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Article

Methodological approach to assessing the digital infrastructure of the northern regions of the Russian Federation

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Abstract: The northern territories of Russia need high-quality strategic digital changes in the structure of the regional economy. Digitalization and the introduction of digital technologies in the medium term will be able to transform economic relations in the old industrial and raw materials regions of the North, improve the quality of life of local communities. The growth of digital inequality among the regions under study leads to disproportions in their socio-economic development. The purpose of this study is to develop and test a methodology for assessing the level of development of the digital infrastructure of the Russian northern regions, including classification of an indicators system for each level of digital infrastructure, calculation of an integral index and typology of the territories under study. The objects of the study were 13 northern regions of the Russian Federation, the entire territory of which is classified as regions of the Extreme North and equivalent areas. The methodology made it possible to determine the level of technical, technological and personnel readiness of the northern regions for digitalization, to identify regions with the best solutions at each level of digital infrastructure development. The analysis of the results in dynamics helped to assess the effectiveness of regional policy for managing digitalization processes. As a result, the authors came to the conclusion that increasing the competitiveness of northern regions in the era of rapid digitalization is possible through investments in human capital and the creation of a network of scientific and technological clusters. The presented approach to assessing the development of individual levels and elements of digital infrastructure will allow for the diagnosis of priority needs of territories under study in the field of digitalization. The results of the study can form the basis for regional policy in the field of sustainable digital development of Russia.

Keywords: digital infrastructure; digitalization of northern regions; methodological approach; levels of digital infrastructure

1. Introduction

In the context of accelerated digitalization of the global economy and the increasing volume of digital data, there is a need to study the economic foundations of developing an infrastructure that allows the digital economy to function. The transition of national economies, entire industries, and transnational corporations to digital technologies is carried out subject to integration into global data transmission and processing networks. Existing conditions in the form of quantitative and

qualitative characteristics of the provision of territories with elements of digital infrastructure can both contribute to successful digital transformation and create certain barriers (Cherepovitsyn and Tretyakov, 2023; Dmitrieva et al., 2023; Voronina et al., 2023). At present, the key direction in the development of the global digital infrastructure is the creation of a network of fiber-optic communication lines, which is laid on land or underwater in order to connect continents and island territories (Iakhiaev et al., 2023). To identify the points of digital divide between territories, the world map of submarine optical fiber cables for digital data transmission is presented in **Figure 1** (Halog et al., 2024).

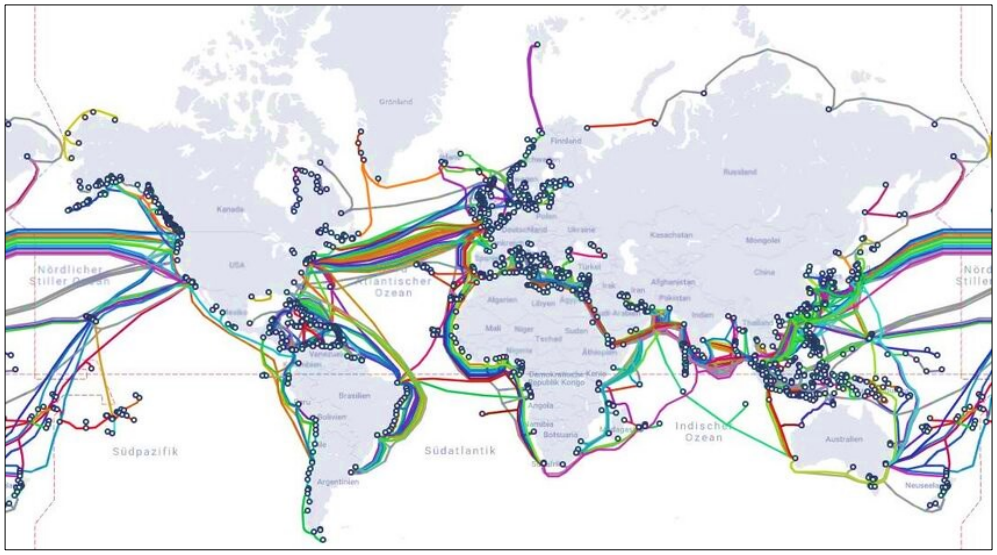


Figure 1. The world map of submarine optical fiber cables for digital data transmission.

Source: Halog et al. (2024). Submarine Infrastructures and the International Legal Framework. Transactions on Maritime Science 13(1).

In dynamics, one can notice an increase in the density of submarine cables, however, the data for the northern territories remains practically unchanged; a digital divide is observed in the northern part of the world. The northern regions of Russia were chosen as the objects of the study, since the development of the digital economy infrastructure of these regions is hampered not only by low investment attractiveness (Kirsanova et al., 2021; Matrokhina et al., 2023; Zhang et al., 2023), but also by other factors: harsh natural and climatic conditions, low population density (Cherepovitsyn and Lebedev, 2023; Kirsanova et al., 2024; Romasheva et al., 2022), the focal nature of economic development, etc. (Babyr et al., 2024; Podoprigora et al., 2024; Ponomarenko et al., 2024; Stroykov et al., 2021). Currently, creating conditions for accelerated socio-economic development of the northern regions is one of the priority tasks of Russia's regional policy (Kirsanova and Lenkovets, 2022; Lapinskas, 2023; Litvinenko et al., 2023). These priorities are reflected in the main strategic documents: the Strategy for the Development of the Arctic Zone until 2035, the Fundamentals of State Policy in the Arctic until 2035, and the Strategy for Spatial Development until 2035.

The high resource intensity of economic activity and the unevenness of industrial and economic development of the northern territories are associated with a low level

of infrastructure development (Nechitailo and Marinina, 2022; Nikolaichuk et al., 2023; Tsiglianu et al., 2023), including digital, as well as underdeveloped market mechanisms and competition in their digital development (Dzhancharova et al., 2023; Pilipchuk et al., 2024; Nevskaya et al., 2023). The process of digital infrastructure development affects the quality of life of the population of these territories in the context of their peripheral status (Nikiforova et al., 2020). For example, the low level of digitalization of the regions hinders the development of high-tech medical care using telemedicine technologies. The authors selected 13 northern regions of Russia as the objects of their research, the entire territory of which is classified as regions of the Extreme North and equivalent areas in accordance with the Decree of the Government of the Russian Federation No. 1946 of November 16, 2021: Republic of Karelia, Republic of Komi, Nenets Autonomous Okrug, Arkhangelsk Oblast, Murmansk Oblast, Khanty-Mansi Autonomous Area–Yugra, Yamalo-Nenets Autonomous Okrug, Republic of Tyva, Kamchatka Krai, Republic of Sakha (Yakutia), Magadan Oblast, Sakhalin Oblast, Chukotka Autonomous Okrug. Many Russian northern experts, such as Fauzer V., Skufina T., Samarina V., Korchak E. and others, adhere to a similar approach when defining the geography of research within the framework of scientific works in the field of socio-economic development of the Russian North (Fauzer, 2013, 2014; Korchak, 2017; Samarina and Skufina, 2018). This geography of research excludes from the list one of the most important regions of Russia, which partially belongs to the North and the Arctic zone of the Russian Federation–Krasnoyarsk Krai (Afanaseva, 2018; Pershin, 2017). The reason is the significant area of the region, which is more than 2 thousand square kilometers and the length from north to south is almost 3000 kilometers. This leads to serious differentiation in the analysis of statistical indicators that characterize the entire territory of the region; while the specifics are not reflected and data is not recorded exclusively for its northern part.

In the scientific literature there is no clear definition of the concept of a region's digital infrastructure, its component composition, or a complete understanding of the characteristics of northern regions in terms of digitalization of territories. Unified approaches exclude the consideration of the specific features characteristic of the Northern regions, which are a barrier to their socio-economic development.

2. Theoretical foundation

In the process of studying the main theoretical approaches to defining the concept of digital infrastructure, the authors of this study identified several key areas that are followed by both Russian and foreign scientists. One of the main approaches is to identify the concepts of "digital infrastructure", "information infrastructure", "information and communication infrastructure" and "telecommunication infrastructure". This approach was reflected in the works of the following scientists: Shemyakina N. and Ponomarenko A.; Gribanov Yu., Rudenko M. and Alenina K.; Ositis A.; Ershova T., Khokhlov Yu., Shaposhnik S.and others. The first group of authors, considering digital infrastructure at the state level, identify transmission networks and data processing centers, and a structured cabling system as the main elements (Shemyakina et al., 2020). Other authors define digital infrastructure as a

complex of mobile and stationary equipment, including systems that ensure their functioning. Scientists substantiate the equivalence of the concepts of "information infrastructure" and "digital infrastructure" by the fact that the current stage of development of the information infrastructure is based on digital technologies (Gribanov et al., 2020). In the study of Ositis (2020), the equivalence of the concepts of "information and communication infrastructure" and "digital infrastructure" is defined through a single spatial basis, which includes communication networks and next-generation networks, and the public Internet. The next group of authors, identifying the concepts of "digital infrastructure" and "telecommunications infrastructure", highlights key elements in the form of data processing centers, digital platforms and services. Scientists highlight mobile and stationary broadband Internet access as the most important factors of digital transformation (Ershova et al., 2018). Kramin and Klimanova (2019) also point to the need to develop broadband Internet, while supplementing the component composition of the digital infrastructure with local networks and servers. Other foreign authors consider digital infrastructure as a set of three components: digital technologies, Internet use and subscription to fixed, mobile cellular communications (Ndubuisi et al., 2021). Thus, the intensity of use of the relevant equipment can act as one of the qualitative characteristics of the elements of the digital infrastructure.

Another approach to defining the object of research is presented in the work of Kozlov A., who identifies the digital infrastructure of the region as an integral part of the innovative infrastructure and considers some northern regions of Russia (Murmansk Oblast, Yamalo-Nenets Autonomous Okrug) as the geography of the study. To determine the quantitative value of the level of development of the digital infrastructure of the region, the authors developed an integral indicator, which was calculated as the arithmetic mean of the normalized partial indicators. The indicators were divided into two groups, the first characterized the material conditions and technical prerequisites for the formation of the digital economy, and the second – the development of the ICT subsystem (Kozlov, 2019).

A research team led by Barns S. studies the digital infrastructure of municipalities in the context of analyzing the implementation of the "smart city" concept. The authors understand the digital infrastructure of a city as the level of development of broadband Internet access (Barns et al., 2016). Assessing the impact of digital infrastructure on the well-being of the population, other foreign authors also consider the municipal level, namely, investments by local telephone companies in the development of a fiber optic cable network and software (Greenstein and Spiller, 1996; Zhang, 2023). Thus, software that allows physical elements of the infrastructure to function can also be included in the component composition of the digital infrastructure.

Some authors consider digital infrastructure not at the macro or meso-level, but at the micro (local) level, that is, at the level of individual organizations (Novikov, 2024). Thus, another group of researchers in their works studies the cause-and-effect relationships of the evolution of digital infrastructure using the example of a Scandinavian airline (Henfridsson and Bygstad, 2013). Other authors also consider the issues of digital infrastructure development within one organization, namely, using the example of the global and dynamic BP oil company. The article examines the company's experience in creating basic elements of digital infrastructure: a network

of fiber optic lines, standardization in the digitalization of processes and digital security, from design to implementation and operation (Otto et al., 2008). The introduction of modern digital technologies into business processes can be barrier-free and effective with an appropriate level of development of the digital infrastructure of the territory as a whole, since any local infrastructure is viable in an integrated format in the global infrastructure when interacting with the external digital environment. It can be concluded that most authors define the availability of ever-increasing access to high-speed broadband Internet among the population and organizations as the basic condition for the development of digital infrastructure and the digital economy as a whole.

Some authors highlight the human resources of the territory as a separate element characterizing the digital infrastructure, namely the digital personnel who participate in the creation, maintenance, and development of its components. For example, they highlight the ecosystem of talents and innovations as an integral part of the holistic ecosystem of the digital economy (Karpunina et al., 2020; Kouladoum, 2023). Human resources and ICT competencies are the driver of digital transformation in the context of global competition. Many scientists point to the important role of human resources and their reproduction in the accelerated transformation of the digital economy (Adi Pratama et al., 2024; Grigorescu et al., 2021; Korneeva et al., 2020; Bykowa et al., 2024). Based on the above, we can conclude that the digital infrastructure is presented at different levels (global, national, regional, municipal, local) and is conditionally linked to a specific territory or organization, since its functioning implies interaction with all elements of the digital infrastructure of other levels.

For the purposes of this study, the authors will consider the digital infrastructure at the regional (subject) level. This will allow us to assess the effectiveness of state policy in the field of digitalization of the northern territories of Russia, taking into account their specifics and features of the creation and development of digital infrastructure here.

In order to form a holistic view of the component composition of the regional digital infrastructure, a comparative analysis of scientific papers was carried out, which reflected the factors influencing the development of the digital infrastructure of the territory and the impact of digital infrastructure on economic sectors. Thus, Logacheva (2021) identified the following factors that determine the digital maturity of the regions: political, social, economic, technological and digital infrastructure factors. Platforms for improving digital literacy, digital services, electronic document management systems, development institutions were attributed to digital infrastructure factors. The author highlights integrated structures as one of the important factors – institutes that unite higher educational institutions, research centers and organizations in the field of IT, the so-called scientific and technological clusters.

Greenstein (2021) in his work considers digital infrastructure as a factor in the development of the sharing economy and social networks. The processes of service provision by both state (municipal) authorities and organizations of the real sector of economy have undergone a serious transformation. The structure of the gross regional product is changing; the share of electronic retail and services provided digitally is increasing. The issues of creation, modernization and development of digital infrastructure of the northern territories, where natural and climatic factors, low level

of economic development and population act as barriers, are relevant for study. Thus, Kozlov et al. (2020) analyze the digital infrastructure of the northern regions of Russia as a factor in their economic and industrial development. The authors highlight reindustrialization and technological modernization for the purpose of digital transformation of business processes of enterprises as a key task. To assess the level of development of digital infrastructure, scientists calculate the integral index for two groups of indicators. The first group characterizes the material factor, and the second reflects the ability of the real sector of economy to use digital technologies, including software. Thus, they were able to identify the key factors that have the greatest influence on the formation of digital infrastructure elements.

Delaunay and Landriault (2020) justify the need to develop digital infrastructure in the northern regions by the existing digital divide and the increasing effect of isolation, which are barriers to interaction between local communities both with each other and with other consumers of digital infrastructure. Internet access in the Arctic region remains uneven and difficult to access in many parts of the circumpolar world. The main limiting factor is the significant volumes of investment required to create the infrastructure, while the number of potential clients of providers or actors is very limited.

Another group of authors addresses the issues of ensuring the environmental safety of the Arctic zone of the Russian Federation through the development and implementation of domestic digital technologies in the extractive and other industries (Kalinina et al., 2024). The specificity of the northern territories is determined by the fragile natural ecosystem, which is most susceptible to the risks of man-made disasters. And it is the digitalization of the extractive industries through the use of innovative solutions that will reduce the risks during the intensive development of unique deposits (Gureeva et al., 2021; Nevskaya et al., 2024).

An important aspect of the development of the northern regions is “digital security” as a component of the sustainability of digital ecosystems for all categories of actors and stakeholders. Digital security issues are relevant not only for the northern territories of the Russian Federation, but also for most Arctic countries: the USA, Norway, Sweden, Canada, Finland, etc. Digital communications, accessibility of information and digital services, and digital literacy are considered as areas for ensuring digital security (Morris and Salminen, 2024). An analysis of scientific literature made it possible to form an idea of approaches to defining digital infrastructure, taking into account modern trends and its component composition. As a result, the features of the development of the digital infrastructure of the northern territories were determined.

3. Materials and methods

3.1. Digital infrastructure of the region: concept, component and composition

As a result of the content analysis, the authors propose the following approach to defining the essence of the digital infrastructure of the region: it is a complex of interconnected systems for transmitting digital data, digital technologies (for creating, collecting, storing, transmitting, and processing data), digital platforms and services

that allow maintaining and developing the digital economy of the region. The authors also include personnel involved in the digital economy of the region among the components of the digital infrastructure. To describe the elements of the digital infrastructure, external and internal factors, and the processes of its creation and development, the authors propose to apply one of the constructivist approaches – actor-network theory (Callon, 1992). The application of this approach made it possible to determine the component composition of the digital infrastructure of the region, presented in **Figure 2**, which includes the population, personnel, and technologies and technical means.

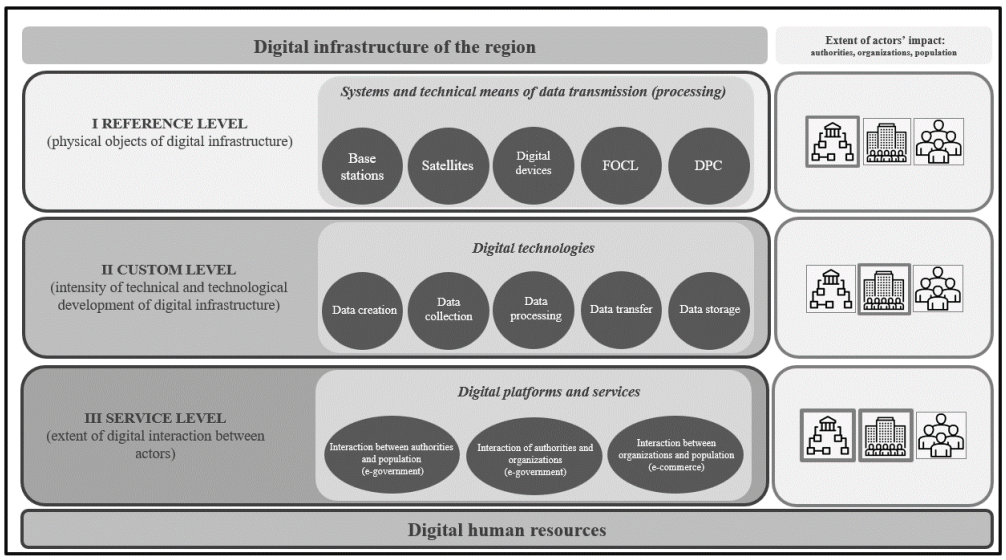


Figure 2. Component composition of the region's digital infrastructure.
Source: compiled by the authors.

The basic level of the digital infrastructure of the region is represented by technical means and systems of data transmission and processing, that is, physical objects that provide an opportunity for the integration and interconnection of all its users. Each actor plays a certain role in the creation, operation and use of systems and technical means. The state, represented by the executive and legislative bodies of regional authorities, acts as an initiator, regulator and investor. For example, it concerns matters of placing base stations (antenna mast structures) on specially designated sites, providing permits for the use of land for the creation of new fiber-optic communication lines, regulating prices and tariffs for the services of telecommunications companies and providers, directly creating fiber-optic lines and big data processing centers. Provider organizations also participate in the creation and development of physical objects of the digital infrastructure by laying new fiber-optic communication lines and servicing existing ones, deploying a network of data processing centers to provide Internet access and other services. All other organizations of the private and public sectors determine the quantitative and qualitative composition of digital devices and local computing servers, which are also elements of the digital infrastructure. Digital devices in the form of computers, tablets, smartphones, etc., with access to the Internet, act as means of creating and processing digital data. The population is an active participant in the process of operating the

existing physical infrastructure and in its creation, acquiring and using various digital tools in the form of smartphones, and tablets. Recently, the flow of digital data through mobile devices has increased several times, thereby overtaking the volume of data generated by stationary digital means, including laptops. This indicates an increase in the number of such mobile devices and the intensity of their use for receiving government and other services, viewing information, and creating content. Thus, digital tools provide an opportunity for the circulation of digital data and interaction of actors with each other. At the basic level, the degree of influence of actors on the creation of digital infrastructure is high, but the state, which is responsible for making strategic decisions, plays a special role.

The user level determines the intensity of technical and technological development of the digital infrastructure by all actors. For the full formation of the digital infrastructure at this level, it is necessary to develop and implement digital technological innovations. The state performs two main roles: firstly, the role of a regulator of relations between innovative organizations and the population; secondly, it creates an ecosystem of innovations, including a system of financial support for innovative activities. The presence of digital technologies for creating, collecting, processing, transmitting, storing information and their widespread use are indicators of the existing digital gap between technology and society. Conceptualization, development and dissemination of new technological solutions are the key task of innovative organizations. Other organizations and the population also influence the formation of infrastructure components of the region, but only in the plane of using and applying the corresponding digital technologies. For example, cloud services today are one of the main ways of securely storing and exchanging digital data. The population acts as their autonomous user, as it is endowed with the ability to independently determine the goals and methods of using digital technologies. However, this autonomy is determined by the conditions formed by the state and innovative organizations. The population functions as one element of a complex sociotechnical network (Callon, 1984). Thus, for full access to the digital infrastructure of the region, the population requires access to technical devices, the presence of technological capabilities for interaction with other technical devices and integration into technological capabilities. At this level, organizations have the greatest degree of influence, while other actors have a medium degree of influence.

The resulting element of the digital infrastructure is the third level – the service level, which characterizes the degree of digital interaction of all groups of actors. The technical component of the digital infrastructure can be active only when the actors mobilize it, that is, show digital activity. The population, organizations, the state and digital personnel act as components of this network and participate in a coordinated collective action. At this level, specialized platforms and services are formed, new points of connection of interests of various actors are created, elements of the supporting and user levels of the digital infrastructure are mobilized, thereby differentiating the methods of interaction of actors. The service level acts as the so-called superstructure, which reflects the methods and techniques used at the supporting and user levels. The frequency of interaction of actors and the conjugacy of elements are the key parameters of the functioning of this level. It is the development of the service level that determines the structure of the regional economy, providing existing

or new markets with ways of integration into the ecosystem of digital interaction. At this level, the degree of influence of each of the actors is estimated as high.

However, for the full and continuous development of each of the above levels of digital infrastructure, human resources are needed, which play an important role in the digital economy of the region. The basis for the formation of the digital economy is the growth in the number of specialists with digital competencies (Gretchenko, 2018). Digital personnel ensure not only the functioning of individual levels of the digital infrastructure of the region, but also the growth of digital competencies and the degree of involvement of actors. Today, experts point to a serious personnel shortage that limits the implementation of the state regional digital agenda, this is especially evident in unfavorable territories characterized by a low quality of life. There are other factors that determine the composition of the region's human resources in the field of information and communication technologies. Despite the fact that the system of training qualified personnel is a key factor in the formation of digital human resources, the authors do not consider it in this study. The results of the implementation of personnel policy in the studied regions in the field of digitalization, including employment of the population in the information and communication technology sector, are analyzed. Building educational processes in universities is the task of the federal ministry. But regional authorities can also influence these processes by creating and supporting competence centers in the field of digital technologies, ensuring digital literacy of the population, involving regional institutions for development and advanced training (Lvov et al., 2019; Samylovskaya et al., 2020; Vasilev et al., 2024). A key marker of a region's provision with digital human resources is the effectiveness of involving specialists with ICT competencies in digital economy processes. Having studied existing methods for calculating the number of employees in the digital economy, the authors came to the conclusion that existing methodological approaches do not take into account all employees of organizations conducting business activities and having digital competencies (computer technology specialists, employees of telecommunications companies and providers, data analysts, etc.).

3.2. Methodology for assessing the level of development of digital infrastructure in the northern regions of Russia

Based on the study conducted by the authors, a methodological apparatus was developed for assessing the level of the digital infrastructure of regions by calculating the integral index. The integral index was calculated based on 17 indicators according to **Table 1**; each level of digital infrastructure corresponds to a group of indicators. The collection and analysis of indicators was carried out for the period 2015–2022, the sources were the official websites of the Federal State Statistics Service (Rosstat) and the Unified Interdepartmental Information and Statistical System (EMISS). All indicators with absolute values were converted into relative values by recalculating the area of the territory or the population of the corresponding region.

Despite the fact that after minor iterations all indicators were presented in relative values, it was necessary to apply one of the methods of their standardization for further calculations. The authors chose a standardization method that is an average between

classical standardization and the minimax method. The disadvantage of these methods of standardization is that they do not allow for significant differences between the objects of study in cases where these differences are significant. The essence of the standardization method lies in the arbitrary determination of the degree of variation between the values of the indicators. The calculation of the integral index was carried out in several stages. At the first stage the data were reduced to a dimensionless form, to a single range from 0 to 1. At this stage, the coefficients for each indicator were calculated within individual levels of the digital infrastructure of a certain region according to the following formula:

$$K_{di} = \frac{log_x - log_{x_{min}}}{log_{x_{max}} - log_{x_{min}}} \quad (1)$$

At the next stage, the aggregation method was used to combine several coefficients in order to obtain a complex sub-index for a group of indicators–a sub-index of the level of digital infrastructure of the region according to the following formula:

$$SI_{di} = \frac{(K_{di1} + K_{di2} + \cdots + K_{dij})}{j} \quad (2)$$

where *j* is the number of indicators characterizing each separately considered level of digital infrastructure of a certain region. At the next stage, the integral index of the digital infrastructure of the region was calculated by calculating the arithmetic mean of the previously obtained subindices using the formula presented below:

$$I_{di} = \frac{(SI_{di1} + SI_{di2} + SI_{di3} + SI_{di4})}{4} \quad (3)$$

Table 1. Classification of indicators for calculating the digital infrastructure index.

Digital infrastructure level	Name of the indicator, unit of measurement
Service level	1). The share of citizens using the mechanism for receiving state and municipal services in electronic form, %
	2) Organizations that had a website, %
	3) Use of electronic document management in organizations: electronic data exchange between their own and external information systems, by document exchange formats, %
	4) The share of the population that used the Internet to order goods and services, in the total population, %
Custom level	1) Use of cloud services by organizations, %
	2) Use of broadband Internet access by organizations, %
	3) Number of active subscribers of fixed broadband Internet access, units per 100 people
	4) Number of active subscribers of mobile broadband Internet access, units per 100 people
	5) Number of active subscribers of satellite Internet access at the end of the reporting period (4 quarters), units per 10 thousand people
Reference level	1) Use of personal computers by organizations, %
	2) Use of local computing servers by organizations, %
	3) Share of households with broadband Internet access in the total number of households, %
	4) Level of digitalization of the local telephone network in urban areas by subjects of the Russian Federation, %

Table 1. (*Continued*).

Digital infrastructure level	Name of the indicator, unit of measurement
	5) Level of digitalization of the local telephone network in rural areas by subjects of the Russian Federation, %
Reference level	6) Length of channels formed by digital transmission systems, channel-kilometer per thousand sq. km
	7) Number of base stations in the 4th quarter, units per 10 thousand people
Digital Human Resources	1) Share of people employed in the ICT sector in the total number of employed population, %

Source: Compiled by the authors.

This operation allowed us to evaluate and compare regions based on a set of various indicators of the level of development of each level of the digital infrastructure of the northern regions.

For the sake of clarity in the presentation of the results and the classification of the northern regions depending on the values of the digital infrastructure index, the authors used the method presented in **Figure 3**. Thus, the authors identified the following levels of development of the digital infrastructure of the regions depending on the index value: 1) very high (0.80–1.00); 2) high (0.60–0.80); 3) average (0.40–0.60); 4) low (0.20–0.40); 5) very low (0–0.20).

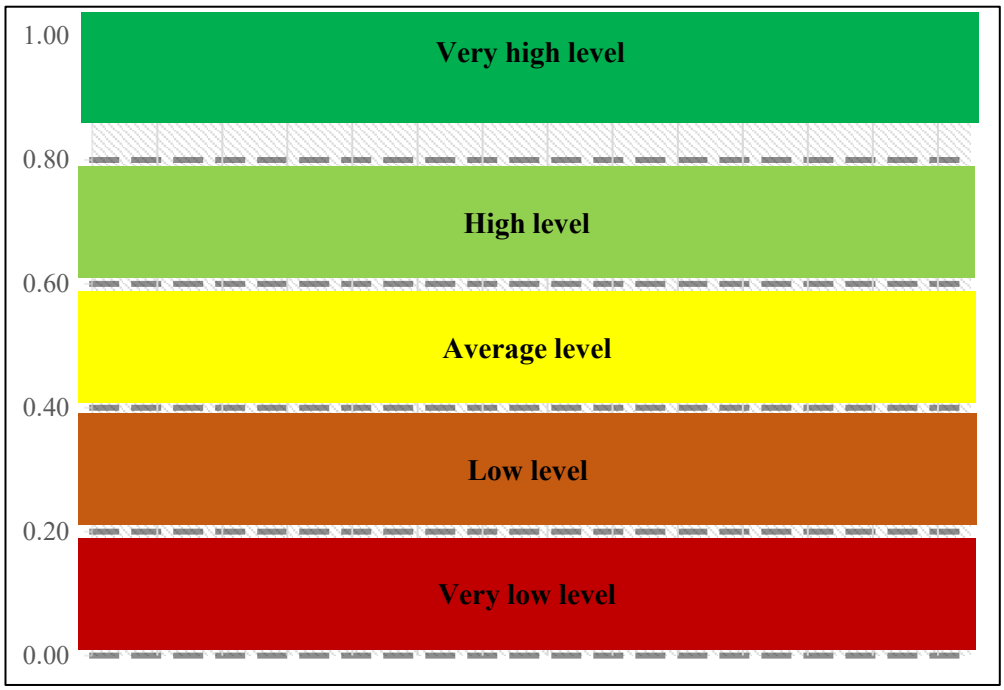


Figure 3. Component composition of the region's digital infrastructure.
Source: Compiled by the authors.

4. Results and discussions

Testing of the author's methodology made it possible to assess the level of development of the digital infrastructure of the northern regions in the period 2015–2022. The values of the integral index of digital infrastructure for 13 northern regions

of Russia for the period 2015–2022 were calculated. The results of the assessment for the entire period are presented in **Figure 4**.

Based on the results of the assessment, none of the northern regions entered the group with a very high level of digital infrastructure development. Extremes were noted on the graph to identify the best and the worst positions in the study period. Sakhalin Oblast was close to the lower threshold of the best level in 2015 and 2017, receiving index values of 0.78 and 0.74, respectively. The maximum index values for the Yamalo-Nenets Autonomous Okrug in 2020 and 2021 reached 0.78. The worst values were received by the Republic of Tyva, in 2019–0.29 and in 2021–0.28. However, none of the regions during this period entered the category with a very low level of digital infrastructure development. The index value for all regions during the study period varied in the range from 0.4 to 0.8. The interim results of the study indicate an average and high level of development of the digital infrastructure of the northern regions. The trends that have emerged since 2018 can be explained by the adoption of the national program "Digital Economy of the Russian Federation" as part of the national development goals within the framework of the Decrees of the President of the Russian Federation.

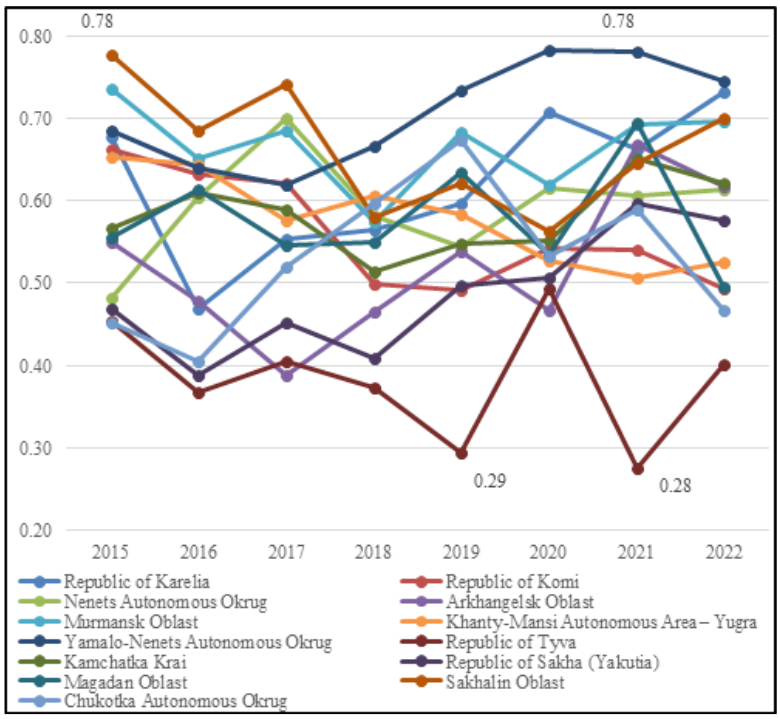


Figure 4. Graph of the values of the digital infrastructure index of the northern regions of Russia for the period 2015–2022.
Source: Compiled by the authors.

Figure 5 presents a visualization of the results obtained for 2015 and 2022 in the form of maps, on which the northern regions are highlighted taking into account the previously proposed typology. The infographics in the Figure is supplemented by a table indicating the values for two years and the trends formed. Analyzing the obtained results, we can conclude that the Republic of Karelia, the Republic of Sakha (Yakutia), Arkhangelsk Oblast, Nenets Autonomous Okrug, Yamalo-Nenets Autonomous Okrug, Chukotka Autonomous Okrug and Kamchatka Krai showed positive dynamics of the

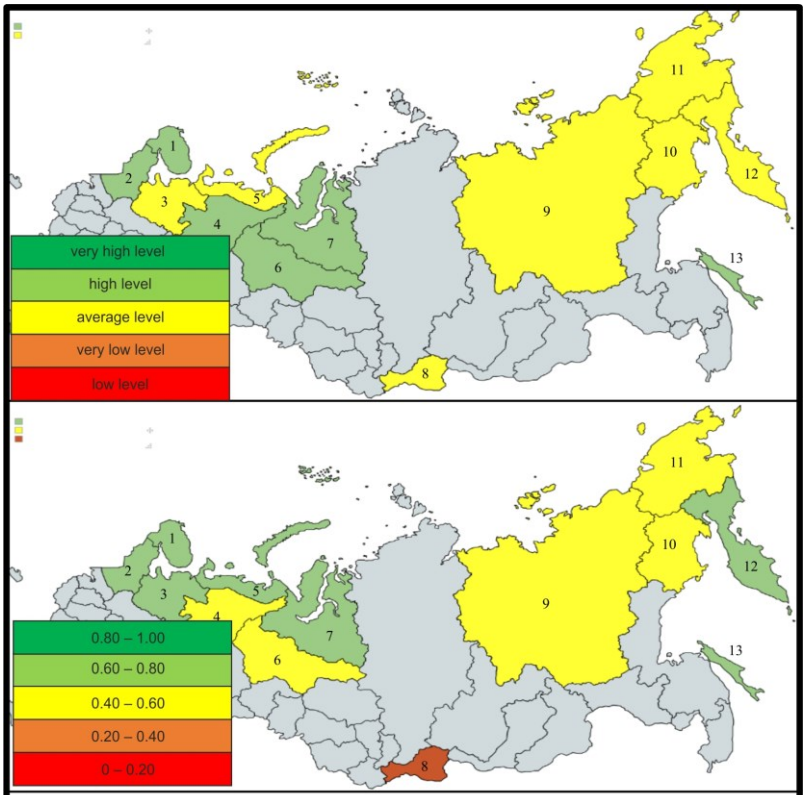
index values, regardless of the typology results. The opposite situation is typical for Murmansk Oblast, Republic of Komi, the Republic of Tyva, Khanty-Mansi Autonomous Okrug-Yugra, Magadan Oblast and Sakhalin Oblast.

According to the authors' methodology, the digital infrastructure index is formed from four sub-indices, each of which characterizes the degree of development of one of the digital infrastructure levels (I–Reference level, II–Custom level, III–Service level, DHR–Digital Human Resources). For a comprehensive analysis of the reasons for the growth or decline in the level of digital infrastructure of the northern regions, the sub-index data for 2015 and 2022 are presented in the form of a radial diagram in Figure 6. In 2015, no region fell into the low-level category, in 2022–the Republic of Tyva.

5. Conclusions and recommendations

The key problem typical for all the regions under study is the low rate of formation of a pool of digital human resources. The situation has noticeably worsened in 2022, while the trends for the entire period under study were negative. This is evidenced by the values of the indicator of the share of people employed in the information and communication technology sector in the northern regions, which are below the Russian average (1.6%–1.8%). The reason is the outflow of the working-age population from the northern regions to territories of the Russian Federation that are more attractive in terms of quality of life and development prospects. According to the authors, to solve this problematic situation, it is necessary to develop regional support measures aimed at the effective and timely employment of IT graduates in local organizations. Also, the executive bodies of regional authorities need to continue implementing the policy of supporting IT specialists, including preferential mortgage lending for housing, and tax benefits. Another aspect of the policy is the creation and development of a comprehensive social infrastructure that ensures a high quality of life, for example, the science city of Innopolis.

For the comprehensive digital development of territories, lagging regions need to develop all levels of digital infrastructure in a harmonized manner. To do this, it is worth considering that the provision of a region with elements of digital infrastructure affects the behavior of actors at all levels. For example, a provider organization in the Arkhangelsk oblast estimated the required minimum population (1500 people) to ensure the economic efficiency of investments in the creation of base communication stations in remote settlements. Despite the small population of many remote northern settlements (<1000 people), provider organizations continue to provide these territories with mobile communication and Internet coverage, since such solutions have a multiplier social and economic effect. Accordingly, a high degree of development of the base level affects the formation of other levels of digital infrastructure, thereby improving digital interaction between local communities, business and the state.



№	Regions	Digital Infrastructure Development Index, 2015	Digital Infrastructure Development Index, 2022	Trend in values
1	Murmansk Oblast	0,73	0,70	↓
2	Republic of Karelia	0,68	0,73	↑
3	Arkhangelsk Oblast	0,55	0,62	↑
4	Republic of Komi	0,66	0,49	↓
5	Nenets Autonomous Okrug	0,48	0,61	↑
6	Khanty-Mansi Autonomous Area – Yugra	0,65	0,52	↓
7	Yamalo-Nenets Autonomous Okrug	0,69	0,75	↑
8	Republic of Tyva	0,45	0,40	↓
9	Republic of Sakha (Yakutia)	0,47	0,57	↑
10	Magadan Oblast	0,55	0,50	↓
11	Chukotka Autonomous Okrug	0,45	0,47	↑
12	Kamchatka Krai	0,57	0,62	↑
13	Sakhalin Oblast	0,78	0,70	↓

Figure 5. Graph of the values of the digital infrastructure index of the northern regions of Russia for the period 2015–2022.
Source: Compiled by the authors.

Despite the high values of service level indicators, the processes of digital infrastructure formation in leading regions are limited by low rates at the Reference and Custom levels. This is due to the low provision of remote territories with physical infrastructure facilities in some locations of the island territories. A significant part of the territory of the northern regions does not have 3G, 4G coverage. This problem is especially acute along major federal transport highways, the digitalization of which is of strategic importance for the spatial and territorial development of the state. The key factor in the low rates of development of the Custom level is the current situation in

which many foreign IT companies have limited or completely ceased their activities in the territory of the Russian Federation. The problem of the lack of available digital technological solutions can be mitigated by the creation of domestic developments, however, the processes of creation and implementation of IT solutions have a delayed effect, that is, real import substitution will begin in the medium term. A possible solution to the identified and analyzed problems of balanced formation of the digital infrastructure of the northern regions may be the creation of scientific and technological clusters. The tasks of such clusters will be to create and implement innovative digital solutions for the Custom level of digital infrastructure, which will be the drivers of the development of the digital economy of the northern regions. The most important task of scientific and technological clusters should be the professional training of qualified personnel for the digital economy (see **Figures 5** and **6**).

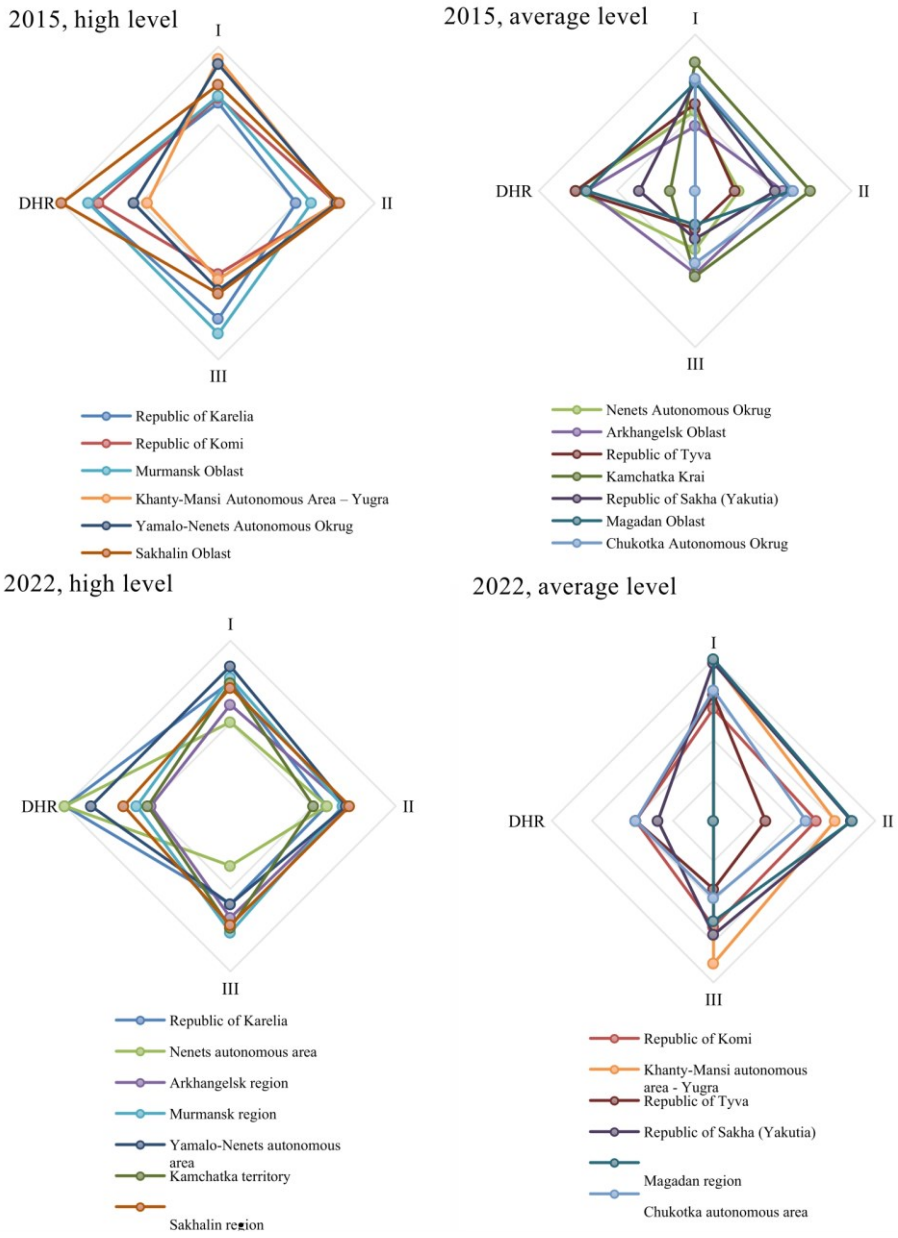


Figure 6. Sub-indices of digital infrastructure of northern regions in 2015 and 2022.
Source: Compiled by the authors.

The main limitations of this study are the lack of a sufficient number of relevant statistical indicators for assessing digital infrastructure, and the length of time series of indicators. It is also necessary to note the insufficient general level of methodological understanding of the research topic in the scientific community, which leaves a niche for future research. Prospects for future research are primarily related to the study and assessment of the influence of factors on the stages and processes of development of the digital infrastructure of the region.

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References

Adi Pratama, I. W., & Diwyarthi, N. D. M. S. (2024). Optimization of Human Resources and Utilization of Information Technology in Driving the Digital Economy. West Science Information System and Technology, 2(01), 49–57. https://doi.org/10.58812/wsist.v2i01.829

Afanaseva, O., & Ilyushin, Y. (2018). Analysis and synthesis of distributed icedrill heating control system of mountain reconnaissance drilling rig. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 18 (2.2), 41-48. https://doi.org/10.5593/sgem2018/2.2/S08.006

Babyr, N. V., Gabov, V. V., Nosov, A. A., et al. (2024). Features of design and work method of mining module at coal deposits in the Russian Arctic. MIAB. Mining Inf. Anal. Bull., 6, 5–16. https://doi.org/10.25018/0236_1493_2024_6_0_5

Barns, S., Cosgrave, E., Acuto, M., et al. (2016). Digital Infrastructures and Urban Governance. Urban Policy and Research, 35(1), 20–31. https://doi.org/10.1080/08111146.2016.1235032

Bykowa, E., Banikevich, T., Zalivatskaya, N., et al. (2024) Modeling the Cadastral Value of Land Plots of Gardening and Horticultural Non-Profit Partnerships Taking into Account the Influence of Local Factors of the Territory. Land, 13, 1004. https://doi.org/10.3390/land13071004

Callon, M. (1984). Some elements for a sociology of translation: Domestication of the scallops and the Fishermen of St. Brieuc Bay. The Sociological Review, 32, 196–233. https://doi.org/10.1111/j.1467-954X.1984.tb00113.x

Callon, M. (1992). The dynamics of techno-economic networks. In: Coombs R., Saviotti P., Walch V. (eds.). Technological Change and Company strategies. Academic Press, 72–102.

Cherepovitsyn, A. E., & Tretyakov, N. A. (2023). Development of new system for assessing the applicability of digital projects in the oil and gas sector. Journal of Mining Institute, 262, 628–642.

Cherepovitsyn, A., & Lebedev, A. (2023). Drill Cuttings Disposal Efficiency in Offshore Oil Drilling. Journal of Marine Science and Engineering, 11(2), 317. https://doi.org/10.3390/jmse11020317

Dmitrieva, D., Chanysheva, A., & Solovyova, V. (2023). A Conceptual Model for the Sustainable Development of the Arctic's Mineral Resources Considering Current Global Trends: Future Scenarios, Key Actors, and Recommendations. Resources, 12(6), 63. https://doi.org/10.3390/resources12060063

Dzhancharova, G., Kosheleva, A., Drobysheva, N., et al. (2023). Economic and Legal Aspects of Foreign Economic Risks Within the Framework of Sustainable Development of Russian Enterprises. Journal of Law and Sustainable Development, 11(3), e317. https://doi.org/10.55908/sdgs.v11i3.317

Ershova, T. V., Khokhlov, Y. E., & Shaposhnik, S. B. (2018). Methodology for assessing the level of development of digital economy as a tool for managing the processes of digital transformation. In: Proceedings of the 11th International Conference; 01–03 October 2018; Moscow, Russia, 198-200.

Fauzer, V. (2013). The Demographic potential of Russia's northern regions as a factor of the economic development of the Arctic. Arctic and North, 10, 1–29.

Fauzer, V. V. (2014). Demographic potential of the Russia's northern regions as a factor and condition of economic development of the Arctic. Economy of Region, 4, 69–81. https://doi.org/10.17059/2014-4-5

Greenstein, S., & Spiller, P. (1996). Estimating the Welfare Effects of Digital Infrastructure. NBER Working Paper 5770. National Bureau of Economic Research. Cambridge. https://doi.org/10.3386/w5770

Greenstein, Sh. (2021). 8. Digital Infrastructure. In Glaeser, E. L., Poterba, J. M. (editors). Economic analysis and infrastructure investment, University of Chicago Press, 409-452. https://doi.org/10.7208/chicago/9780226800615-011

Gretchenko, A. (2018). Training of highly qualified personnel for the digital economy. Russia: trends and prospects of development, 13(1), 824–827.

Gribanov, Yu. I., Rudenko, M. N., & Alenina, K. A. (2020). Modern Approaches to Formation of Digital Infrastructure. Administrative Consulting, 8, 88–98. https://doi.org/10.22394/1726-1139-2020-8-88-98

Grigorescu, A., Pelinescu, E., Ion, A. E., et al. (2021). Human Capital in Digital Economy: An Empirical Analysis of Central and Eastern European Countries from the European Union. Sustainability, 13(4), 2020. https://doi.org/10.3390/su13042020

Gureeva, M. A., Valyavskiy, A. Y., Nikolaevich, I. M., et al. (2021). Digital Development Of The Arctic Zone And Ensuring National Security. In N. Lomakin (Ed.), Finance, Entrepreneurship and Technologies in Digital Economy, vol 103. European Proceedings of Social and Behavioural Sciences European Publisher, 160-169. https://doi.org/10.15405/epsbs.2021.03.21

Halog, J., Margat, P., & Stadermann, M. (2024). Submarine Infrastructures and the International Legal Framework. Transactions on Maritime Science, 13(1). https://doi.org/10.7225/toms.v13.n01.w16

Henfridsson, O., & Bygstad, B. (2013). The Generative Mechanisms of Digital Infrastructure Evolution. MIS Quarterly, 37(3), 907–931. https://doi.org/10.25300/misq/2013/37.3.11

Iakhiaev, D., Grigorishchin, A., Voronina, L., et al. (2023). Conceptual foundations and global challenges in the formation of digital sovereignty of the state. Nexo Revista Científica, 36(05), 169–179. https://doi.org/10.5377/nexo.v36i05.17305

Kalinina, O., Metkin, D., & Bichevaya, O. (2024). The Application of Green Seismic Survey Technology in Forested Areas and Its Ecological and Economic Effectiveness: Methodology and Practice of Application. Sustainability, 16, 1476. https://doi.org/10.3390/su16041476

Kirsanova, N. Y., & Lenkovets, O. M. (2022). Assessment of accountability in state regulation of Arctic zone of the Russian Federation in current institutional environment. Север и Рынок: Формирование Экономического Порядка, 75(1/2022), 47–57. https://doi.org/10.37614/2220-802x.1.2022.75.004

Kirsanova, N., Lenkovets, O., & Tkacheva, E. (2021). Shadow Economy In Oil And Gas Industry As Threat To Russias Economic Security: Issues And Options. In: Proceedings of the 21st SGEM International Multidisciplinary Scientific GeoConference, Ecology, Economics, Education and Legislation, 21, 863–870. https://doi.org/10.5593/sgem2021/5.1/s21.104

Kirsanova, N., Nevskaya, M., & Raikhlin, S. (2024). Sustainable Development of Mining Regions in the Arctic Zone of the Russian Federation. Sustainability, 16(5), 2060. https://doi.org/10.3390/su16052060

Korchak, E. (2017). The Labor potential of northern regions within the implementation of the state policy of the Russian Federation in the Arctic. Apatity, Luzin Institute for Economic Studies, Federal Research Centre "Kola Science Centre of the Russian Academy of Sciences" Publishing, 174 p.

Kouladoum, J.-C. (2023). Digital infrastructural development and inclusive growth in Sub-Saharan Africa. Journal of Social and Economic Development, 25(2), 403–427. https://doi.org/10.1007/s40847-023-00240-5

Kozlov, A. (2019). Determining the level of digital infrastructure development in the region: methodology and comparative analysis on the example of the territories of the Russian Arctic. Regional Economics and Management: Electronic Scientific Journal, 2(58), 13.

Kozlov, A., Kankovskaya, A., & Teslya, A. (2020). Digital infrastructure as the factor of economic and industrial development: case of Arctic regions of Russian North-West. IOP Conference Series: Earth and Environmental Science, 539(1), 012061. https://doi.org/10.1088/1755-1315/539/1/012061

Kramin, T. V., & Klimanova, A. R. (2019). Development of Digital Infrastructure in the Russian Regions. TERRA ECONOMICUS, 17(2), 60-76. https://doi.org/10.23683/2073-6606-2019-17-2-60-76

Lapinskas, A. (2023). Influence of mining rent on the efficiency of using natural potential: the paradox of plenty and its Russian specifics. Journal of Mining Institute, 259, 79–94. https://doi.org/10.31897/pmi.2023.

Litvinenko, V., Petrov, E., Vasilevskaya, D., et al. (2022). Assessment of the role of the state in the management of mineral resources. Journal of Mining Institute, 259, 95-111. https://doi.org/10.31897/pmi.2022.100

Logacheva, N. (2021). Assessig the level of digital maturity of the region in the context of strategic development. Izvestiya St. Petersburg State University of Economics Publishing. 2(128), pp. 147–152.

Lvov, V. V., Smirnova, Z. V., Artemova, E. I., et al. (2019). State of university – employer interaction models in Russia. Journal of Entrepreneurship Education, 4, 1–9.

Matrokhina, K., Trofimets, V., Mazakov, E., et al. (2023). Development of methodology for scenario analysis of investment projects of enterprises of the mineral resource complex. Journal of Mining Institute, 259, 112–124. https://doi.org/10.31897/pmi.2023.3

Ndubuisi, G., Otioma, C., & Tetteh, G. K. (2021). Digital infrastructure and employment in services: Evidence from Sub-Saharan African countries. Telecommunications Policy, 45(8), 102153. https://doi.org/10.1016/j.telpol.2021.102153

Nechitailo, A. R., & Marinina, O. A. (2022). Analysis of technological directions of electrification of hydrocarbon production facilities in poorly developed territories. Север и Рынок: Формирование Экономического Порядка, 25(2/2022), 45–57. https://doi.org/10.37614/2220-802x.2.2022.76.004

Nevskaya, M. A., Raikhlin, S. M., Vinogradova, V. V., et al. (2023). A Study of Factors Affecting National Energy Efficiency. Energies, 16(13), 5170. https://doi.org/10.3390/en16135170

Nevskaya, M., Shabalova, A., Kosovtseva, T., et al. (2024). Applications of simulation modeling in mining project risk management: criteria, algorithm, evaluation. Journal of Infrastructure, Policy and Development, 8(8), 5375. https://doi.org/10.24294/jipd.v8i8.5375

Nikiforova, V. D., Achba, L. V., Nikiforov, A. A., et al. (2020). Dialectics of the processes of digitization of the socio-economic system. In: Popkova E., Sergi B. (eds.). The digital economy: complexity and diversity versus rationality. ISC 2019. Lecture Notes in Networks and Systems, 87, 690–697. Springer, Cham. https://doi.org/10.1007/978-3-030-29586-8_80

Nikolaichuk, L., Ignatiev, K., Filatova, I., et al. (2023). Diversification of Portfolio of International Oil and Gas Assets using Cluster Analysis. International Journal of Engineering, 36(10), 1783–1792. https://doi.org/10.5829/ije.2023.36.10a.06

Novikov, A. (2024). Strategic factors for ensuring the sustainability of economic development of industrial complexes (on the example of shipbuilding industry). Journal of Infrastructure, Policy and Development, 8(8): 6061. http://dx.doi.org/10.24294/jipd.v8i8.6061

Ositis, A. (2020). Digital infrastructure for economic transformation: Challenges and opportunities. In: Proceedings of the 24th International Forum; 05 November 2020; Moscow, Russia, 135.

Otto, G., Foreman, R., & Verra, G. (2008). Field of the Future Digital Infrastructure and IT Architecture. Paper presented at the Intelligent Energy Conference and Exhibition, Amsterdam, The Netherlands, February 2008. https://doi.org/10.2118/112149-ms

Pershin, I. M., Pervukhin, D. A., Ilyushin, Y. V., et al. (2017). Design of distributed systems of hydrolithospere processes management. Selection of optimal number of extracting wells. IOP Conference Series: Earth and Environmental Science, 87 (3), 032030. https://doi.org/10.1088/1755-1315/87/3/032030

Pilipchuk, N. V., Aksenova, Z. A., Lupacheva, S. V., et al. (2024). Digital development of Russian Regions: Prospects and contradictions in a period of turbulence. In: Ecological Footprint of the Modern Economy and the Ways to Reduce It. Advances in Science, Technology and Innovation, Part F2356, 393-398. https://doi.org/10.1007/978-3-031-49711-7_65

Podoprigora, D. G., Sabukevich, V. S., Korobov, G. Y., et al. (2024). Justification of Developed System Measures to Increase Productivity of Wells in Eastern Part of Pechora Sea Oil Field. International Journal of Engineering, 37(11), 2303-2313. https://doi.org/10.5829/ije.2024.37.11b.15

Ponomarenko, T. V., Gorbatyuk, I. G., & Cherepovitsyn, A. E. (2024). Industrial clusters as an organizational model for the development of Russia petrochemical industry. Journal of Mining Institute, 1–13.

Romasheva, N. V., Babenko, M. A., & Nikolaichuk, L. A. (2022). Sustainable development of the Russian Arctic region: Environmental problems and ways to solve them. MIAB. Mining Inf. Anal. Bull., 10(2), 78–87. https://doi.org/0.25018/0236_1493_2022_102_0_78

Samarina, V., & Skufina, T. (2018). Russia's Northern Regions as Frontier Territories: Evaluation of Demographic Indicators and Innovations in Management. Innovations, 11(241), 39–44.

Samylovskaya, E., Kudryavtseva, R.-E., Medvedev, D., et al. (2020). Transformation of the Personnel Training System for Oil and Gas Projects in the Russian Arctic. Resources, 9(11), 137. https://doi.org/10.3390/resources9110137

Shemyakina, N. V., & Ponomarenko, A. A. (2020). Digital infrastructure as a basic element of digital transformation. Economics and marketing in the 21st century: problems, experience, prospects. In: Proceedings of the 16th International Scientific-Practical Conference: dedicated to the 100th anniversary of the DNTU; 19–20 November 2020; Donetsk, Ukraine, 119–124.

Stroykov, G., Vasilev, Y. N., & Zhukov, O. V. (2021). Basic Principles (Indicators) for Assessing the Technical and Economic Potential of Developing Arctic Offshore Oil and Gas Fields. Journal of Marine Science and Engineering, 9(12), 1400. https://doi.org/10.3390/jmse9121400

Tsiglianu, P., Romasheva, N., & Nenko, A. (2023). Conceptual Management Framework for Oil and Gas Engineering Project Implementation. Resources, 12(6), 64. https://doi.org/10.3390/resources12060064

Vasilev, Y., Vasileva, P., Batova, O., et al. (2024). Assessment of Factors Influencing Educational Effectiveness in Higher Educational Institutions. Sustainability, 16(12), 4886. https://doi.org/10.3390/ su16124886

Voronina, L., Grigorishchin, A., & Iakhiaev, D. (2023). Assessing the Impact of Factors on the Education Infrastructure in the Arctic Zone of the Northern Macroregion. Economic and Social Changes: Facts, Trends, Forecast, 4 (88). https://doi.org/10.15838/esc.2023.4.88.8

Zhang, B., Ma, J., Khan, M. A., et al. (2023). The Effect of Economic Policy Uncertainty on Foreign Direct Investment in the Era of Global Value Chain: Evidence from the Asian Countries. Sustainability, 15(7), 6131. https://doi.org/10.3390/su15076131

Zhang, J., Yang, Z., & He, B. (2023). Does Digital Infrastructure Improve Urban Economic Resilience? Evidence from the Yangtze River Economic Belt in China. Sustainability, 15(19), 14289. https://doi.org/10.3390/su151914289