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Formation of Territorial Heat Supply Systems in the Northern and Arctic Regions of Russia

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Abstract. The article deals with the most important problems of the communal complex in the subjects of the Far North and the Arctic zone of the Russian Federation. The main attention is paid to the aspects of formation of territorial heat supply systems, which are the basic components of the infrastructure of life support in harsh polar natural and climatic conditions. The impact of the growth of utility tariffs on the structure of consumer spending of households in the northern and arctic regions is assessed. It is shown that the state of the municipal energy sector determines the formation of the socio-economic environment and investment attractiveness of the Arctic municipalities. Its renewal and modernization are the main conditions that contribute to reducing the rate of migration outflow of the local population, increasing industrial production and the state military–strategic presence in this important macro-region. Despite the predominance of energy sector specialization in the list of leading industrial enterprises, the presence of the necessary fuel and raw materials base and increased inflow of investment resources in the energy sector, there is further obsolescence and reduction of fixed assets of municipal energy supply units as well as the highest level of utility consumer costs in comparison with all-Russian indicators. The conclusion about the loss of previously available territorial infrastructure advantages of the Russian Arctic regions is substantiated: there has been a reduction in the total number of heat sources, territorial energy production, the length of heat communication networks. The increase of these energy threats is a factor limiting the socio-economic growth of Russia's northern and arctic territories.
Keywords: *Arctic, Far North, infrastructure, public utility, tariff on utility service, heat supply, system*

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Introduction

The issues of resource provision, organization of services, the level of prices and quality of services provided by housing and communal energy enterprises have been in the focus of public attention throughout the entire modern history of Russia. An important factor in their functioning in the Russian Far North and in the Arctic is the insufficient infrastructural development of these territories. There are no large oil refining facilities in the Arctic zone of Russia, so the considerable

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energy needs of local industry, thermal power plants and boiler houses are met by long-distance fuel supplies from the Leningrad Oblast, the Komi Republic, the Khanty-Mansi Autonomous Okrug, the south of the Krasnoyarsk and Khabarovsk krais. There are also no enterprises producing complex energy equipment. Regional supply chains of fuel and energy complex enterprises (FEC) have a pronounced imported and predominantly seasonal nature, characterized by the unevenness, low rhythm of cargo deliveries, and enormous transport distances. Underdevelopment of transport and transport-energy infrastructure, dependence on seasonal patterns of operation and the state road networks determine the use of multimodal transport schemes, the organization of intermodal fuel storage facilities and the accumulation of irreducible reserves. The slow pace of implementation of programs for territorial gasification, construction of main gas transmission and gas distribution systems lead to the dominance of outdated technologies for delivery and use of energy carriers, limiting the opportunities for economic development of heat and power companies. The high level of physical deterioration of their equipment greatly complicates the solution of local energy problems, affects the cost of supplied heat energy and the formation of utility tariffs. Due to the high social significance of the sustainable operation of the public utilities sector, the regional state authorities and local self-governments are empowered to monitor the preparation and passage of the winter heating season, to coordinate the joint activities of the economic entities, and to limit the growth rate of utility tariffs through the application of price regulation mechanisms. The increase in the cost of imported fuel resources leads to the need for additional subsidizing of heat supply organizations from the budgets of the Arctic and northern regions, since the consequences of establishing economically justified energy tariffs and a sharp rise in the cost of heat supply services for the population have so far been recognized as unacceptable. Thus, an appropriate way to understand the essence of the problems considered in this article can be a definition that allows us to outline the main issues of regional heat supply in the Far North as “investment-intensive, with non-market tariffs, complex socially significant infrastructure in need of urgent technological renewal”. At the same time, it seems decisively insufficient to limit them to any single sector of the regional economy, for example, fuel and energy or housing and communal sectors. Overcoming these territorial energy problems is indeed a complex national economic task, the solution of which in the northern and Arctic regions is complicated by the presence of close links with many other systemic threats due to unfavorable natural and climatic features of residence and economic activity, as well as known features of socio-economic development [1, p. 39]. Therefore, studies aimed at finding possible common approaches to improving the key elements of the territorial infrastructure, both in the central regions, with more developed infrastructure, and in the peripheral ones, with their special features, are of particular scientific value. It should be expected that the development of a scientifically based methodology that contributes to the solution of the above socially significant problems will have a positive impact on the state of the economy, investment attractiveness, and the comfort of people living in areas with the most severe natural and climatic conditions.

The Arctic, the Far North and the Far East of Russia are considered by the federal authorities as strategically important macro-regions. Moreover, they are singled out as separate independent subjects of state administration. In 2019, the Ministry of the Russian Federation for the Development of the Far East (Minvostokrazvitiya) was reorganized with additional functions for the development of the Arctic and was renamed into the Ministry of the Russian Federation for the Development of the Far East and the Arctic — so significant is the contribution of the Arctic and Far Eastern industries to the national economy. The Ministry has developed plans for the accelerated development of the infrastructure complex, which, in addition to ensuring economic objectives, should become the foundation for further socio-economic growth, improving the quality of life of northerners. It should be admitted that there has been some progress in this direction — over the past few years, six major projects have been implemented in the Arctic zone of the Russian Federation (hereinafter referred to as AZRF), specializing in the transport and energy sectors (for more details [2, Biev A., Serova N.]) . The most large-scale and significant events for the entire Russian Far North were the construction and launch of a gas pipeline branch at the section of the main gas pipeline “Bovanenkovo (Yamal-Nenets Autonomous Okrug) —Ukhta (Komi Republic)”, the construction of gas distribution infrastructure and the conversion to natural gas of TPP- 2, Central hot water boiler house in Vorkuta (Komi Republic). The start of commercial operation of the floating nuclear thermal power plant of project 20870 “Akademik Lomonosov” in the city of Pevek (Chukotka Autonomous Okrug) can be considered the first example of such a high-tech solution to the problem of territorial energy supply of the AZRF based on the use of non-stationary mobile platforms. The ambitious gasification project of the Murmansk Oblast, which provides for the construction of the Volkhov–Murmansk gas pipeline route, as well as the creation of an appropriate gas distribution infrastructure with connection of the largest industrial enterprises and heat sources located not only on the Kola Peninsula, but also in the northern part of the Republic of Karelia, has received a new impetus. These projects are directly linked to the long-term plans for the modernization of public utilities in the Arctic and subarctic regions. However, despite the attention and financial support from the federal center, the pace and scale of updating transport and energy infrastructure networks lag far behind the planned stages of their commissioning. In this regard, experts recognize the need to develop a separate state program for them, without which the reality of further economic development of the Arctic is questioned [3, Saneev B., Ivanova I., Izhbuldin A., Tuguzova T., p. 95]. Most scientific opinions on the causes and consequences of the “shift of schedules to the right” do not come into sharp conflict with the conclusions of federal officials regarding the priority of the implementation of critically important Arctic investment projects. Of practical interest are separate additions to the general positions, consisting in the fact that the regional energy subsystems will contribute to a greater autonomization of the sphere of territorial life support, overcoming the consequences of interregional economic differentiation and infrastructure gap [4, Zmieva K.A., p. 6]. One can fully agree with them, given that the Arctic transport complex is now a fairly highly specialized type of infrastructure designed to ensure, in the current paradigm of managing the development of the Arctic and the Far North, first of all, the stable functioning of the raw material industry and the seasonal replenishment of transient inventories. Northern delivery, transportation of extracted raw materials along the Northern Sea Route, export and interregional transportation of commercial products and building materials for the construction of new industrial facilities occupy the largest share in the total indicators of regional transport services [5, Baranov S.V., Bazhutova E.A., Biev A.A. et al., p. 75]. At the same time, the Arctic communal energy and heat supply, based on the expanded application of new technologies of local and renewable resources use, as their desirable vision for the perspective until 2030 is described in the fundamental strategic documents [1], are much more focused on strengthening territorial self-sufficiency, inflow of qualified labor force, improvement of stationary living conditions. The development and implementation of comprehensive investment plans for the modernization of the municipal energy sector, the introduction of innovative energy-saving and environmentally friendly technologies should contribute to stabilization of the socio-economic situation, the size of the local population in remote depressed areas by providing affordable public services, meeting the basic needs of people with reference to the conditions of a particular territory.

The issues of updating socially significant infrastructure in the Far North and the Arctic, in addition to departmental control, are also the focus of attention of the country's top leadership. The principled position of the head of state on maintaining the unconditional priority of the previously approved plans for the economic development of the Russian Arctic territories and ensuring their military security, taking into account the radically changed geopolitical situation, is well known. It was very clearly stated at the Government meeting on the development of the Russian Arctic on April 13, 2022 [2]. During the meeting, the importance of implementing proposals related to the development of the housing and communal sector of closed administrative-territorial units (CATUs) of the Arctic zone was especially emphasized. The President gave instructions to ensure the comprehensive modernization of energy, residential and social facilities in the Murmansk Oblast CATU, where large military bases, enterprises of the military-industrial complex and ship repair facilities are located, by the end of 2024.

The strategic documents of the Russian Federation, as the main tools for implementing communal renovation programs in the Arctic, provide for organizational mechanisms for "state guarantees to support projects for the modernization of energy and engineering infrastructure, stimulating the participation of state corporations, private investors and companies with state participation" [3]. Most of the funds for these purposes are allocated by the Government of the Rus-

[1] Energeticheskaya strategiya Rossii na period do 2030 goda: utv. Raspor. Pravitel'stva RF ot 13.11.2009 № 1715-r [Energy strategy of Russia for the period up to 2030: approved by Decree of Government of the Russian Federation dated November 13, 2009 No. 1715-r]. URL: https://minenergo.gov.ru/node/1026 (accessed 15 February 2022).

[2] See in more detail the transcript of the Government meeting on the development of the Arctic zone of the Russian Federation. April 22, 2022. URL: http://prezident.org/tekst/stenogramma-soveschanija-putina-po-voprosam-razvitija-arkticheskoi-zony-13-04-2022.html? (accessed 10 May 2022).

[3] Strategiya razvitiya Arkticheskoy zony Rossiyskoy Federatsii i obespecheniya natsional'noy bezopasnosti na period do 2035 goda (s izmeneniyami i dopolneniyami), utverzhdena Ukazom Prezidenta RF ot 26 oktyabrya 2020 g. № 645

sian Federation from the federal budget as part of the state program “Socio-economic development of the Arctic zone of the Russian Federation” [4]. Several state funds are used: first of all, the target Fund to promote reform of the housing and utilities sector (reorganized in 2022 by joining the public law company “Territorial Development Fund”). In 2021, it was decided to additionally use the funds of the National Welfare Fund (NWF), the share of which in the financing of Arctic infrastructure projects should increase significantly — up to 80% of their total cost [5]. In January 2022, the Government Commission for regional development approved the allocation of 386 million rubles of NWF loan money to the Murmansk Oblast to upgrade the boiler plant in Olenegorsk (total funding should be 483 million rubles). Pre-approval of applications for the financing of boiler equipment upgrade projects in four other municipalities of the region (Kandalaksha, Revda, Lovozero, Vysokiy) for a total amount of more than 2 billion rubles was successfully passed. For projects in the Republic of Yakutia, a loan in the amount of 273.3 million rubles was provided from the NWF for the same purpose. However, due to the beginning of the active phase of the Russian-Ukrainian conflict in February 2022, the amount of funds raised from the NWF is likely to be adjusted.

The tightening of the US sanctions policy, as well as the introduction of unprecedented military and economic countermeasures by a number of European Union states have significantly exacerbated the issues of modernizing the enterprises of the Russian energy complex. The most immediate consequences of the actions of the US and the EU for the domestic thermal power industry was the rise in the cost of banking services, the provision of borrowed resources, and insurance of project risks. There has been a reduction in the possibility of importing key components of technological equipment of TPPs and boiler houses, which our country does not yet produce in sufficient quantities and range. Russia has not yet managed to develop serial production of gas turbines with a capacity exceeding 110 MW — the main equipment for TPPs with a combined cycle, although such strategic objectives were set by the Government back in 2014–2016. According to the results of industry surveys conducted at that time, experts identified steam-gas turbines and turbine generators, compressor units, high-pressure circulating pumps, heat exchangers, electronic modules for automated control, instrumentation and diagnostics, temperature sensors, complex assemblies of shut-off and control valves for water supply, water disposal and water

[Strategy for developing the Russian Arctic zone and ensuring national security until 2035 (with amendments and additions), approved by Decree of the President of the Russian Federation of October 26, 2020 No. 645]. URL: https://base.garant.ru/74810556/? (accessed 10 April 2022).

[4] Kompleksnaya gosudarstvennaya programma Rossiyskoy Federatsii «Sotsial'no-ekonomicheskoe razvitie Arkticheskoy zony Rossiyskoy Federatsii» (s izmeneniyami i dopolneniyami ot 30 oktyabrya 2021 g.), utverzhdena Postanovleniem Pravitel'stva RF ot 30 marta 2021 g. № 484 [The Comprehensive state program of the Russian Federation "Social and economic development of the Arctic Zone of the Russian Federation" (as amended and supplemented on October 30, 2021), approved by Decree of the Government of the Russian Federation of March 30, 2021 No. 484]. URL: https://base.garant.ru/400534977/? (accessed 15 February 2022).

[5] Rasporyazhenie prem'er — ministra Pravitel'stva RF M. Mishustina, utverzhdennoe 25 yanvarya 2022 g. № 82-r [Order of the Prime Minister of the Government of the Russian Federation M. Mishustin, approved on January 25, 2022 No. 82-r]. URL: http://static.government.ru/media/files/ilSRhWpKfIgS3ZFpyYPVrT2BKH55veky.pdf (accessed 27 April 2022).

treatment, rubber products and equipment as critical types of thermal power equipment that should be localized in our country. The importance of the development of specialized software was also mentioned [6]. The continued dependence of Russian Arctic projects in the field of renewable energy on the products of foreign suppliers is noted by foreign researchers [6, Mortensen L., Hansen A.M., Shestakov A., p. 175]. In addition, there are significant logistical difficulties in using multimodal transport schemes for the delivery of large-sized energy equipment from abroad, especially to areas with seasonal transport accessibility, which often caused a long delay in territorial development plans [7, Antonenkov D., Kiushkina V., p. 240]. At present, the supply and service support of industrial equipment of Western production has stopped for an indefinite period of time, and the possibilities of search for alternative suppliers, parallel import of certain categories of goods, such as gas turbines, boilers, turbo generators, manufactured individually for each project, are limited. Therefore, from the perspective of assessing the prospects for the further development of import substitution as one of the institutions of national technological sovereignty, it is of particular interest to study the Russian experience of developing competitive models of equipment for low-power energy sources. To the fullest extent, the operating conditions in the gasified regions of the Far North, the Arctic part of Eastern Siberia and the Far East meet the production characteristics of block-modular gas boilers — the most efficient, cheap to construct, environmentally safe [8, Mikhaylova L.Yu., Germanova T.V., Kurilenko N.I., Shcherbakova E.N., p. 95–96]. In Russia, there are examples of successful creation and practical testing of their standard equipment [9–10], however, overcoming the difficulties of organizing mass production and maintenance will require significant investment, time and material resources, which will cause an accelerated growth in industry tariffs. This systemic problem of the Far North and Arctic regions should be discussed in more detail.

Social aspect of the problem of tariff disproportions and utility tariff regulation in the Far North and the Arctic

Solving the problems of tariff imbalances in utilities, providing investment resources for programs and projects of housing and communal services modernization, overcoming the technological backwardness of the industry, introducing public-private partnerships in municipal energy sector are the main tasks of regional management of heat supply development [11, Chayka L.V., p. 78.]. Federal authorities also form additional financial support instruments that take into account the specifics of the operation of existing heat supply sources in special climatic conditions. The accelerated growth of operating costs and the need to improve the economic performance of large thermal power plants operating in the Russian Arctic in the so-called “forced” mode, led to further development of the initiative of the Russian FAS to use a special procedure for calculating sector

[6] Aktual'nye voprosy importozameshcheniya v teplosnabzhenii i energetike Rossii [Topical issues of import substitution in the heat supply and energy sector of Russia]. Aqua-Term. URL: https://aqua-therm.ru/kruglyy-stol/spec-proekty_8.html? (accessed 15 April 2022).

tariffs, taking into account the climate coefficient (30%) [7]. As steps to improve the investment attractiveness of utility projects and to ensure the return of substantial financial resources from the state budget, the Government proposed in 2021 to consider the possibility of mitigating the effect of tariff regulation mechanisms, which is generally not typical for the domestic practice of organizing work with natural monopolies, established over the past decade. On behalf of the Deputy Prime Minister of the Government of the Russian Federation M. Khusnullin, the industry scenarios that allow for gradual increase and establishment of so-called economically justified tariffs in those constituent entities of the Federation, where investment projects in the utilities sector are actively implemented, continue to be actively studied. Such views, promoted once again both at the level of expert positions of top state representatives and at the level of adoption of conceptual planning documents, leave quite a contradictory impression. On the one hand, the interest in stimulating the growth of investment attractiveness and creating the necessary conditions for payback of the plans of socially significant infrastructure renovation is declared (under the policy of maximum tariff restraint, there are really few people who want to invest in housing and communal services in the Arctic and northern municipalities). On the other hand, these provisions run counter to the national security interests, aimed at maintaining state sovereignty, control over vast sparsely populated areas, because it becomes more and more difficult to ensure it by maintaining a sufficient number of economically active population in the Arctic in the conditions of increasing tariff pressure and reducing the availability of public utilities. According to the estimates of regional authorities, the current growth rate of tariff levels has become a systemic factor stimulating migration outflow [8]. The opinions widespread among the scientific community are also very unambiguous: the underdevelopment of the communal infrastructure of the Far North, its unsatisfactory condition, leading to the growth of utility costs, high cost of the minimum consumer basket are among the main motives for the decision to move to the regions with more comfortable living conditions as in Russia [12, Mkrtchyan N.V., Florinskaya Yu.F., p. 149–150] and abroad [13, Withers S.D., Clark W.A.V., p. 286–288]. The results of sociological research conducted by scientists of the North-Eastern Federal University (NEFU) have shown that the growing share of mandatory payments and utility costs is not only a purely internal factor of increasing social tension in the Russian Far North and the Arctic, but also a global trend that affects the social well-being of residents in the Arctic communities of the largest foreign countries — the USA and Canada. The general pattern of socio-demographic processes in our country and in other Arctic states is that in

[7] Smertina P. Arkticheskim TES nachislyat severnye [Arctic thermal power plants will be credited with northern ones]. Newspaper "Kommersant". No. 56 of 01.04.2021, p. 7. URL: https://www.kommersant.ru/doc/4752680 (accessed 15 April 2021).

[8] On July 22, 2020, the Governor of the Murmansk Oblast Andrey Chibis during a meeting of the Federation Council on gasification of the constituent entities of the Russian Federation, said that the increase in the cost of housing and communal services is "one of the factors stimulating the departure of people from the territory". IA TASS Source: The Murmansk region may become a pilot region for the transfer of heat supply systems to LNG. July 22, 2020. URL: https://tass.ru/ekonomika/9028823?utm_source=yandex.ru&utm_medium=organic&utm_campaign=yandex.ru&utm_referrer=yandex.ru (accessed 25 April 2022).

extreme living conditions, the increase in the cost of socially important services causes a sharper manifestation of negative social effects, in particular, the growth of poverty [9]. So far, there are only separate departmental assessments of how adequate should be the response expansion of the list of measures of targeted social support from the federal and regional authorities, capable to compensate the aggravation of this major social problem. The experts agree that there is an objective need for a significant increase in the volume of subsidies for low-income categories of citizens, whose share in the Far North remains consistently high [14, Korchak E.A., p. 54]. It remains unclear how exactly the above-mentioned attempts of the federal government to change the established approach to the formation of utility tariffs will be able to stimulate the redistribution of regional investment flows and accelerate long overdue transformations in the utility sector. Theoretically, they could lead to the formation of the basic conditions for the investment attractiveness of the industry. However, in practice, it is necessary to meet a number of conditions [15, Loktionov V.I., Mazurova O.V., p. 1312]. The main one is a multiple increase in the share of socially oriented investments directed to the public utility sector, to the communal energy sector, accompanied by an increase in income of the local population, able to pay for higher quality, but also more expensive services, to ensure sustainable effective demand for energy. There is no clarity on how the federal and regional authorities are going to achieve it against the backdrop of crisis manifestations and further sanctions on the Russian economy, which will undoubtedly intensify in the near and medium term. Meanwhile, the scenario of an accelerated increase in the tariff burden on utility consumers under the plausible pretext of "the need to ensure the uninterrupted operation and development of the housing and communal services infrastructure across the country" (Head of the Ministry of Economic Development Maxim Reshetnikov, September 23, 2022) began to be implemented. The government announced the early postponement of the annual indexation of tariffs for gas, electricity, water and heat supply from July 1, 2023 to December 1, 2022. In 2022, utility tariffs in the Russian Federation were indexed twice. Annual growth may exceed 15.5%, which will significantly accelerate inflationary processes, further accumulation of consumer debt for services, and lead to an aggravation of the social situation in the northern and Arctic regions of Russia.

The principle of prioritizing the social aspects of the regional energy systems development and the interests of the population — a special category of consumers in the regional heat markets — is absolutely justified, since households form the main indicators of energy demand and are a key object of socio-economic assessment. Despite the increased attention of federal authorities to the Arctic social agenda, the results of studying the dynamics of a number of economic and statistical indicators of the state of housing and communal services (growth of debt for consumed energy resources, number of utility accidents, share of dilapidated heating networks, emergency housing stock, etc.) should be interpreted as a manifestation of signs of a systemic deterioration in

[9] Vyyavleny obshchie prichiny bednosti v arkticheskikh regionakh Rossii, Kanady i SShA [Common causes of poverty in the Arctic regions of Russia are identified, Canada and the USA]. IA TASS — Nauka. August 19, 2021. URL: https://nauka.tass.ru/nauka/12166507? (accessed 15 April 2022).

living conditions and the availability of public services in the Far North and the AZRF. One of the most frequently used indicators of social well-being and assessment of investment attractiveness of the territory is the indicator of the share of household expenditures allocated to pay for housing and communal services, which is, at the same time, a characteristic marker of the growth of the “high cost of living” in the North. The main part in the structure of their cost is the utility component — the cost of fuel, electricity and heat. Due to climatic features, it is traditionally high: in the Arctic regions of the Far East, the share of utility bills in the total cost of housing and communal services reaches 84.5% [16, Naiden S.N., p. 41]. Therefore, the impact of increased marginal costs of territorial fuel and energy supply — one of the well-known manifestations of the “northern rise in prices” phenomenon and a special condition for the functioning of regional fuel and energy systems — exerts strong pressure on the formation of the dynamics of the indicator proposed for consideration. Fig. 1 shows the trends of its change over the past twenty years.

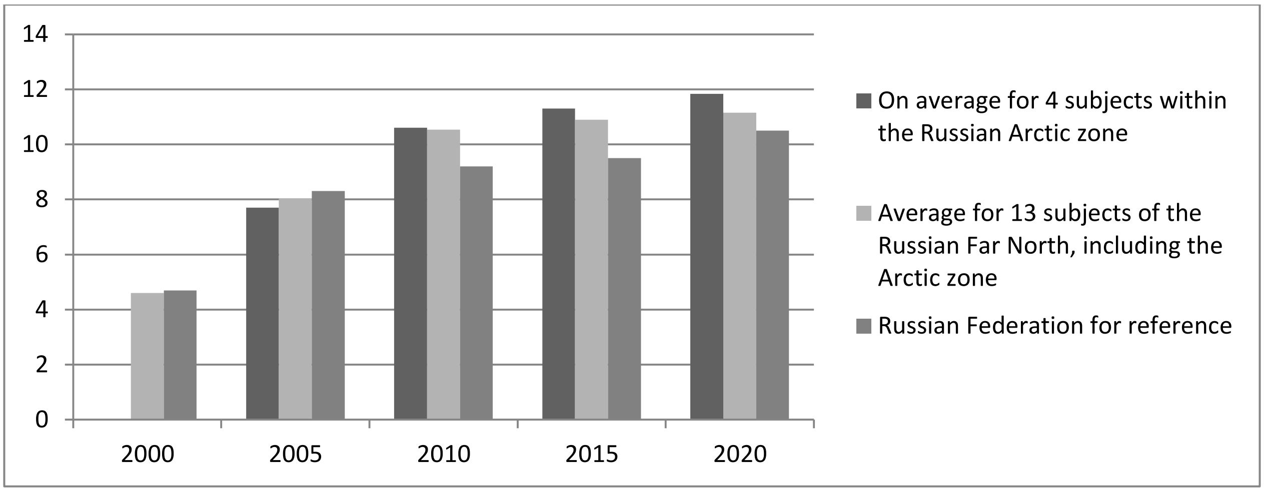

Fig. 1. Dynamics of the share of household expenditures in the northern and Arctic regions of the Russian Federation allocated to pay for housing and communal services, in % of the total amount of consumer spending [10].

The increase in the share of this type of consumer spending is noted as an irreversible trend, which is quite clearly expressed both in a narrow regional context of the Far North and the Arctic, and on a federal scale. Attention is drawn to the sharp, almost two-fold increase in the indicator that occurred over the period from 2000 to 2010, which marked the beginning of the sectoral reform of heat supply. At that time, the growth rate of utility costs of the population in the Arctic regions was significantly ahead of the Russian average, thereby “pulling” up the values of all the “northern” ones. It can be noted that there is a temporal relationship between the period of the most intensive growth of utility tariffs (in 2000–2010) and the change in the vector of tariff policy in the infrastructure sector of Russia, which since 2002 was determined by the scenario conditions of the “Forecasts for the socio-economic development of the Russian Federation”, which provided for a significant increase in economic indicators of regional production. They also largely determined the dynamics of tariff rates for households. As economic growth slowed down,

[10] Source: calculated by the author based on UISIS data.

tariff indexation began to be carried out at a rate below inflation [11], which subsequently prompted representatives of the FAS to argue that "... compliance with this principle in regulatory and supervisory activity prevents the indexation of citizens' payments by more than the rate of inflation" [12]. Indeed, independent studies show that, as of 2021, the utility tariff setting system was at its lowest rate of growth over the past 19 years [13]. Obviously, ten years is the answer to the question of how long it was possible to continue the policy of maximum containment of utility tariffs in the conditions of almost complete physical depreciation of the main assets of housing and communal services; now the situation is changing. Entering a new stage of the utility reform aimed primarily at revising the tariff setting principles, and forming new sources of investment in the sector, as in previous years, will be associated with a sharp increase in the tariff burden of consumers. It remains to be hoped that the federal government, embarking on the next phase of restructuring the utility industry, is fully aware of the scale of consequences of the planned changes in state policy regarding the development of critically important territorial infrastructure, errors in the implementation of which in the Arctic and the Far North are fraught with a full-scale escalation of crisis socio-economic manifestations.

The increased level of public utility costs remains the special feature of almost all northern and Arctic regions. In the expert community, opinions are very widespread that as the Arctic climate steadily warms and energy technologies are improved, regional climatic features will have less and less influence on the cost of production of the most energy-intensive utilities (heating and hot water supply) [17, Nefedova L.V., p. 94]. Socio-economic factors of territorial development have become very important, if not determinative, in ensuring energy security of the Arctic and the North [ibid]. Long-term shortage of financing of socially important projects reflects the obvious exhaustion of the current model of financial and investment support of local municipalities. Experts generally agree with the organizational decisions outlined in the latest version of the Russian Arctic Development Strategy dated October 26, 2020, noting, however, that the main emphasis in overcoming the problem of chronic underfunding of the utility industry in modern conditions should be placed on attracting private investment [18, Shakirov V.A., Tuguzova T.F., Muzychuk R.I., p. 110] and joint public-private partnership [19, Potravnyy I.M., Yashalova N.N., Borukhin D.S., Tolstoukhova M.P., p. 158–159]. Such opinions are absolutely fair, since the systemic problem of the lack of public investment in the development of social infrastructure in the Far North is well known. It has touched the Arctic municipal energy sector in full measure, and now one of the basic

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[11] Since 2017, tariff regulation has been established by indexing them to the level of forecast (target) inflation using sectoral efficiency ratios (inflation minus). Source: Tariff policy in the Russian Federation in the utilities sector: priorities, problems, prospects: report on 21st Apr. internat. scientific conf. on the problems of economic and social development]. Moscow, 2020.

[12] Vitaly Korolev, Deputy Head of the FAS Russia, January 26, 2021. Source: FAS Russia: the "inflation-minus" principle made it possible to avoid an unlimited increase in tariffs for housing and communal services in 2020. Federal Antimonopoly Service of Russia. 26.01.2021. URL: https://fas.gov.ru/news/31093 (accessed 15 April 2022).

[13] According to the international audit and consulting network FinExpertiza. Source: Research: growth in prices for housing and communal services in the pandemic year was the lowest in 19 years. 26.01.2021. URL: https://www.banki.ru/news/lenta/?id=10940515 (accessed 15 April 2022).

criteria for establishing the priority of state support for regional investment projects is the ratio of private investment and budget funds allocated for their implementation [20, Novoselov A., Potravnyy I., Novoselova I., Gassiy v.]. Private companies are also slow to invest in public energy infrastructure. According to the experts of the Institute of economic problems of the Kola scientific center of RAS, the share of plans for the modernization of municipal energy facilities in the AZRF (gasification of boiler houses, construction of new heat sources, renovation and reconstruction of heat networks, engineering communications) accounts for only about 2.25% of the total volume of financial support for investment projects of the fuel and energy complex [21, Skufina T.P., Serova N.A., Bazhutova E.A., Baranov S.V. et al., p. 102]. It can be argued that the chronic underfunding of public utilities, as well as the lack of full understanding in the scientific community, at the regional and top levels of public administration of the directions and sources of funding on which its reform plans will be based, remain a very serious threat to the socio-economic development of the Russian Far North and the Arctic.

Materials and methods

The analysis of the regional heat and power infrastructure includes the study of the characteristics of the quantitative and qualitative structure of territorial heat and power facilities, heat communication networks, operational and production parameters of their functioning. In the text of this article, they are reviewed in more detail. Below we present the results of comparative analysis of heat and power infrastructure formation processes in the Russian Arctic, both separately and as part of the Far North macro-region. In order to preserve the possibility of their comparison with the scientific results obtained at earlier stages of the study, a list of 13 constituent entities of the Russian Federation is considered as a macro-region of the Far North, the territories of which are fully or partially assigned to the regions of the Far North and equated areas, according to the Decree of the Government of the Russian Federation of 16.11 .2021 No. 1946 [14].

Four indicators available in the UISIS system were taken as the basis for the methodology of the regional heat and power infrastructure analysis. The dynamics of their changes during the current historical period of Russia's development, from 2000 to 2020, is demonstrated. The first indicator, territorial generation of thermal energy, characterizes the volume of energy production and trends in energy demand. The second one — the change in the number of heat sources — is a quantitative indicator of energy supply and economic development of the territory. The third one is the total installed heat capacity of thermal power facilities, a quantitative criterion demonstrating the territorial energy potential and the ability of energy systems to meet current and future demand. The fourth indicator is the length of heating networks, another quantitative characteris-

[14] This study considers a list of 13 constituent entities of the Russian Federation, the territories of which are fully or partially attributed to the Far North and equivalent areas by current legislation: Magadan, Murmansk, Arkhangelsk, Sakhalin oblasts, the republics of Komi, Tyva, Karelia, Sakha (Yakutia), Kamchatka Krai, Nenets, Yamalo-Nenets, Khanty-Mansi and Chukotka Autonomous okrugs.

tic that allows determining the degree of infrastructure development of the territory, as well as the level of equipment of consumers and the population with centralized heat supply systems.

When assessing the factors that most strongly influenced the change in the quantitative and qualitative composition of heat generation sources, the factor of a prolonged demographic decline was identified, which determines the acceleration of the infrastructural contraction processes. That is why the scope of research data in the framework of this work was chosen quite broadly, with a focus on specific indicators, based on the existence of a set of relationships between migration processes, population decline in the Far North subjects, in the AZRF, and the transformation of the utility sector of these territories — gradual degradation of communal infrastructure, an increase in the unprofitability of district heating systems in conditions of reduced energy demand from the population. The main hypothesis of the study was the assumption that negative demographic processes, along with climate change, are becoming the main reasons for the decrease in demand for thermal energy and the corresponding transformation of territorial heat supply systems in the Far North. The reduction in the number of residents is directly related to the narrowing of the choice of possible sources of project financing, the limited required investment inflow directed by large business structures, primarily to the development of the raw materials industry, the extractive sector of the economy.

Results and discussion

Table 1 shows changes in the quantitative composition of heat supply sources in the Russian Arctic. During the period 2000–2015, there has been a significant reduction in their total number, and the share of northern and arctic heat generation facilities in the federal scale has decreased. The predominance of liquidation processes over commissioning of new heating capacities, until relatively recently, led to a significant strengthening of the competitive positions of district heating in the AZRF. Until 2015, the Russian Arctic showed a steady increase in the number of inhabitants per one heat supply source on average. In the Far North, this trend continued in 2015–2020. In the Russian Arctic, by contrast, the situation has begun to change over the last five years. The commissioning of new small modular sources, mainly in the Murmansk Oblast, the Nenets and Chukotka Autonomous okrugs, caused a sharp decline in the 2020 specific indicators, returning them almost to the baseline level (2000), which can partly be explained by the phenomenon of population loss — acceleration migration outflow, simultaneously accompanied by an increase in the total number of sources.

Table 1

Number of heat supply sources in the subjects of the Russian Arctic and the Far North, units [15]

Subjects of the Arctic zone of the Russian Federation	2000	2005	2010	2015	2020
Nenets Autonomous Okrug	56	57	51	65	109
Murmansk Oblast	117	147	139	121	142
Yamalo-Nenets Autonomous Okrug	357	305	274	250	241

[15] Source: calculated by the author based on UISIS data.

Chukotka Autonomous Okrug	88	74	49	44	71
Russian Arctic zone, total	618	583	513	480	563
Russian Far North (including Russian Arctic zone) *	6444	5926	5132	4948	4978
Russian Federation, for reference	67 913	64 895	73 120	75 955	76 696
Share of the Russian Arctic zone on a national scale, %	0.9	0.9	0.7	0.6	0.7
Share of the Russian Far North (including Russian Arctic zone) on a national scale, %	9.5	9.1	7.0	6.5	6.5
Number of residents per heat supply unit in the Russian Arctic Zone	2492	2513	2762	2915	2456
Number of residents per heat supply unit in the Russian Far North (including Russian Arctic zone)	1318	1397	1551	1600	1580
Number of residents per heat supply unit in the Russian Federation	2163	2211	1954	1926	1905
Note: * calculated by the author using additional data for 13 subjects of the Federation, the territories of which are fully or partially assigned to the regions of the Far North and equivalent areas					

It is obvious that in the medium term, as the demographic situation continues to deteriorate, the connected heat load will gradually decrease. A similar trend can be observed in the all-Russian cross-section — the decentralized energy potential is being actively built up. This conclusion is also confirmed by the results of studies conducted at the Institute of economic forecasting of RAS [22, Nekrasov A.S., Voronina S.A., Semikashev, V.V., p. 132–133]. At the same time, it was found that among the fifteen most powerful operating heat supply facilities in the Russian Arctic, only one (Noyabrskaya steam-gas power plant, 2010) was built in the post-Soviet period. Their total installed heat capacity is more than 90% of the total capacity of all heat supply sources located in the Russian Arctic. In the near future, some of them (Vorkutinskaya TPP-1, Chaunskaya TPP, Egvekinotskaya GRES) are planned to be decommissioned. However, despite the lower economic efficiency of large thermal power plants compared to modern small modular TPPs, excessive capacity in the context of declining energy demand, moral and physical obsolescence, there will be no full-fledged alternative to most of them in the Russian Arctic for a long time. Therefore, modernization of the remaining plants and the possibility of putting some of their technological equipment into reserve are the main conditions for maintaining a reliable energy supply and deploying new industrial production facilities in the near future. The decrease in the number of permanent residents in the Russian Arctic and the Far North has the most negative impact on the economic efficiency of the sources with the highest productivity, reducing the possibility of obtaining "scale effects" [16], which is the basis of all centralized models of territorial heat supply. The inclusion of additional costs in the tariff to maintain the operation of excess energy capacity quite naturally leads to a further increase in the cost of territorial heating services. In this regard, the author considers it necessary to develop organizational mechanisms for integrating decentralized

[16] First of all, reducing the specific production costs of a heat source during technological connection to its networks of the maximum possible number of consumers, which is limited by the available heat capacity.

energy supply systems in the regional heat and power complexes of the North and the Arctic on the basis of industry investment programs aimed to preserve their energy potential and optimize the composition of technological equipment. They should consider new technologies that can complement the existing functionality of traditional systems where it is economically feasible, taking into account the territorial specifics.

Table 2 shows the dynamics of changes in the total installed capacity of territorial heat supply sources in the Russian Arctic in comparison with the general situation at the federal level, as well as in comparison with the macro-region of the Far North of Russia. As can be seen, after a slight decrease, the energy potential of the AZRF remains approximately at the same level due to the implementation of plans to extend the active operation of large energy facilities built back in Soviet times. In addition to them, as mentioned above, projects are being implemented for the construction of new low-capacity sources aimed at modernizing or replacing some of the unprofitable boilers and heating plants using petroleum products and solid fuels as the main fuel resource (in the Murmansk Oblast and the Chukotka Autonomous Okrug). There is a gradual decrease in the current values of the total installed heat capacity from the maximum level reached in 2000 in the Far North. This indicates a serious reduction in the overall energy potential on the scale of all northern regions, which is generally typical for the all-Russian situation, when the increase in the efficiency of using the installed capacity of generation facilities is due to the withdrawal of excess capacity. However, in the particular case of the Russian Arctic, on the contrary, it remains quite high. The overall result, based on the data presented, was a decrease in the total thermal capacity of heat supply sources in the entire Far North by 5.5 thousand Gcal/h (the reduction was 9%). The most intensive decommissioning of heat generating capacities was in the Komi and Tyva Republics (reduced by almost half), as well as in the northern regions of the Far East (Magadan Oblast and Kamchatka Krai). In the Russian Arctic, the reduction in the installed capacity of sources occurred only in the Yamalo-Nenets Autonomous Okrug.

Table 2

Total capacity of heat supply sources in the subjects of the Russian Arctic and the Far North, Gcal per hour [17]

Subjects of the Arctic zone of the Russian Federation	2000	2005	2010	2015	2020
Nenets Autonomous Okrug	191	176	178	206	217
Murmansk Oblast	5299	5706	5834	5071	5610
Yamalo-Nenets Autonomous Okrug	5672	5270	4962	4793	5208
Chukotka Autonomous Okrug	689	627	711	276	832
Russian Arctic zone, total	11851	11779	11685	10346	11867
Russian Far North (including Russian Arctic zone) *	60413	59841	54956	52878	54955
Russian Federation, for reference	664862	623211	581777	609239	582984
Share of the Russian Arctic zone on a national scale, %	1.8	1.9	2.0	1.7	2.0
Share of the Russian Far North (including Russian Arctic zone) on a national scale, %	9.1	9.6	9.5	8.7	9.4
Average installed heat capacity of sources in	19.2	20.2	22.8	21.6	21.0

[17] Source: calculated by the author based on UISIS data.

the Russian Arctic zone					
Average installed heat capacity of sources in the Russian Far North (including Russian Arctic zone)*	9.4	10.1	10.7	10.7	11.0
Average installed heat capacity of sources in the Russian Federation	9.8	9.6	8.0	8.0	7.6
Note: * calculated by the author using additional data for 13 subjects of the Federation, the territories of which are fully or partially assigned to the regions of the Far North and equivalent areas					

The lower part of the table 2 is of particular interest. It shows that in the Far North, during the gradual transformation of the energy infrastructure, the average indicators of the installed capacity of heat supply sources are growing. In turn, at the federal level, there is a decreasing trend in the average capacity of heat sources throughout the entire study horizon. In general, the main emphasis in the North is on the continued use of highly centralized heat supply schemes for utility consumers, in which the majority of the heat load is based on several dozen thermal power plants with a capacity of over 500 Gcal per hour. The implementation of plans for further preservation of sources with high thermal capacity as part of the heat and power complex is linked to the need for additional large-scale investments aimed at their modernization, reducing the energy costs of consumers, which they are now forced to bear in the form of an increased tariff burden. In the Russian Arctic, there are signs of a change in the general trend — the average indicators have stabilized and are gradually declining. Thus, we note the increasing redundancy of the available capacities of heat sources in the Russian Arctic, primarily in the Murmansk Oblast, as well as in the Chukotka Autonomous Okrug, where it will be necessary to decommission some of the sources, or reconstruct them with appropriate optimization of the coverage areas of new heat supply sources in the near future.

Table 3 shows the dynamics of territorial heat production in the regions of the Russian Arctic and the Far North. The indicators of the table show a steady trend of a long-term decline in the territorial production of thermal energy. In the AZRF, the decline was more than 29% compared to the baseline in 2000. The decline in production was the largest then. In the entire Far North, heat production decreased by 24%. The reduction in energy production at the federal level was 22%. The share of energy production in the Arctic regions on a national scale decreased by 0.2 p.p., and the share of the Far North — by 0.4 p.p. Comparison of the specific values of heat generation per capita in the Russian Arctic and the Far North with the federal level shows more than a twofold excess. It is noted throughout the entire observation period of the current 20-year historical stage of the development of the Russian Arctic, indicating the preservation of specific features of the functioning of life support systems in the northern and Arctic regions. Thus, despite the objectively existing changes in the average annual temperature regimes, which have most affected areas located in the Arctic and subarctic climatic zones over the past few decades, the need for increased energy costs aimed at ensuring the stay of people and economic activity in the extreme conditions of the Russian Far North and the Arctic remains. At the same time, the overall dynamics of specific production per capita is negative. Average indicators of heat production per unit of heat supply, shown in the bottom part of Table 3, also show a decrease. Thus, the demand for equipping heat sources with even less productive, but more technologically advanced and economically affordable equipment as part of the implementation of investment projects aimed at increasing energy efficiency, localizing zones of efficient heat supply and reducing heat losses during its transmission to the consumer through networks , confirms the conclusion about the increasing relevance of programs for the development of small-scale distributed energy, their preference in the context of a prolonged reduction in energy demand.

Table 3

Heat energy production in the subjects of the Russian Arctic and the Far North, thousand Gcal [18]

Subjects of the Arctic zone of the Russian Federation	2000	2005	2010	2015	2020
Nenets Autonomous Okrug	385	379	409	368	335
Murmansk Oblast	10 362	9 772	9 580	7 958	8709
Yamalo-Nenets Autonomous Okrug	10 154	8 563	8 308	7 080	5897
Chukotka Autonomous Okrug	967	1105	971	1 009	953
Russian Arctic zone, total	21 868	19 819	19 268	16 415	15 894
Russian Far North (including Russian Arctic zone) *	106738	104858	94035	83202	80983
Russian Federation, for reference	998 678	952 210	872 847	792 314	787 010
Share of the Russian Arctic zone on a national scale, %	2.2	2.1	2.2	2.1	2.0
Share of the Russian Far North (including Russian Arctic zone) on a national scale, %	10.7	11.0	10.8	10.5	10.3
Heat energy generation per capita in the Russian Arctic zone, Gcal	14.2	13.5	13.6	11.7	11.5
Heat energy generation per capita in the Russian Far North (including Russian Arctic zone)*	12.6	12.7	11.8	10.5	10.3
Heat energy generation per capita in the Russian Federation, Gcal	6.8	6.6	6.1	5.4	5.3
Heat energy generation per heat supply unit in the Russian Arctic zone, thousands Gcal	35.4	33.9	37.6	34.2	28.2
Heat energy generation per heat supply unit in the Russian Far North (including Russian Arctic zone)*	16.6	17.7	18.3	16.8	16.3
Heat energy generation per heat supply unit in the Russian Federation, thousands Gcal	14.7	14.6	11.9	10.4	10.3

The decrease in energy demand and the corresponding reduction of heat energy production in the northern regions have a decisive influence on the heat energy transportation subsystems, i.e. heat and steam networks. Table 4 shows the indicators of the length of heat and steam pipeline communications in the subjects of the Far North and the Russian Arctic. Similar trend of refraction of the dynamics of indicators after 2015 can be seen, which is also observed in Table 1. It can be explained by their direct relationship — an increase in the number of heat supply sources is accompanied by the commissioning of new heat utilities. The largest increase in their length in the Russian Arctic has recently been observed in the Murmansk Oblast. It is related to construc-

[18] Note: * calculated by the author using additional data for 13 subjects of the Federation, the territories of which are fully or partially assigned to the regions of the Far North and equivalent areas.

tion of new and renovation of some existing boiler houses, located in the northern and central parts of the Kola Peninsula. There is still more than a twofold excess of specific indicators of network coverage per capita (it is calculated per thousand people in Table 4). At the same time, in a long-term twenty-year retrospective, on the contrary, one can see a general decrease in the indicators of infrastructure provision in all northern and Arctic regions, as well as in the Russian Federation in general.

Table 4

Length of heat networks in two-pipe terms in the subjects of the Russian Arctic and the Far North, km [19]

Subjects of the Arctic zone of the Russian Federation	2000	2005	2010	2015	2020
Nenets Autonomous Okrug	100	89	71	82	96
Murmansk Oblast	1 346	1 388	1 091	1 068	1 203
Yamalo-Nenets Autonomous Okrug	2 256	2 029	2 033	1 985	1 978
Chukotka Autonomous Okrug	293	230	301	291	280
Russian Arctic zone, total	3 994	3 735	3 497	3 426	3 557
Russian Far North (including Russian Arctic zone)*	20591	19814	18449	18249	18921
Russian Federation, for reference	186 586	177 175	171 276	171 448	173 650
Share of the Russian Arctic zone on a national scale, %	2.1	2.1	2.0	1.9	2.0
Share of the Russian Far North (including Russian Arctic zone) on a national scale, %	11.0	11.2	10.8	10.6	10.9
Length of heat networks per thousand of the population of the Russian Arctic zone	2.6	2.6	2.5	2.5	2.6
Length of heat networks per thousand of the population of the Russian Far North (including Russian Arctic zone)*	2.4	2.4	2.3	2.3	2.4
Length of heat networks per thousand of the population of the Russian Federation	1.3	1.2	1.2	1.2	1.2
Length of heat networks per thousand square kilometers of the territory of the Russian Arctic zone	2.2	2.1	1.9	1.9	2.0
Length of heat networks per thousand square kilometers of the territory of the Russian Far North (including Russian Arctic zone)*	2.7	2.6	2.4	2.4	2.5
Length of heat networks per thousand square kilometers of the territory of the Russian Federation	10.9	10.4	10.0	10.0	10.1

Reduced lengths of heat and steam networks in the Russian Arctic and in the Far North amounted to 437 and 1670 km, respectively. Thus, despite the multidirectional, but generally positive growth dynamics of absolute values at the final time period of observations (2015–2020), the relative shares of indicators of the length of the heat networks of the Russian Arctic and the Far North became less on the national scale. There was a reduction in the territorial availability of heat and steam networks in the Russian Arctic and in the Far North. We note in particular that the described infrastructural decline processes are commensurate with population decline. Therefore,

[19] Note: * calculated by the author using additional data for 13 subjects of the Federation, the territories of which are fully or partially assigned to the regions of the Far North and equivalent areas.

the numerical series of the line "Length of networks per thousand people" in Table 4 is practically unchanged — it confirms the relationship between changes in the number of population and heat supply infrastructure serving it. At the same time, the specific indicator of availability of networks per unit area is expected to decrease, because, unlike the population, the area of the Far North and the Russian North was taken as a constant in the calculations. The image of the so-called infrastructural discrimination of the North and the Arctic remains; it is expressed in almost fivefold lag of specific parameters of network provision per unit area of the territory. The noted processes of infrastructure reduction represented both in absolute and specific indicators are of a long-term nature, showing a general downward trend in infrastructure development of the Arctic and the northern territories.

Conclusion

1. The decision made by the Government of the Russian Federation to move to a new stage of the municipal reform, the implementation of which was launched in 2022 with an extraordinary indexation of utility tariffs, was not accompanied by the creation of the necessary prerequisites for the growth of the investment attractiveness of the communal sector. Already in the next five years, the growth in the share of utility costs of households in the Far North and the Russian Arctic may reach an average of 13–14% in the total amount of consumer spending. The necessary investment support for the renewal of public utilities is possible through the creation of specialized funds formed from tax deductions from residents of the territories of advanced socio-economic development of the Arctic zone of the Russian Federation.

2. In recent years, the territorial heat supply systems of the Far North and the Arctic have undergone significant changes in infrastructural and organizational aspects. It is associated with the reduction in energy production, the number of heat sources, the length of heat communications, and their relative share in the total communal heat and power infrastructure of the country. This may have an impact on the development of district heating schemes and the possibility of additional connection of consumers to networks.

3. The formation of energy supply systems in the Arctic and Northern regions takes place in different directions, which complicates the implementation of long-term plans for territorial development. In order to unify organizational mechanisms for modernization of the territorial energy infrastructure, it is proposed to develop a state energy development program in the Far Eastern Federal District and in the Russian Arctic for the period up to 2035. Its target indicators should be linked to existing regional programs for the development of fuel and energy, housing and communal, transport, industrial complexes in terms of investment plans relating to projects for the construction of main gas pipelines, territorial gasification facilities, new local oil and gas processing enterprises, and the renovation of public utilities.

In the regional energy subsystems, prerequisites for the development of a territorial heat supply model have been created.

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