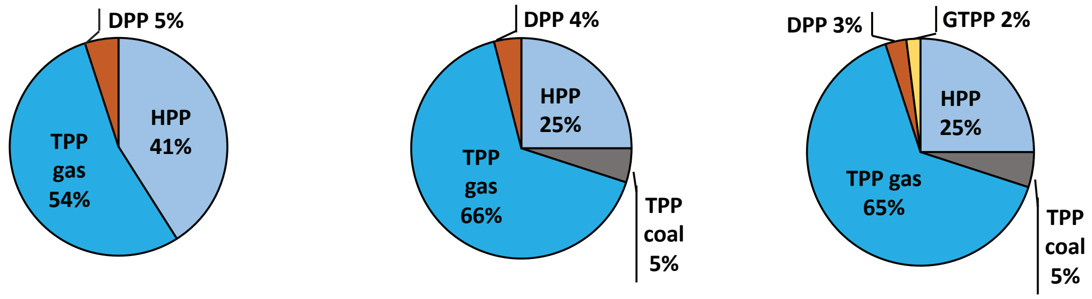
VI. Changes in the structure of generating capacities

Depending on the amount of electrical energy required to implement the projects for the development of deposits and for the creation of infrastructure, the increase in capacity by zone can make up 1.7–2.3 times.

Taimyr-Turukhan zone

Both scenarios envisage a growth in capacity due to a double increase in capacity of gas-fired TPPs and construction of coal-fired TPPs. Construction of nuclear power plants and use of renewable energy sources in this zone are not planned (Table 1).

No significant changes are expected in the capacity structure of energy sources: the share of HPPs will decrease

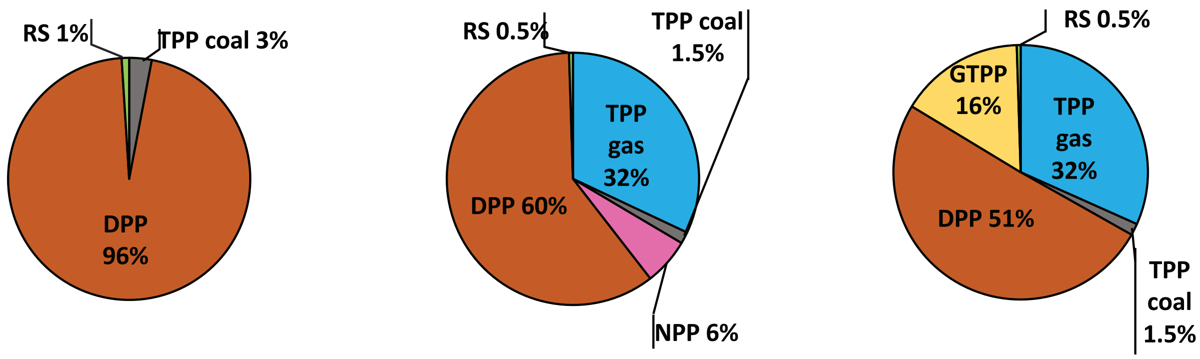


Current state Nuclear scenario Gas scenario

Fig.2. The structure of changes in the installed capacity of energy sources.

TABLE 2. Change in the Installed Capacity of Energy Sources, MW

State/Scenario	Gas-fired TPP	Coal-fired TPP	NPP	DPP	GTPP	Renewable sources	Total
Current state	-	7.5	-	208.9	-	2.5	218.9
Nuclear scenario	162	8	32	307	-	2.5	511
Gas scenario	162	8	-	259	80	2.5	511



Current state Nuclear scenario Gas scenario

Fig. 3. The structure of changes in the installed capacity of energy sources.

due to an increase in the proportion of gas-fired TPPs and the commissioning of coal-fired TPPs in both scenarios. The share of diesel power plants in the gas scenario will slightly go down due to the commissioning of gas turbine power plants (Fig. 2).

North Yakutsk zone

Both scenarios suggest an increase in the installed capacity due to the commissioning of gas-fired TPPs. The nuclear scenario involves the construction of NPPs to supply energy to Kyuchus field and the commissioning of new diesel capacities. The gas scenario envisages the commissioning of diesel power plants and gas turbine units (Table 2).

The capacity structure of energy sources will change significantly compared to the existing state. In both scenarios, despite the growth in capacity, the share of DPPs declines considerably due to the construction of gas-fired TPPs and NPPs in the nuclear scenario, and the construction of gas turbine plants in the gas scenario (Fig. 3).

Chukotka zone

In both scenarios, the installed capacity of energy sources will increase through construction of coal-fired TPPs and DPPs. In addition, the nuclear scenario suggests the construction of nuclear power plants to meet the demand for power when developing Baimskoye and Kekura deposits. In the gas scenario, an alternative to nuclear thermal power plants (NTPPs) is the construction of gas turbine power plants for power supply to the enterprises of Peshchanka and Kekura deposits, and those in the coastal areas (Table 3).

The capacity of gas-fired TPPs will remain at the current level, the capacity of coal-fired TPPs and DPPs will increase, however, their proportion in the capacity structure will decrease due to the construction of NTPPs in the nuclear scenario, and the commissioning of GTPPs, whose share will be slightly less than 50%, in the gas

Table 3. Change in Installed Capacity of Energy Sources, MW

State/Scenario	Gas-fired TPP	Coal-fired TPP	NTPP	DPP	GTPP	Renewable sources	Total
Current state	68.3	60	106	123	-	4	361
Nuclear scenario	68	121	374	191	-	4	758
Gas scenario	68	121	70	161	334	4	758

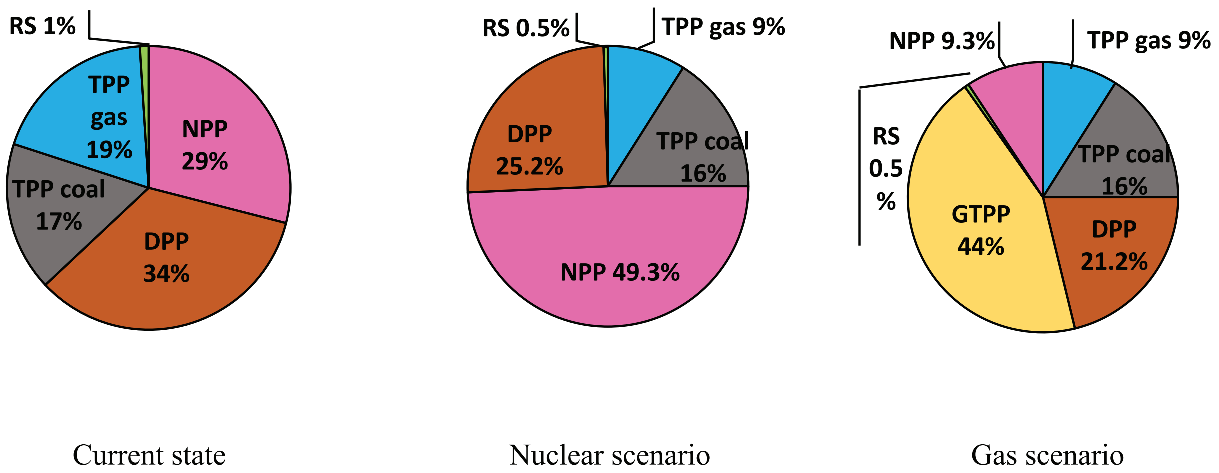


Fig. 4. The structure of changes in the installed capacity of energy sources.

scenario (Fig. 4).

The fuel needs of new generating capacities at the resource development enterprises is estimated at 5–5.6 million t.c.e., of which about 60% falls on projects for the extraction of oil, gas, and coal. The rest of the increase in the demand will be met by the resources delivered from other areas, which will significantly increase the load on the transport system. The complex multi-link seasonal fuel delivery to the areas of the Eastern Arctic and the state of year-round and winter roads are the reasons why the transport infrastructure can become a barrier to the large-scale development of mineral resources. In this regard, the Arctic regions of Russia need a state program for the development of transport and energy infrastructure. The absence of the program calls into question the reality of the economic development of the Arctic [Energy Policy].

VII. Conclusion

The implementation of projects for the development of mineral resources in the Arctic, which are outlined in the state strategic documents, will require the feasibility study of power supply schemes. With this in view, the study should take into account the characteristics of the Eastern Arctic, i.e., partial isolation of the territories from the Unified Energy System of the Russian Federation, the focal nature of development, the absence of established transport and industrial infrastructure.

More than 2.5 GW of additional generating capacity will be required to support projects in the Taimyr-Turukhan, North Yakutsk, and Chukotka zones. The total electricity consumption of the projects is estimated at 13.7 billion kWh/year.

In order to meet the necessary demand of each zone, a separate assessment of possible transformations in the structure of generating capacities was made compared to the current state. A methodological multi-stage approach developed to substantiate the energy supply options was used. The new approach is based on a special set of simulation economic-mathematical and production-financial models.

Two scenarios for the energy infrastructure development are considered: the creation of a low-capacity nuclear power industry and the establishment of a liquefied natural gas infrastructure.

Based on the research findings, the following solutions are presented.

In the Taimyr-Turukhan zone, both scenarios envisage a twofold increase in the capacity of gas-fired TPPs and the construction of coal-fired TPPs. The construction of nuclear power plants and the use of renewable energy sources in this zone are not planned.

In the North Yakutsk zone, the commissioning of gas-fired TPPs will increase the capacity in both scenarios, thereby reducing the share of diesel power plants significantly.

In the Chukotka zone, in both scenarios, an increase in the capacity of energy sources will be achieved through the construction of coal-fired TPPs and DPPs. In addition, the nuclear scenario involves the construction of a nuclear power plant to meet the demand for energy when developing the Peshchanka and Kekura deposits. In the gas scenario, an alternative to NTPPs is the construction of

GTPPs for auxiliary power supply at these deposits.

The demand of new power plants for fuel is estimated at 5–5.6 million t.c.e. Projects for the extraction of fuel resources intended for auxiliary power supply to these plants account for about 60%. Metal ore mining projects in the coastal areas can be supplied with liquefied natural gas, the effectiveness of this energy supply option has been proven by the research.

The large-scale development of mineral resources in the Arctic regions of Russia is impossible without a state program for the development of transport and energy infrastructure.

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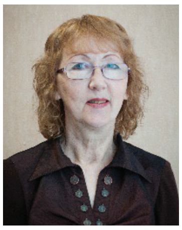

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