TERRITORIAL ORGANIZATION AND MANAGEMENT

DOI: 10.15838/ptd.2026.3.143.2
UDC 332.1 | LBC 65.04

MODELING THE DEVELOPMENT OF THE ARCTIC MACRO-REGION

EVGENIYA A. KUKLINA
North-West Institute of Management, Russian Presidential Academy of National Economy and Public Administration
Institute for Regional Economic Studies, Russian Academy of Sciences
Saint Petersburg, Russian Federation
e-mail: kuklina-ea@ranepa.ru
ORCID: 0000-0003-0457-2658; ResearcherID: ABJ-0748-2022

DARIMA D. ULZETUEVA
North-West Institute of Management, Russian Presidential Academy of National Economy and Public Administration
Institute for Regional Economic Studies, Russian Academy of Sciences
Saint Petersburg, Russian Federation
e-mail: ulzetueva-dd@ranepa.ru
ORCID: 0000-0003-2216-835X; ResearcherID: A-9644-2018

The relevance of the research topic is determined by the importance and role of the Arctic potential for solving Russia's strategic tasks in modern conditions of challenges and threats, as well as the possibilities of modeling in forming a qualitative basis for managerial decision-making to improve the effectiveness of public administration. Fundamentally new infrastructure and production solutions are being implemented in the Arctic macro-region, which can be scaled in the future, which determines the importance of modeling the development of the Arctic zone of the Russian Federation based on modern data analysis methods. When modeling the development of the Arctic macro-region, it is necessary to take into account such features as the limited and fragmented information collected, as well as the complexity of integrating heterogeneous data (economic, social, environmental, etc.). In this regard, the implementation of a set of modeling tasks based on modern data analysis methods requires various approaches (econometric modeling, cognitive technologies, machine learning, and big data analysis

For citation: Kuklina E.A., Ulzetueva D.D. (2026). Modeling the development of the Arctic macro-region. *Problems of Territory's Development*, 30(3), 10–29. DOI: 10.15838/ptd.2026. 3.143.2

methods) that allow analyzing complex socio-economic, environmental, and infrastructural processes. The combination of various methodological approaches makes it possible to ensure the accuracy of the model, which can be used in developing strategies for the sustainable development of Arctic territories, planning infrastructure projects and making management decisions. The aim of the study is to explore the possibilities of modeling the development of the Arctic macro-region using modern data analysis methods. The aim defined the objectives of the study: to analyze the results of research in this subject area; to consider the clustering method (cluster analysis) as one of the effective methods of substantiating management decisions on the implementation of the Development Strategy of the Arctic zone of the Russian Federation; to identify promising areas of future research. The work used a systematic approach, logical analysis, synthesis, open source content analysis, regression analysis, and cluster analysis. The information base was compiled by Rosstat data on the Arctic regions for the period 2015–2023. As a result of the study, the expediency of using the hierarchical clustering procedure implemented using the JASP data analysis program is substantiated. During the cluster analysis, all the Arctic regions of Russia were grouped into two clusters based on the proximity of specific GRP values, which allows for subsequent regression analysis within each cluster to obtain more accurate results. As a promising area of research, the use of synthetic control methodology is proposed, which makes it possible to create an alternative scenario for the development of a macro-region for comparison with real development and assessment of the economic effect of implementing a set of strategic decisions of the state. The scientific novelty of the study is to improve the approach to modeling the development of the Arctic macro-region using predictive (predictive) analytics methods such as regression analysis, time series method, clustering. The practical significance of the results is determined by the possibility of their application by public authorities and management to develop forecasts for the development of the Arctic zone.

Regional development, Arctic macro-region, modeling, forecast, econometric model, data, predictive analytics, cluster analysis.

ACKNOWLEDGMENT

The study was carried out within the framework of the initiative research of the North-West Institute of Management of the RANEPA under the President of the Russian Federation "Assessment of the prospects for cooperation between the BRICS Forum states in the Arctic economic space (in the context of updating global governance institutions)", number in the EGISU R&D system 125022002759-3 dated 02/20/2025.

Introduction

The goals, objectives and priorities of the development of the Russian Arctic zone are set out in such strategic documents as Presidential Decree 645, dated October 26, 2020 "On the Strategy for the Development of the Arctic Zone of the Russian Federation and Ensuring National Security for the Period up to 2035", "Fundamentals of State Policy in the Arctic until 2035" (approved by Presidential Decree 164, dated March 5, 2020), RF Government Resolution 3014-r, dated October 27, 2025 on long-term plans for the integrated socio-economic development of the Arctic zone's anchor settlements for the period up to 2035, the Strategy of the State National Policy of Russia for the period up to 2036 (RF Government Resolution 4147-r, dated December 29, 2025). According to these documents, one of the strategic priorities of the Russian Federation is the development of the economic potential of the Arctic zone of the Russian Federation (hereinafter – AZRF) for the purpose of balanced regional development, which is a rather difficult task: the Arctic macro-region as a space for economic activity has specific features of natural (harsh climate, remoteness from the center) and socio-economic (low population density, insufficient level of development of transport and social infrastructure, uneven industrial and economic development of individual territories) character. It is worth noting the high resource intensity of economic activity in the Arctic, as well as the stable geographical, historical and economic connection with the Northern Sea Route, which is currently the dominant development of the Arctic macro-region.

The specifics of economic activity shape the peculiarities of Arctic projects: difficult conditions for carrying out production activities; the use of a public-private partnership mechanism involving debt financing; the fragility of the Arctic ecosystem and its extreme vulnerability (Kuklina, 2025). The fragility and vulnerability of the Arctic ecosystem make it critically important to ensure the environmental safety of economic activity (Greaves, 2016).

One of the key factors in the regional development of the northern regions is the differentiation of the socio-economic environment (Skufina et al., 2018). The analysis of ongoing processes and the determination of the prospects for the development of the Arctic macro-region shape the choice of public policy instruments (Arctic Space ..., 2016; Schach, Madlener, 2018). But development here is always "a compromise between the need, on the one hand, to ensure environmental protection and adaptation to the effects of climate change, and, on the other hand, the need to develop economic activity" (Heininen, 2020).

Russia's modern Arctic policy is focused on creating conditions and frameworks for launching innovative projects as the basis for solving all other development tasks in the Russian Arctic. Fundamentally new infrastructure and production solutions are currently being implemented in the Arctic macro-region, which can be further scaled both in the subarctic regions and throughout the country as a whole. This determines the importance of modeling the development of the Russian Arctic based on modern data analysis methods. The use of models will make it possible to form the most reliable and qualitative basis for making managerial decisions in order to increase the effectiveness of public administration and strategizing. Modeling GRP and GDP makes it possible to identify the factors that need to be optimized first, as this can become a decisive lever for accelerating the economic growth of regions and the country as a whole.

The aim of this study is to explore the possibilities of modeling the development of the Arctic macro-region using modern data analysis methods. The aim defined the objectives of the study: to analyze the research results in this subject area; to consider the clustering method (cluster analysis) as one of the effective ways to justify management decisions on the implementation of the Development Strategy of the Russian Arctic; to identify promising areas for future research.

Methodological approaches and research methods

The theoretical and methodological basis of the research is the works of Russian and foreign scientists devoted to the AZRF development in terms of analysis, forecasting, and modeling. A systematic approach, logical analysis, synthesis, open-source content analysis, regression analysis, and cluster analysis were used as the methodological basis of the study.

We propose a comprehensive use of predictive analytics methods, including two consecutive stages, to improve the accuracy of estimates for making managerial decisions regarding the development of the Russian Arctic: at the first stage, a hierarchical clustering procedure is performed (for example, using the JASP2 data analysis program); at the second stage, regression analysis is performed within each selected cluster using an integrated autoregression model based on the moving average method for analyzing and predicting ARIMA (0,1,0) time series with Drift in Python 3.

Extent of elaboration of the problem

The key mechanism for achieving strategic interests and ensuring national security in the AZRF is the supporting development zones (hereinafter referred to as the SDZ), which develop as integral projects, including transport, industrial and social projects. If we consider the SDZ in the context of the implementation of resource projects (The Economy of…, 2020), which seems logical, given the powerful natural resource potential of the macro-region and the importance of its development for solving strategic tasks of the state, then seven development zones can be identified within the borders of the AZRF (Kola, Arkhangelsk, Taimyr-Turukhansk, Yamal-Nenets, Chukotka, North-Yakut, Nenets), which differ both in quantitative (territory, population, etc.) and qualitative (economic potential, level of socio-economic development, GRP, etc.) metrics.

The evolution of the normative economic and spatial image of the SDZ is presented in detail in a study by specialists from the Institute for Socio-Economic & Energy Problems of the Komi Science Research Centre of the Ural Branch of the Russian Academy of Sciences (Dmitrieva, Buryi, 2019). To analyze the activities of economic entities and develop development forecasts in the territory of the Russian Arctic, reference, basic and industrial settlements are distinguished, differing in the composition of economic entities and the population (Fauzer et al., 2019). The basic taxonomic unit of the SDZ is supporting settlements (hereinafter referred to as SS), which perform several functions: strategic, including ensuring security; administrative and managerial; scientific and research; ensuring accessibility to residents of all types of infrastructure; hosting unique enterprises; cultural development (Maracha, Krasnikova, 2024).

Thus, an object of modeling for the development of forecasts and strategies of socio-economic development can be as follows (listed in order of increasing their area as a geometric characteristic): SS; SDZ; Arctic region (subject of the Russian Federation); a group of regions identified by any criteria; the Russian Arctic as a whole.

We consider it necessary to note the achieved and promising significant research results in this subject area.

For instance, the work (Zemskov et al., 2022) carried out an assessment of the economic contribution of the Russian Arctic to the overall economic development of the country and constructed a linear model of the dependence of GDP on development indicators based on regression analysis. The advantage of this study, in our opinion, is the adjustment of estimated indicators (development indicators) using a correction factor calculated based on the number of administrative-territorial units belonging to the AZRF.

The article (Smirennikova et al., 2019) uses two opposite approaches: 1) individualization of scenarios for the socio-economic development of the AZRF territories; 2) development of generalized models that take into account the fundamental similarities of the AZRF subjects. We group all Arctic regions into three groups, propose three indicators for the development of Arctic socio-ecological and economic systems, and build regression models. As an advantage of the results obtained, we consider it necessary to note the fact that the authors have grouped the regions according to the appropriate criteria, i.e. their aggregation. Thus, further, for the purposes of analysis and forecasting, it is possible to operate not with local data for individual regions, but on their totality.

The paper (Kikkas, 2015) presents a model of six econometric equations for analyzing the sustainable development of the Chukotka Autonomous Area[1]. To model the development of a sustainable type, the author's version of the content of the category "sustainable development of the region's space" is proposed as a controlled process of development of three spheres of human activity (production, society, environmental management). The author defines indicators of sustainable development in the context of three areas: industrial development, social development, and the state of environmental management. The main idea of the author was to form a set of indicators reflecting the sustainability of development in each of the analyzed areas. On the one hand, the proposed approach is intuitive and quite easy to implement in practice for assessment and analysis, but on the other hand, it does not allow building a comprehensive model that takes into account all these areas as a whole, as a system consisting of three subsystems (economic, social and environmental)[2]. The author concludes that the methodological principles of building the model and the results of its solution can be successfully used in the future when developing a strategy for the sustainable development of a municipality, a separate Arctic region, or the totality of all Arctic regions of the Russian Federation. It seems to us that this conclusion is not correct due to the fact that all regions are different, they differ in their metrics, and there cannot be a universal model applicable to all equally, especially to the AZRF as a whole.

The study (Didenko, Skripnyuk, 2014) presents an approach to modeling the sustainable socio-economic development of the AZRF regions using a system of econometric equations, formulates the concept of regional typologization of the Arctic territories, and substantiates a model of growth and development of the Arctic regions, taking into account the type of territory. Thus, the proposed models take into account the specifics of the research object – a region of a certain type, which allows for more accurate results.

In the paper (Antipov, 2019), an innovation economy model for the Yamal-Nenets Autonomous Area was built on the basis of the ADL model, based on the results of previous research (Didenko, Kunze, 2014; Romashkina et al., 2017). The developed model represents a system of econometric equations reflecting a set of key indicators that make it possible to create an innovative economy, as well as factors that have a significant impact on achieving this goal. The strengths of the performed study include a fairly representative set of factors, including five endogenous and eight exogenous factors.

In continuation of research in this subject area, the same author built a model based on neural networks for three areas of the Murmansk Region (Antipov, 2022). The advantage of this modeling approach is due to the ability to quickly build a model with any given number of hidden layers and input variables. The model

[1] As an ADL model.

[2] In this context, it is worth noting that this problem was discussed earlier in the article "Comparison of regional sustainability assessments using indicator systems: is it feasible or not?" (Zeijl-Rozema et al., 2011), but no clear answer has been received; we adhere to the view that the answer to this question, most likely, it is negative.

is capable of scaling and almost unlimited increase in the amount of data, the effectiveness of its application is explained by the coverage of the assessed factors. The author considers the development of "more global cluster models describing not only individual regions, but also the entire Arctic zone as a whole" to be a promising vector of research in this subject area (Antipov, 2022, p. 156), and we fully support him in this.

In recent years, machine learning methods have been successfully applied to model the region's macroeconomic indicators and forecast GDP. For example, in the work (Adewale et al., 2024), ensemble methods (Random Forest Regressor, XGBoost Regressor and Linear Regression) were considered, Random Forest Regressor was recognized as the most reliable: the coefficient of determination is 0.96; the average absolute error (MAE) is 24.29.

In the study (Maikova et al., 2025), machine learning methods using the Python programming language were used to predict GRP. The choice of exogenous variables combining both traditional economic indicators and digitalization factors (the volume of investments in fixed assets aimed at acquiring information, computer and telecommunications equipment; the share of people employed in the ICT sector in the total number of employed people, etc.), made it possible to take into account current trends in the digital transformation of regional development, which is an undoubted advantage of this study.

At the end of a brief overview of the degree of study and elaboration of the topic, we consider it necessary to note a certain gap in scientific knowledge due to the practical lack of models describing the AZRF as a whole. Our study is an attempt to close this gap.

Results and their discussion

Decisions on the development of economic systems at any level are based, as a rule, on the results of predictive analytics and are focused mainly on the accuracy of the results obtained and the number of factors considered. The key idea of predictive analytics as an approach to data analysis that allows predicting future events (actions) based on existing ones (which have occurred) is that past data contains patterns that can be used to predict the future. The emergence of new data analysis and machine learning tools allows for deeper analysis based on structured information.

Currently, there are three groups of predictive analytics methods:

classical statistical methods based on calculations based on mathematical formulas selected depending on the type of task (regression analysis, clustering, time series analysis, etc.);

machine learning methods – predictions that apply automated algorithms using historical data (decision trees, neural networks, etc.);

large language models – solutions obtained using neural networks that are trained on information from the Internet or data provided by it.

The clustering method (cluster analysis) is a method of data processing by dividing a large group of objects into small groups based on similarity: each cluster includes objects that are as similar as possible, and objects from different clusters differ significantly[3].

Previously, we have successfully applied cluster analysis to substantiate proposals for the development of forms of tourism organization in China based on a spatial approach involving

[3] Seol H. (2025). SnowCluster: Multivariate Analysis. (Version 7.4.8) [jamovi module]. Available at: https://github.com/hyunsooseol/snowCluster

the creation of tourist macro-territories and the "master plan" tool; Random Forest Regressor was used, which implements the data analysis procedure through decision trees (Kuklina et al., 2025).

The information base for economic and mathematical modeling of the development of the Russian Arctic in this study was compiled by Rosstat data for the period 2015–2023 for nine subjects of the AZRF.

To select a similarity metric, a three-factor model was constructed and correlation coefficients were calculated *(Tab. 1)* between the resulting indicator – the GRP of the Arctic regions (*Y*) and three variables: specific GRP (X_1); average monthly memorial wages of employees in a full range of organizations in the economy as a whole (X_2); internal costs of research and development (X_3).

Figure 1 shows regression statistics and the results of regression analysis of the three-factor linear model.

Figure 2 presents a graphical interpretation of the results.

Table 1. Correlation coefficients for factors X_i

GRP per capita, thousand rubles	Average monthly nominal accrued salary of employees in full range of organizations in the economy as a whole, rubles	Internal research and development costs, million rubles
X_1	X_2	X_3
0.9637583	0.918878	0.947745
Source: own compilation.		

Regression statistics	
Multiple R	0.981
R-square	0.962
Normalized R-square	0.943
Standard error	1724.145
	10

	df	*SS*	*MS*	*F*	*Significance of F*
Regression	3	448980173.3	149660057.8	50.34525032	0.000120251
Remains	6	17836048.9	2972674.817		
Total	9	466816222.2			

	Coefficients	*Standard error*	*t-statistics*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95%*	*Upper 95%*
Y-intersection	115751.2718	6136.461094	18.86287064	1.43413E-06	100735.8925	130766.6512	100735.8925	130766.6512
Variable X_1	0.039093822	0.02035194	1.92088919	0.103138892	-0.010705582	0.088893226	-0.010705582	0.088893226
Variable X_2	0.02325724	0.010647696	2.184250945	0.071640246	-0.002796734	0.049311214	-0.002796734	0.049311214
Variable X_3	-0.026400099	0.022018481	-1.198997276	0.275728887	-0.080277382	0.027477184	-0.080277382	0.027477184

Figure 1. Results of regression analysis of three-factor linear model
Source: own compilation.

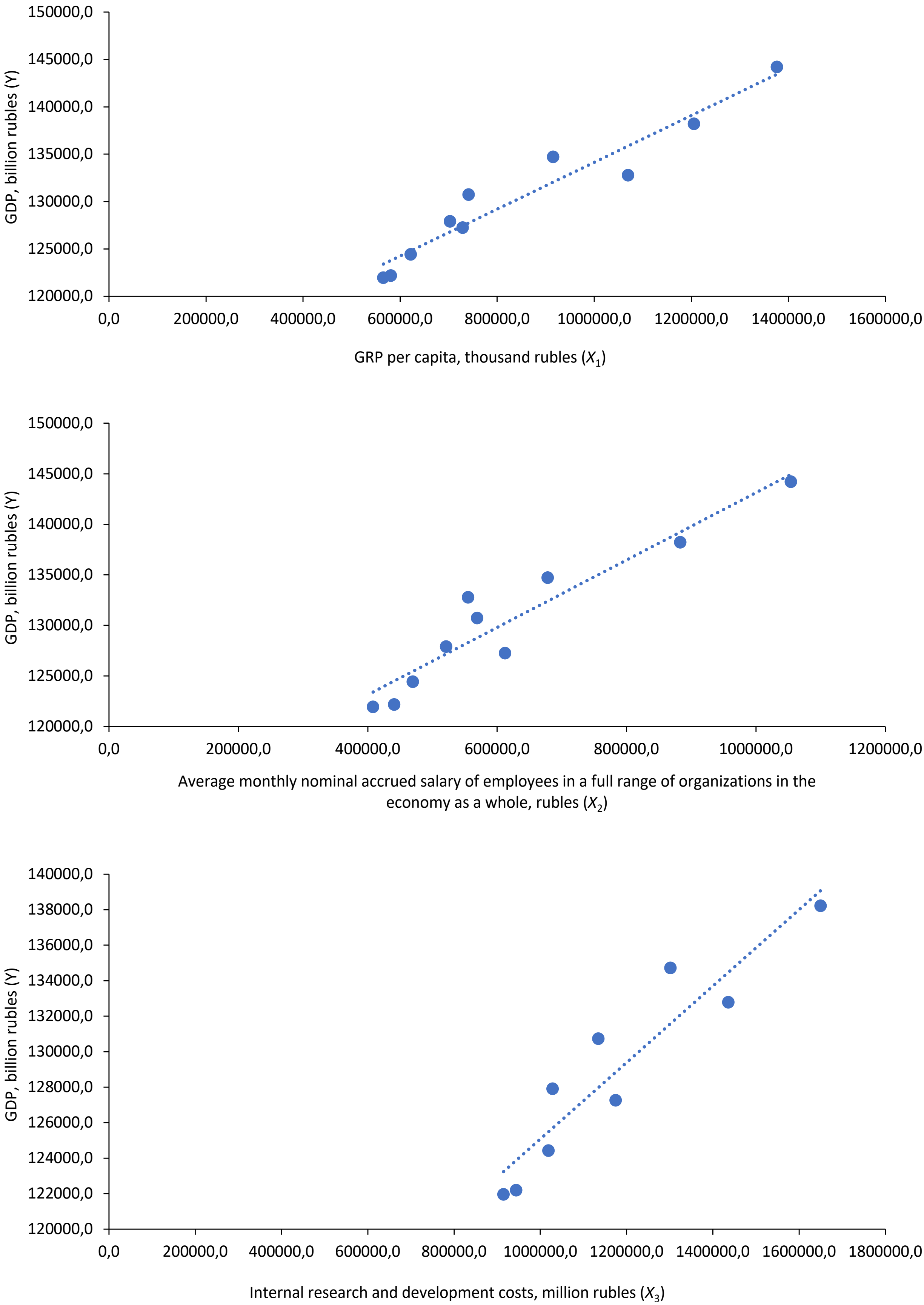


Figure 2. Graphical interpretation of regression analysis results

Source: own compilation.

The obtained results allowed selecting the indicator X_1 with the highest correlation coefficient (0.964) as a sign of similarity. Thus, the specific GRP indicator (i.e., per capita GRP) was further used when performing the Ward. D2 cluster analysis based on the hierarchical clustering procedure and calculating the Euclidean value for two selected clusters *(Fig. 3)*.

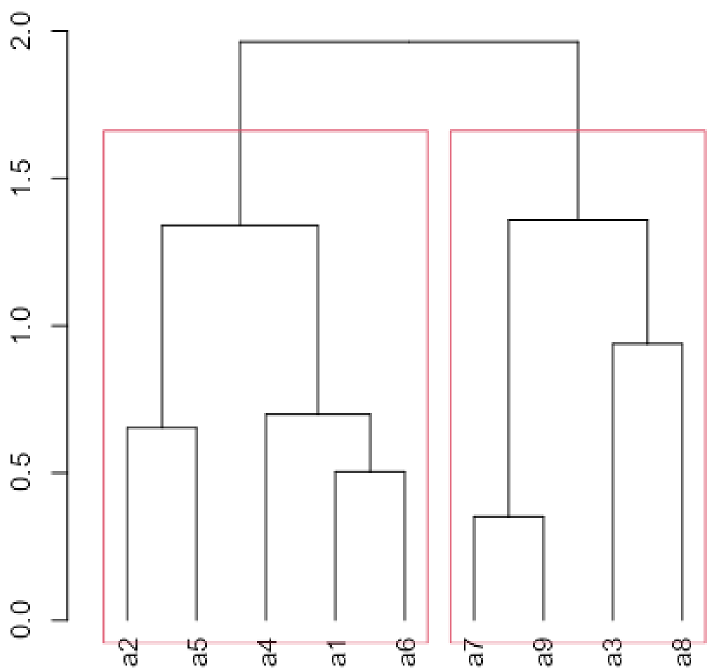
Visualization of the results of the performed hierarchical clustering is shown on the dendrogram *(Fig. 4)*.

Thus, the first cluster includes five Arctic regions, and the second cluster includes four regions of the AZRF. At the same time, most of the subjects of the first cluster (60%) are the old-developed regions of the Arctic (Komi Republic, Republic of Karelia, Arkhangelsk Region), characterized by an average level of economic development with a developed manufacturing industry, negative demographic trends, insufficient economic and transport development of the territory, and a low standard of living for the population. Half of the regions in the second cluster are two autonomous areas (Yamal-Nenets and Chukotka) with high levels of economic development and living standards, but with low levels of economic development and transport accessibility.

Cluster No	Count
1	5
2	4

Variables	Cases	Distances	Clustering method
8	9	euclidean	Ward.D2

Figure 3. Results of hierarchical data clustering
Source: own compilation.



Symbols:

a1 – Arkhangelsk Region;
a2 – Krasnoyarsk Territoty;
a3 – Murmansk Region;
a4 – Nenets AA;
a5 – Republic of Karelia;
a6 – Komi Republic;
a7 – Republic of Sakha (Yakutia);
a8 – Chukotka AA;
a9 – Yamal-Nenets AA

Figure 4. Dendrogram by regions of the Arctic zone of the Russian Federation
Source: own compilation.

Based on the results of the regression analysis, it can be seen that the confidence value of the R^2 approximation for the two clusters is almost the same for both the variant without data processing *(Fig. 5a)* and with data processing *(Fig. 5b)*.

For more advanced analytics, one should make a forecast for two clusters using an integrated ARIMA (0,1,0) moving average autoregression model with Drift in Python 3. As a result, to justify management decisions, it is possible to obtain more accurate data adequate to the internal structure of the objects of the two clusters than the regression analysis data obtained using indicators for all Arctic regions in aggregate. In this case, improved forecast accuracy is provided by more structured and homogeneous information within each of the two aggregates – the first cluster *(Fig. 6a)* and the second cluster *(Fig. 6b)*.

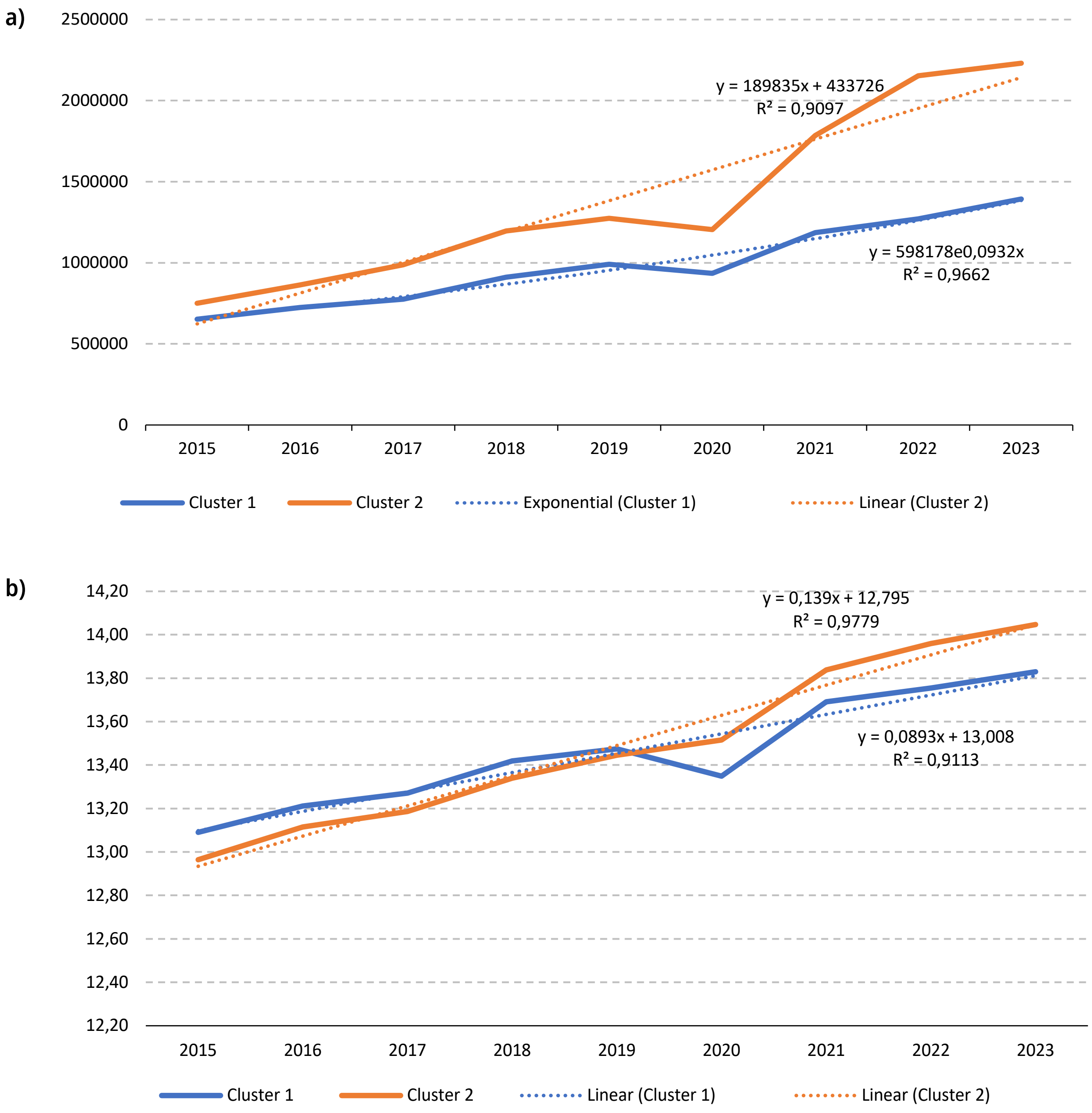
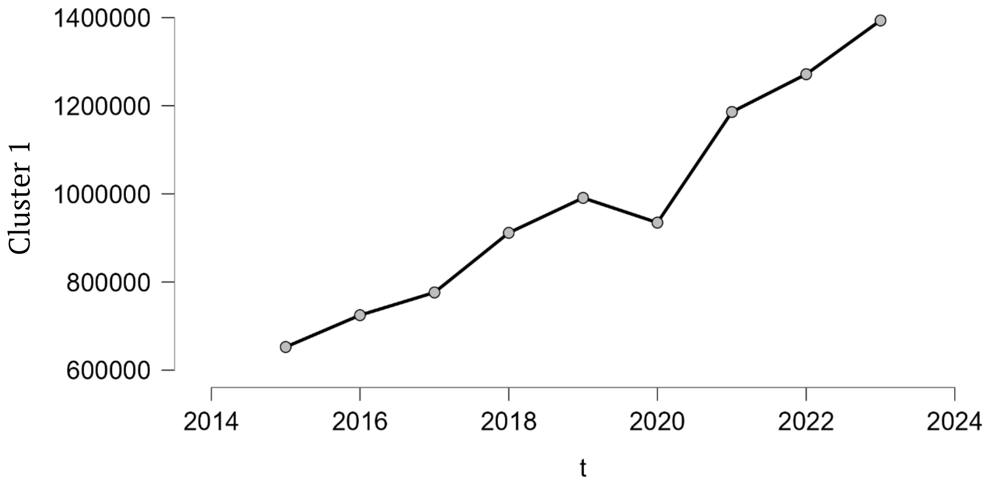


Figure 5. Time cluster graphs with a trend line and their approximation

Source: own compilation.

a) ARIMA

Time Series Plot



Model Summary

σ²	Log-Likelihood	AICc	AIC	BIC
$7{,}469 \times 10^{+9}$	-101,754	209,907	207,507	207,666

Coefficients

					95% CI	
	Estimate	Standard Error	t	p	Lower	Upper
Drift	92635,460	28582,011	3,241	0,014	25049,743	160221,177

Note. An ARIMA (0, 1, 0) model was fitted.

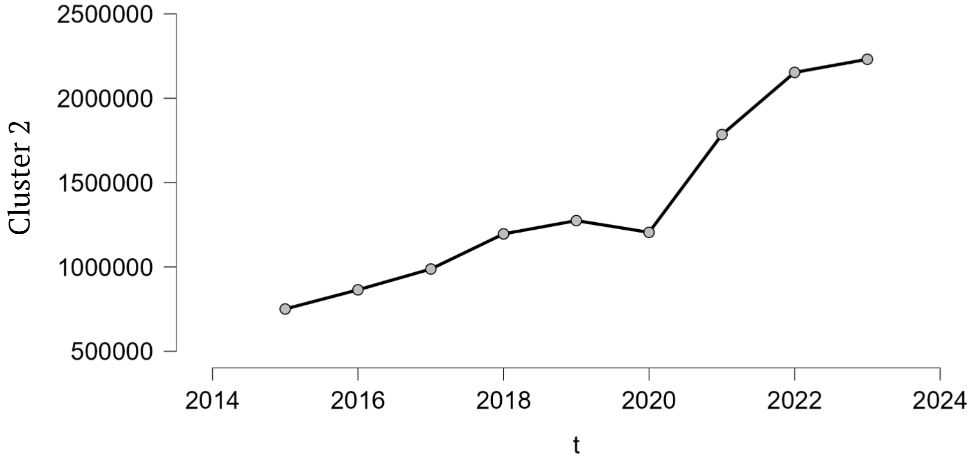
Stationarity Tests

Test	Statistic	Truncation lag parameter	p	H_0
Augmented Dickey-Fuller t	-5,415	2	0,010[a]	Non-stationary
Phillips-Perron regression coefficient ρ	-7,798	2	0,623	Non-stationary
Phillips-Perron studentized τ	-2,375	2	0,429	Non-stationary

[a] The p-value is actually less than p-value shown (see Help file).

6) ARIMA

Time Series Plot



Model Summary

σ^2	Log-Likelihood	AICc	AIC	BIC
4,091×10+10	-108,556	223,511	221,111	221,270

Coefficients

					95% CI	
	Estimate	Standard Error	t	p	Lower	Upper
Drift	185021,234	66890,297	2,766	0,028	26850,817	343191,652

Note. An ARIMA (0, 1, 0) model was fitted.

Stationarity Tests

Test	Statistic	Truncation lag parameter	p	H_0
Augmented Dickey-Fuller t	2,654	2	0,990[a]	Non-stationary
Phillips-Perron regression coefficient ρ	-4,517	2	0,843	Non-stationary
Phillips-Perron studentized τ	-1,546	2	0,745	Non-stationary

[a] The p-value is actually less than p-value shown (see Help file).

Figure 6. Time series graphs for two clusters

Source: own compilation.

The data obtained through the Time Series using ARIMA (0, 1, 0) allows concluding that the time series for both clusters are unstable – the obtained confidence intervals give a vague estimate due to the small number of observations. *Table 2* shows the time series graphs show a point and interval forecast for clusters (Forecast Time Series Plot) *(Fig. 7a, 7b)*, their numerical values.

Table 2. Point and interval estimates of the forecast for clusters

Forecasts

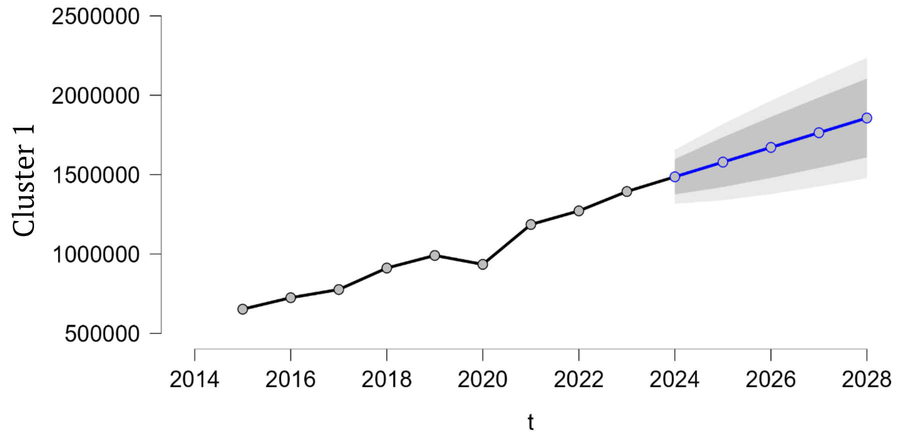
		80% CI (dark fill)		95% CI (light gray fill)	
t	Cluster 1	Lower	Upper	Lower	Upper
2024-01-01	$1,486\times10^{+6}$	$1,375\times10^{+6}$	$1,597\times10^{+6}$	$1,317\times10^{+6}$	$1,656\times10^{+6}$
2025-01-01	$1,579\times10^{+6}$	$1,422\times10^{+6}$	$1,735\times10^{+6}$	$1,339\times10^{+6}$	$1,818\times10^{+6}$
2026-01-01	$1,671\times10^{+6}$	$1,480\times10^{+6}$	$1,863\times10^{+6}$	$1,378\times10^{+6}$	$1,965\times10^{+6}$
2027-01-01	$1,764\times10^{+6}$	$1,543\times10^{+6}$	$1,986\times10^{+6}$	$1,425\times10^{+6}$	$2,103\times10^{+6}$
2028-01-01	$1,857\times10^{+6}$	$1,609\times10^{+6}$	$2,104\times10^{+6}$	$1,478\times10^{+6}$	$2,236\times10^{+6}$

Forecasts

		80% CI (dark fill)		95% CI (light gray fill)	
t	Cluster 2	Lower	Upper	Lower	Upper
2024-01-01	$2,416\times10^{+6}$	$2,157\times10^{+6}$	$2,675\times10^{+6}$	$2,019\times10^{+6}$	$2,812\times10^{+6}$
2025-01-01	$2,601\times10^{+6}$	$2,234\times10^{+6}$	$2,967\times10^{+6}$	$2,040\times10^{+6}$	$3,162\times10^{+6}$
2026-01-01	$2,786\times10^{+6}$	$2,337\times10^{+6}$	$3,235\times10^{+6}$	$2,099\times10^{+6}$	$3,473\times10^{+6}$
2027-01-01	$2,971\times10^{+6}$	$2,453\times10^{+6}$	$3,489\times10^{+6}$	$2,178\times10^{+6}$	$3,764\times10^{+6}$
2028-01-01	$3,156\times10^{+6}$	$2,576\times10^{+6}$	$3,736\times10^{+6}$	$2,270\times10^{+6}$	$4,042\times10^{+6}$

Source: own compilation.

a) Forecast Time Series Plot



b) Forecast Time Series Plot

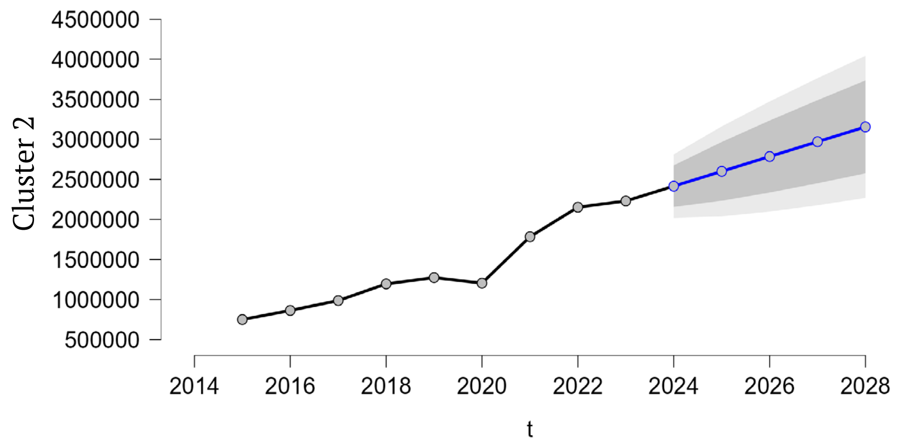


Figure 7. Time series graphs for two clusters with forecast

Source: own compilation.

On the graphs, the blue line shows a point forecast of GRP values from 2024 to 2028, calculated using the ARIMA autoregressive model (0, 1, 0). Since there are few observed values for building models, the confidence intervals turn out to be quite wide, however, with further research and an increase in the sample size, the width of the confidence intervals may decrease. In our case, the confidence interval for predicting GRP values is shown in the graphs *(Fig. 7a, 7b)*: a darker fill shows the confidence interval with a probability of 80%; The light gray fill is a 95% confidence interval.

Table 2 shows the numerical values of the confidence intervals for the levels of the series from 2024 to 2028. As the level of the series increases, the confidence interval becomes wider, so the forecast for this model for a longer period of time becomes meaningless; for a more accurate forecast, it is necessary to increase the number of observations.

A separate difficult task is the assessment of the results of the implementation of large, integrated projects that affect the economic development of each Arctic region of the Russian Federation in which they are localized.

It seems to us that for this purpose it is advisable to use the methodology of synthetic control, formed by solving the optimization problem, minimizing the differences between the real and synthetic units according to the given predictors in the previous period.

The synthetic control method (hereinafter referred to as SCM) was developed by A. Abadie, J. Gardeazabal (Abadie et al., 2003) and later improved by A. Abadie, A. Diamond, J. Hainmueller. (Abadie et al., 2010) in the direction of expanding the methodological apparatus. For example, formal conditions for the validity of synthetic control were developed, statistical tests were compiled to assess the significance of the results, advanced algorithms for selecting weights were created, and the applicability of the method for comparative case studies in conditions of a small number of observations was substantiated.

This method is widely used in economics to assess the impact of economic shocks, social programs, and political changes (for example, to assess the impact of "new" policies on economic performance), and is also useful in cases where traditional randomized controlled trials are not possible for ethical, logistical, or practical reasons. The disadvantage of SCM is the lack of knowledge about what would have happened with non-intervention – this is the problem of missing data, which affects the ability to draw conclusions about causality. In relation to our task, SCM allows creating an alternative scenario for the development of the Arctic macro-region for comparison with real development to assess the economic impact of the implementation of a set of strategic decisions of the state.

The Synth package has been developed for SCM data analysis in statistical software for the R language (Abadie et al., 2011).

Using this tool, for example, in 2015, S. Klößner, A. Kaul, G. Pfeifer, M. Schieler "synthesized" counterfactual Germany based on such metrics as per capita GDP, investment level, trade openness, number of schools, the share of industry in the surplus product of Austria (42%), the USA (22%), Japan (16%), Switzerland (11%) and the Netherlands (9%) (Klößner et al., 2018). Examples of the use of SCM by Russian researchers can be given. For example, SCM was previously used to assess the impact of the creation of the Titanium Valley SEZ in the Sverdlovsk Region (Podkorytova, 2019) and to assess the impact of policy on real GRP per capita in the Far Eastern Federal District (Goryunov et al., 2023). The synthetic control was created using the software package for statistical analysis of Stata data[4]. The SCM was also used to assess the consequences of the adoption of a law banning smoking in public places and its impact on the smoking rate in Russia (Potekhina et al., 2018).

The experience of using SCM suggests that this method is particularly effective for analyzing rare events in small samples. Thus, evaluating the effectiveness of government initiatives to implement large, integrated projects in the AZRF using the SCM method is a promising area of future research.

Conclusion

The performed research allowed confirming the assumption about the expediency of using cluster analysis as one of the effective methods of substantiating management decisions on the implementation of the Development Strategy of the AZRF. To select a similarity metric, a three-factor model was built and correlation coefficients were calculated between the resulting indicator (GRP of the Arctic regions of the Russian Federation) and

[4] Designed for statistical research on a variety of data samples from various subject areas and disciplines, it is used by researchers and analysts for data analysis, modeling and visualization.

three variables (specific GRP, average monthly memorial wages of employees in a full range of organizations in the economy as a whole, internal costs of research and development). The results obtained made it possible to select the "specific GRP" indicator with the highest correlation coefficient as a sign of similarity. When using the JASP data analysis program, all Arctic regions of Russia were grouped into two clusters based on the proximity of specific GRP values, including, respectively, five and four subjects of the Russian Federation. Regression analysis performed without and with data processing showed high reliability of the R2 approximation for both clusters. The results of applying the integrated ARIMA (0, 1, 0) moving average autoregression model with Drift in Python 3 made it possible to make a point forecast of GRP values from 2024 to 2028 and formulate the conclusion that both clusters of the time series are non-stationary (data obtained through the Time Series Time Series), the values for the two clusters time also have a significant effect on the forecast (data on the number of forecast levels).

The theoretical and methodological significance of the research lies in the development of approaches to modeling the development of the Arctic macro-region using modern data analysis methods (predictive analytics). The practical significance of the study is determined by the possibility of using the results obtained by public authorities and management to develop forecasts for the development of the AZRF in the context of both the Arctic regions of the Russian Federation and the Arctic macro-region as a whole.

REFERENCES

Abadie A., Diamond A., Hainmueller J. (2011). Synth: An R package for synthetic control methods in comparative case studies. *Journal of Statistical Software,* 42, 13. DOI: 10.18637/jss.v042.i13

Abadie A., Diamond A., Hainmueller J. (2010). Synthetic control methods for comparative case studies. *Journal of the American Statistical Association,* 105, 490, 493–505. DOI: 10.1198/jasa.2009.ap08746

Abadie A., Gardeazabal J. (2003). The economic costs of conflict: A case study of the Basque country. *American Economic Review*, 93, 1, 113–132. DOI: 10.1257/000282803321455188

Adewale M.D., Ebem D.U., Awodele O. et al. (2024). Predicting gross domestic product using the ensemble machine learning method. *Systems and Soft Computing,* 6, Art. 200132. DOI: 10.1016/j.sasc.20 24.200132

Antipov S.K. (2019). Development of an innovative economy model in the Arctic regions of Russia (using the example of the Yamalo-Nenets Autonomous Okrug). *Sever i rynok: formirovanie ekonomicheskogo poryadka*, 1(63), 99–109 (in Russian).

Antipov S.K. (2022). Modeling the sustainable development of the Arctic regions of the Russian Federation (using the example of the Murmansk Region). *π-Economy*, 15(6), 146–159. DOI: 10.18721/JE.15610 (in Russian).

Didenko N., Kunze K. (2014). relationship between energy policies and quality of life in Russia. *WIT Transactions on Ecology and the Environment*, 3(1), 186.

Didenko N.I., Skripnyuk D.F. (2014). Modeling of sustainable socio-economic development of the Arctic regions of the Russian Federation using a system of econometric equations. In: *Strategicheskie prioritety razvitiya Rossiiskoi Arktiki: sbornik nauchnykh trudov* [Strategic Priorities for the Development of the Russian Arctic: Collection of Scientific Papers]. Moscow: FGAU VPO SPbGPU (in Russian).

Dmitrieva T.E., Buryi O.V. (2019). Reference zones for the development of the Russian Arctic: Content, ratings, and projects. *EKO=ECO Journal*, 1, 41–59 DOI: 10.30680/ECO0131-7652-2019-1-41-59 (in Russian).

Fauzer V.V., Smirnov A.V., Lytkina T.S., Fauzer G.N. (2019). Methodology for determining pivotal settlements of the Russian Arctic. *Ekonomicheskie i sotsial'nye peremeny: fakty, tendentsii, prognoz=Economic and Social Changes: Facts, Trends, Forecast,* 12(5), 25–43. DOI: 10.15838/esc.2019.5.65.2 (in Russian).

Goryunov A., Ageshina E., Lavrentev I., Peretyatko P. (2023). Estimating the effect of Russia's development policy in the Far Eastern region: The synthetic control approach. *Applied Econometrics,* 4(72), 59–73. DOI: 10.22394/1993-7601-2023-72-58-72. EDN: MZPYWQ

Greaves W. (2016) Securing sustainability: The case for critical environmental security in the Arctic. *Polar Record,* 52(6), 660–671. DOI: 10.1017/S 0032247416000218

Ivanter V.V. (Ed.). (2016). *Arkticheskoe prostranstvo v XXI veke: faktory razvitiya, organizatsii upravleniya* [Arctic Space in the 21st Century: Development Factors, Management Organizations]. Saint Petersburg: Izdatel'skii dom "Nauka".

Khaininen L. (2020). Review of Arctic policy and strategies. *Arktika i Sever*, 39, 195–202. DOI: 10.37482/issn2221-2698.2020.39.195 (in Russian).

Kikkas K.N. (2015). Modeling the sustainable development of the Russian Arctic region. *MIR (Modernizatsiya. Innovatsii. Razvitie)*, 6(4), 142–147. DOI: 10.18184/2079-4665.2015.6.4.142.147 (in Russian).

Klößner S., Kaul A., Pfeifer G., Schieler M. (2018). Comparative politics and the synthetic control method revisited: A note on Abadie et al. (2015). *Swiss Journal of Economics and Statistics*, 154, 1. DOI: 10.1186/s41937-017-0004-9

Kryukov V.A., Skuf'ina T.P., Korchak E.A (Eds.). (2020). *Ekonomika sovremennoi Arktiki: v osnove uspeshnosti effektivnoe vzaimodeistvie i upravlenie integral'nymi riskami: monografiya* [The Economy of the Modern Arctic: Effective Interaction and Integrated Risk Management at the Heart of Success: Monograph]. Apatity: FITS KNTS RAN. DOI: 10.37614/978.5.91137.416.7 (in Russian).

Kuklina E.A. (2025). Russia's Arctic Agenda: Projects, problems, digital solutions. *Upravlencheskoe konsul'tirovanie=Administrative Consulting*, 5, 170–186 (in Russian).

Kuklina E.A., Borshcheva E.D. (2025). Development of forms of tourism organization in China based on a spatial approach: Implementation of Russia's experience. *Evraziiskaya integratsiya: ekonomika, pravo, politika=Eurasian Integration: Economics, Law, Politics*, 19(1), 56–70. DOI: 10.22394/2073-2929-2025-01-56-70 (in Russian).

Maikova A.A., Starchenkova O.D., Skhvediani A.E. (2025). Gross regional product modeling with machine learning methods. *Vestnik Permskogo universiteta. Seriya "Ekonomika"=Perm University Herald. Economy*, 20(4), 449–467. DOI: 10.17072/1994-9960-2025-4-449-467 (in Russian).

Maracha V.G., Krasnikova T.S. (2024). Supporting settlements in the Arctic zone of Russia: Their main functions and the content of comprehensive long-term development plans. *Arktika 2035: aktual'nye voprosy, problemy, resheniya*, 1(17), 32–50 (in Russian).

Podkorytova E.V. (2019). Application of the synthetic control method on the example of the special economic zone "Titanium Valley". *Nauchnyi al'manakh*, 12-1(62), 87–90 (in Russian).

Potekhina E.V., Faminskaya M.V. (2019). Assessment of the impact of the "anti-smoking" law on the smoking rate in Russia: Synthetic control method. *Sotsial'naya politika i sotsiologiya*, 18, 4(133), 73–85. DOI: 10.17922/2071-3665-2019-18-4-73-85 (in Russian).

Romashkina G.F, Didenko N.I., Skripnuk D.F. (2017). Socioeconomic modernization of Russia and its Arctic regions. *Studies on Russian Economic Development,* 28(1), 22–30.

Schach M., Madlener R. (2018). Impact of an ice-free northeast passage on LNG markets and geopolitics. *Energy Police,* 122, 433–448. DOI: https://doi.org/10.1016/j.enpol.2018.07.009

Skufina T., Baranov S., Samarina V. (2018). Differentiation of socioeconomical environment as factors of regional development (the case study of Murmansk Region, Russia). *Advanced Science Letters*, 24(9), 6329–6331. DOI: 10.1166/asl.2018.13045

Smirennikova E.V., Ukhanova A.V., Voronina L.V. (2019). A system of models for forecasting the socio-economic development of the regions of the Arctic zone of the Russian Federation. *Upravlencheskoe konsul'tirovanie=Administrative Consulting*, 12, 142–157. DOI: 10.22394/1726-1139-2019-12-142-157 (in Russian).

Zeijl-Rozema A., Ferraguto L., Caratti P. (2011). Comparing region-specific sustainability assessments through indicator systems: Feasible or not? *Ecological Economics [Elsevier]*, 70(3), 475–486.

Zemskov V.V., Prasolov V.I., Khudyakov D.S., Kanashina A.I., Timofeev E.A. (2022). Assessment of the contribution of the Arctic zone to the economic development of the country. *Finansy: teoriya i praktika=Finance: Theory and Practice*, 26(2), 160–174. DOI: 10.26794/2587 5671-2022-26-2-160-174 (in Russian).

INFORMATION ABOUT THE AUTHORS

Evgeniya A. Kuklina – Doctor of Sciences (Economics), Professor, professor of department, North-West Institute of Management, Russian Presidential Academy of National Economy and Public Administration (57/34, Sredny Avenue, Saint Petersburg, 199178, Russian Federation); Chief Researcher, Institute for Regional Economic Studies, Russian Academy of Sciences (38, Serpukhovskaya Street, Saint Petersburg, 190013, Russian Federation; e-mail: kuklina-ea@ranepa.ru)

Darima D. Ulzetueva – Candidate of Sciences (Engineering), associate professor of department, North-West Institute of Management, Russian Presidential Academy of National Economy and Public Administration (57/34, Sredny Avenue, Saint Petersburg, 199178, Russian Federation; e-mail: ulzetueva-dd@ranepa.ru)

Куклина Е.А., Ульзетуева Д.Д.

МОДЕЛИРОВАНИЕ РАЗВИТИЯ АРКТИЧЕСКОГО МАКРОРЕГИОНА

Актуальность темы исследования определяется значением и ролью арктического потенциала для решения стратегических задач России в современных условиях вызовов и угроз, а также возможностями моделирования в формировании качественной базы для принятия управленческих решений с целью повышения эффективности государственного управления. В Арктическом макрорегионе реализуются принципиально новые инфраструктурные и производственные решения, которые в дальнейшем могут быть масштабированы, что обусловливает значимость моделирования развития Арктической зоны Российской Федерации на основе современных методов анализа данных. При моделировании развития Арктического макрорегиона необходимо учитывать такие особенности, как ограниченность и фрагментарность собираемой информации, а также сложность интеграции разнородных данных (экономических, социальных, экологических и др.). В связи с этим реализация комплекса задач моделирования на основе современных методов анализа данных требует различных подходов (эконометрическое моделирование, когнитивные технологии, методы машинного обучения и анализа больших данных), позволяющих анализировать сложные социально-экономические, экологические и инфраструктурные процессы. Сочетание различных методологических подходов дает возможность обеспечить точность модели, которая может быть использована при разработке стратегий устойчивого развития арктических территорий, планировании инфраструктурных проектов и принятии управленческих решений. Цель исследования состояла в изучении возможностей моделирования развития Арктического макрорегиона с помощью современных методов анализа данных. Поставленная цель определила задачи исследования: проанализировать результаты исследований в данной предметной области; рассмотреть метод кластеризации (кластерный анализ) как *один из эффективных методов обоснования управленческих решений по реализации Стратегии развития Арктической зоны Российской Федерации; выявить перспективные направления будущих исследований. В ходе работы использовались системный подход, логический анализ, синтез, контент-анализ открытых источников, регрессионный анализ, кластерный анализ. Информационную базу составили данные Росстата по арктическим регионам за период 2015–2023 гг. В результате исследования обоснована целесообразность применения процедуры иерархической кластеризации, реализованной с помощью программы для анализа данных JASP. В ходе кластерного анализа все арктические регионы России по признаку близости значений удельного ВРП сгруппировались в два кластера, что позволяет выполнять последующий регрессионный анализ внутри каждого кластера с получением более точных результатов. В качестве перспективного направления исследований предложено использование методологии синтетического контроля, позволяющей создать альтернативный сценарий развития макрорегиона для сравнения с реальным развитием и оценки экономического эффекта от реализации комплекса стратегических решений государства. Научная новизна исследования заключается в совершенствовании подхода к моделированию развития Арктического макрорегиона с использованием методов предиктивной (прогнозной) аналитики, таких как регрессионный анализ, метод временных рядов, кластеризация. Практическая значимость результатов определяется возможностью их применения органами государственной власти и управления для разработки прогнозов развития Арктической зоны.*

Региональное развитие, Арктический макрорегион, моделирование, прогноз, эконометрическая модель, данные, предиктивная аналитика, кластерный анализ.

ЛИТЕРАТУРА

Антипов С.К. (2019). Разработка модели инновационной экономики в арктических регионах России (на примере Ямало-Ненецкого автономного округа) // Север и рынок: формирование экономического порядка. № 1 (63). С. 99–109.

Антипов С.К. (2022). Моделирование устойчивого развития арктических регионов Российской Федерации (на примере Мурманской области) // π-Economy. Т. 15. № 6. С. 146–159. DOI: 10.18721/JE.15610

Арктическое пространство в XXI веке: факторы развития, организации управления (2016) / под ред. акад. В.В. Ивантера. СПб.: Издательский дом «Наука». 1040 с.

Диденко Н.И., Скрипнюк Д.Ф. (2014). Моделирование устойчивого социально-экономического развития регионов арктического пространства РФ с использованием системы эконометрических уравнений // Стратегические приоритеты развития Российской Арктики: сборник научных трудов. Москва: ФГАУ ВПО СПбГПУ. С. 63–77.

Дмитриева Т.Е., Бурый О.В. (2019). Опорные зоны развития Российской Арктики: содержание, рейтинги и проекты // ЭКО. № 1. С. 41–59 DOI: 10.30680/ECO0131-7652-2019-1-41-59

Земсков В.В., Прасолов В.И., Худяков Д.С., Канашина А.И., Тимофеев Е.А. (2022). Оценка вклада Арктической зоны в экономическое развитие страны // Финансы: теория и практика. № 26 (2). С. 160–174. DOI: 10.26794/2587 5671-2022-26-2-160-174

Киккас К.Н. (2015). Моделирование устойчивого развития арктического региона России // МИР (Модернизация. Инновации. Развитие). Т. 6. № 4. С. 142–147. DOI: 10.18184/2079-4665.2015.6.4.142.147

Куклина Е.А. (2025). Арктическая повестка России: проекты, проблемы, цифровые решения // Управленческое консультирование. № 5. С. 170–186.

Куклина Е.А., Борщева Е.Д. (2025). Развитие форм организации туризма в КНР на основе пространственного подхода: имплементация российского опыта // Евразийская интеграция: экономика, право, политика. № 19 (1). С. 56–70. DOI: 10.22394/2073-2929-2025-01-56-70

Майкова А.А., Старченкова О.Д., Схведиани А.Е. (2025). Моделирование валового регионального продукта при помощи методов машинного обучения // Вестник Пермского университета. Серия «Экономика». Т. 20. № 4. С. 449–467. DOI: 10.17072/1994-9960-2025-4-449-467

Марача В.Г., Красникова Т.С. (2024). Опорные населенные пункты в арктической зоне России: их основные функции и содержание комплексных планов долгосрочного развития // Арктика 2035: актуальные вопросы, проблемы, решения. № 1 (17). С. 32–50.

Подкорытова Е.В. (2019). Применение метода синтетического контроля на примере особой экономической зоны «Титановая долина» // Научный альманах. Изд-во: ООО «Консалтинговая компания Юком». № 12-1 (62). С. 87–90.

Потехина Е.В., Фаминская М.В. (2019). Оценка влияния «антитабачного» закона на уровень курения в России: метод синтетического контроля // Социальная политика и социология. Т. 18. № 4 (133). С. 73–85. DOI: 10.17922/2071-3665-2019-18-4-73-85

Смиренникова Е.В., Уханова А.В., Воронина Л.В. (2019). Система моделей для прогнозирования социально-экономического развития регионов Арктической зоны Российской Федерации // Управленческое консультирование. № 12. С. 142–157. DOI: 10.22394/1726-1139-2019-12-142-157

Фаузер В.В., Смирнов А.В., Лыткина Т.С., Фаузер Г.Н. (2019). Методика определения опорных поселений российской Арктики // Экономические и социальные перемены: факты, тенденции, прогноз. Т. 12. № 5. С. 25–43. DOI: 10.15838/esc.2019.5.65.2

Хайнинен Л. (2020). Обзор арктической политики и стратегий // Арктика и Север. № 39. С. 195–202. DOI: 10.37482/issn2221-2698.2020.39.195

Экономика современной Арктики: в основе успешности эффективное взаимодействие и управление интегральными рисками (2020): монография / под научной редакцией В.А. Крюкова, Т.П. Скуфьиной, Е.А. Корчак. Апатиты: ФИЦ КНЦ РАН. 245 с. DOI: 10.37614/978.5.91137.416.7

Abadie A., Gardeazabal J. (2003). The economic costs of conflict: A case study of the Basque country. *American Economic Review*, 93, 1, 113–132. DOI: 10.1257/000282803321455188

Abadie A., Diamond A., Hainmueller J. (2010). Synthetic control methods for comparative case studies. *Journal of the American Statistical Association,* 105, 490, 493–505. DOI: 10.1198/jasa.2009.ap08746

Abadie A., Diamond A., Hainmueller J. *(2011).* Synth: An R package for synthetic control methods in comparative case studies. *Journal of Statistical Software, 42,* 13. DOI: 10.18637/jss.v042.i13

Adewale M.D., Ebem D.U., Awodele O. et al. (2024). Predicting gross domestic product using the ensemble machine learning method. *Systems and Soft Computing,* 6, Art. 200132. DOI: 10.1016/j.sasc.20 24.200132

Didenko N., Kunze K. (2014). relationship between energy policies and quality of life in Russia. *WIT Transactions on Ecology and the Environment*, 3(1), 186.

Goryunov A., Ageshina E., Lavrentev I., Peretyatko P. (2023). Estimating the effect of Russia's development policy in the Far Eastern region: The synthetic control approach. *Applied Econometrics,* 4(72), 59–73. DOI: 10.22394/1993-7601-2023-72-58-72. EDN: MZPYWQ

Greaves W. (2016) Securing sustainability: The case for critical environmental security in the Arctic. *Polar Record,* 52(6), 660–671. DOI: 10.1017/S 0032247416000218

Klößner S., Kaul A., Pfeifer G., Schieler M. (2018). Comparative politics and the synthetic control method revisited: A note on Abadie et al. (2015). *Swiss Journal of Economics and Statistics*, 154, 1. DOI: 10.1186/s41937-017-0004-9

Schach M., Madlener R. (2018). Impact of an ice-free northeast passage on LNG markets and geopolitics. *Energy Police,* 122, 433–448. DOI: https://doi.org/10.1016/j.enpol.2018.07.009

Skufina T., Baranov S., Samarina V. (2018). Differentiation of socioeconomical environment as factors of regional development (the case study of Murmansk Region, Russia). *Advanced Science Letters*, 24(9), 6329–6331. DOI: 10.1166/asl.2018.13045

Romashkina G.F, Didenko N.I., Skripnuk D.F. (2017). Socioeconomic modernization of Russia and its Arctic regions. *Studies on Russian Economic Development,* 28(1), 22–30.

Zeijl-Rozema A., Ferraguto L., Caratti P. (2011). Comparing region-specific sustainability assessments through indicator systems: Feasible or not? *Ecological Economics [Elsevier]*, 70(3), 475–486.

ИНФОРМАЦИЯ ОБ АВТОРАХ

Евгения Анатольевна Куклина – доктор экономических наук, профессор, профессор кафедры, Северо-Западный институт управления Российской академии народного хозяйства и государственной службы при Президенте Российской Федерации (Российская Федерация, 199178, г. Санкт-Петербург, Средний пр-т, д. 57/34); главный научный сотрудник, Институт проблем региональной экономики РАН (Российская Федерация, 190013, г. Санкт-Петербург, ул. Серпуховская, д. 38; e-mail: kuklina-ea@ranepa.ru)

Дарима Дамдиновна Ульзетуева – кандидат технических наук, доцент кафедры, Северо-Западный институт управления Российской академии народного хозяйства и государственной службы при Президенте Российской Федерации (Российская Федерация, 199178, г. Санкт-Петербург, Средний пр-т, д. 57/34; e-mail: ulzetueva-dd@ranepa.ru)