Comparing Models of Sustainable Development for the Arctic Region of the Russian Federation

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Abstract. This paper outlines the concept of sustainability in regard to regional development, examines basic premises of modeling regional relations in the Arctic zone of the Russian Federation, describes the principles and investigates the specifics of building models for sustainable development in regions of the Arctic. It presents methods to build a model that can fully characterize sustainable regional development in the Russian Arctic and lays out requirements for such a model and its corresponding indicators. The paper also considers possibilities for using and adapting already existing mathematical models exemplified by an autoregressive distributed lag (ADL) model and a neural network model. The authors specify under what conditions these models can fully meet all the requirements, what statistical indicators are of key importance to a numerical representation of sustainable development, what factors can be prioritized to be incorporated in the models, what limitations they have and why these very models show the most promise in terms of both analyzing the current state of affairs and making forecasts. The paper presents the results of testing the models on the basis of real statistical data gathered across the Murmansk region and compares the derived outcomes to raw conclusions from the obtained data. It also summarizes the findings from the built models and assesses the prospects for their further application in forecasting sustainable regional development and utilizing projected outcomes in making management decisions to implement the strategy for the development of the Russian Arctic regions.

1. Introduction

The fundamental principles of strategic development in the Arctic Zone of the Russian Federation [1] provide for the consolidation of the resources and efforts of the federal authorities and the authorities of the constituent entities of the Russian Federation whose territories lie wholly or partially within the Arctic Zone, local self-government authorities, and organizations addressing key challenges for development and national security in the Russian Arctic. In fact, the Strategy, developed and approved as early as 2013, aims to ensure sustainable development in Arctic regions, and one of its major aspects is to consider all municipalities collectively, as a cohesive mechanism. It is quite obvious that implementing this mechanism requires an integrated and comprehensive assessment of regional activity involving socio-economic development, advancement of science and technology, state-of-the-art information and telecommunications infrastructure development, environmental security, expansion of international cooperation, military security, national border control and security, and preservation of sovereignty.
Development of Arctic regions in particular is essentially defined by extremely challenging weather conditions, vast territories with underdeveloped infrastructure and therefore lack of workforce. Attracting experienced professionals cannot be addressed without increased funding for compensation packages. This fact is best exemplified by the relationship between two indicators reflective of science development, where the first indicator is current internal costs of research and the second one is development projects and a number of staff engaged in research and development. When the correlation between these indicators is calculated, it results in $r = 0.65$ and is distinctly indicative of a significant linear relationship. The presented histogram (fig.1) clearly exhibits the obtained regularity: a number of research staff diminishes along with a decrease in funding. It is to a large extent due to an outflow of contract researchers. The declining rate of growth in the number of staff in 2018 is accounted for by volatility in funding and precarious prospects, both of which are detrimental to improvements in permanent staff numbers.

![Figure 1. Correlation between research costs and research staff numbers in the RF Arctic zone](https://www.gks.ru)

A similar analytics is found in other sectors. The major issue is that Arctic regions are almost entirely dependent on federal funding, which in turn lessens the opportunities to implement local development strategies. Solving this issue would first require qualitatively assessing the potential for interregional engagement and then quantitatively modeling it. This approach will allow making the best use of all opportunities and mitigating risks. It will also ensure effective choices in management decision making, mostly relating to medium- and long-term development.

This paper aims to compare two most promising models of sustainable development in the Arctic regions of the Russian Federation.

2. Literature review
Sustainability is a priority trend in the present-day economy. It is no secret to anyone that traditional economic systems are completely unsustainable and, in many ways, even detrimental to our planet. Irresponsible consumption of limited resources and the global ecological state of affairs can result in a situation where future generations may experience a critical shortage of essential resources. To prevent this, the global economic system has to be well-balanced and environmentally friendly but not at the
expense of living standards. The United Nations pays special attention to this issue: it has even coined the term 'climate neutrality' and developed the Greening the Blue platform [2] which regulates global economic activities and sets out certain goals and objectives for all the member states.

Going back to the concept of sustainability, we should note that the UN distinguishes 17 fundamental goals which define the so-called Green Economy in three dimensions – economic, environmental and social. Only systematic and integrated development in each of these dimensions can ensure sustainability of resource conservation. This issue is of acute importance in neutral territories and mineral- and hydrocarbon-rich territories, especially those with challenging weather conditions. For the Russian Federation, sustainability is also considered to be the most promising way to exercise economic activity [3]. This first and foremost applies to Arctic regions. All of the above necessitates building economic-mathematical models [4].

To date, sustainability theory has been given careful consideration in the works of many researchers in the field. S. Baker describes the need for sustainable development and its quantitative assessment in her book “Sustainable Development” [4] as do R. Hoffmann and C. Park in the papers under the same title. D.S. Khaidukov and K.A. Tasalov in their papers “Osnovy obespecheniya ustoichivogo razvitiya gorodskoy aglomeratsii” [Fundamentals of sustainable development in urban agglomeration] and “Realizatsiya kontseptsiy ustoichivogo razvitiya v regionalnom upravlenii” [Implementation of the sustainability concept in regional governance] assess the potential for sustainable development from a regional perspective. In his handbook “Teoriya ustoichivogo razvitiya goroda” [Theory of urban sustainability], A.N. Gushchin investigates the issues from a city planning perspective. Extensive research has been done by Yanliang Hou, Ruixin Long, Linling Zhang, Meifen Wu in regards to sustainable development of coal-mining towns [5].

Sustainable development modeling has been examined in the works of N.I. Didenko, D.F. Skripnuk and K. N. Kikkas [6], [7]. Choosing quantitative parameters to assess regional sustainability is considered in works [7], [8], [9].

3. Analysis of international expertise in sustainable development of Arctic regions

Responsibility for the Arctic is shared by five states — the Russian Federation, the United States, Norway, Denmark, and Canada. Each of the states holds ownership over designated water and land areas with clearly defined borders and is determined to preserve the integrity of its borders, thereby maintaining the geopolitical balance as well as to maximize the development of controlled territories. The expertise of Canada is the most interesting of all since it owns almost as much land as Russia: 25% vs 40% of the total Arctic area. Direction for the development of Canadian Arctic regions is laid out in the 2009 federal report “Canada's Northern Strategy: Our North, Our Heritage, Our Future” [http://northernstrategy.gc.ca] that reflects the fundamental principles of sustainable development in Arctic regions. In terms of geographic coverage, the Canadian Arctic area is in large part represented by insular archipelagos, which adds to the challenge of infrastructure development. Overall, the principles of Canada's Northern Strategy are not very different from Russia's own even though they place stronger emphasis on socio-economic development, protection of indigenous peoples and natural resources, adaptation to climate change, healthcare and education development. Canada has established consistent and balanced funding for all industries in the regions and strives to ensure sustainable economic growth in those territories.

Denmark adheres to a similar policy. “Kingdom of Denmark Strategy for the Arctic 2011–2020” [10] published in 2011 to a great extent relies on the sustainable development of Greenland and the Faroe Islands. Taking into account this strategy and the geographic and geological structure of the areas under Denmark's control, it is safe to assume that the Kingdom will apply implementation approaches substantially different from those chosen by the Russian Federation. Denmark's Strategy also highlights the need to enhance international cooperation in the Arctic area, especially in respect to main transportation routes and resolution of disputed continental shelf ownership.
Whereas Russia and Canada prioritize domestic policy concerns and Denmark maintains a certain balance, the USA and Norway assign primary importance to foreign policy issues. In its foreign policy, Norway as a member of the Barents Euro-Arctic Council relies on furthering cooperation with the Russian Federation aimed at business development and security provision, as is notably specified in “Norway’s Arctic Strategy — between geopolitics and social development” published by the Norwegian Government in 2017 [11].

In the interim, the United States makes every effort to appropriate resources, to increase its ownership share in the Arctic, to gain greater control over the Arctic shelf, and along with it to change policies on transportation routes, especially the Northern Sea Route, all of which is clearly stated in the U.S. Arctic Policy reflected in the 2009 National Security Presidential Directive [12]. The Directive also covers prospects for cooperation with Canada in both national security and geological exploration.

Despite exercising different approaches to foreign policy, all of the above-mentioned strategies of the five countries underscore the need to ensure sustainable development in Arctic regions, which involves:

1. advancing knowledge on climate and environment;
2. improving the system of control, emergency response and maritime security in northern waters;
3. developing infrastructure and business;
4. preserving the identity and culture of indigenous peoples, ensuring their livelihoods;
5. furthering international cooperation.

4. Methods to build models of sustainable development for the Russian Arctic

It is quite obvious that conducting successful analysis and forecasting regional sustainability are both premised on establishing main indicators that specify this sustainability, identifying correlations among them and assessing factors that affect them [13], [14], [15], [16]. Then, it is possible to proceed with modeling per se – establishing a form of correlation and express this correlation as mathematical regularities [17], [18], [19]. In the preliminary phase, it is of no principle importance what kind of a model there will be produced in the end, but to have a clear understanding what it can be translated into, it is necessary to lay out certain requirement for the modeling process:

1. there has to be a possibility to adjust the model both by a number of input factors and by a number of identifiable parameters;
2. it is important that the model express numerically all specific features of sustainable development in particular regions and their correlation, which, in fact, means that the model has to be multi-level and encompass at least three major dimensions: economic, environmental and social;
3. the resulting model should be highly flexible and allow effecting forecasting even when some input data is missing;
4. human interaction is minimized, which allows preventing human faults;
5. the resulting parameters should be highly demonstrable and easy to comprehend, ensuring the simplicity of analytics for further decision-making.

From all the foregoing, it may be noted that almost none of the existing models can fully meet all the prescribed requirements. Special consideration should be given to two most promising modeling methods that can be elaborated into great mathematical apparatus to achieve the defined objectives.

To choose the optimal forecasting method, two models of sustainable development for the Murmansk region were built and compared against each other.

Distributed time-lag models are the ones most adaptable. Formally, achieving the stated objectives would require building and determining the parameters of not one individual model but of a whole family of them; some can be divided into blocks to establish systems of interrelated ADL-equations [20], [21], [22]. The preferred option would be to create a discrete system for each Arctic region, incorporating three equations that numerically describe social and economic development as well as the environmental situation in a region. Such a model is easily applicable in terms of its demonstratibility
and simply calculated parameters. Another benefit is that it allows tracing interrelations with consideration of lags, which makes it possible to identify and describe hidden regularities. Yet, this method is not without its faults, one of the most prominent of which is a need to carry out preliminary preparation of time-series data, verify the stationarity and heteroscedasticity of the series and estimate correlations among them. All of the above is time-consuming and human-error prone and thereby complicates the model-building process.

An ADL-model formulated in general terms takes the form:

\[
\begin{align*}
Y^1_t &= f(Y^1_{t-1}, Y^2_{t-1}, Y^3_{t-1}, X^1_{t-1}, X^2_{t-1}, X^m_{t-1}) \\
Y^2_t &= f(Y^1_{t-1}, Y^2_{t-1}, Y^3_{t-1}, X^1_{t-1}, X^2_{t-1}, X^m_{t-1}) \\
Y^3_t &= f(Y^1_{t-1}, Y^2_{t-1}, Y^3_{t-1}, X^1_{t-1}, X^2_{t-1}, X^m_{t-1})
\end{align*}
\]

where \(Y^1_t, Y^2_t, Y^3_t\) are key indicators for each of the considered dimensions (economic, social, and environmental) and \(X^j_t\) are factors having the most considerable impact on these indicators.

The second option is neural network-based models. Input variables essentially become the input layer. When information is propagated through its hidden layers, the neural network infers the relationships among the inputs and assigns to each of them its own value (weight), after which only those most significant are passed to the output layer including output variables (fig.2). This method has proven itself and is widely used in the big data domain, which means that it will lead to adequate results in fulfilling the defined objective [23], [24], [25]. However, there is an issue of choosing a threshold function that the neural network will employ to filter data by its significance levels. To this end, each S node holds a sumulator that estimates the threshold relying on standard functions, such as:

\[
y = F(\sum_{i=0}^{n} w_i x_i)
\]

where \(x_i\) is neuron entries; \(w_i\) is weight coefficients of synaptic neuron connections. \(x_0 = -1\), and \(w_0\) is a neuron threshold level.

![Figure 2. General principle of neural network design](image)
Figure 2 shows the general principle for designing a neural network with \( k \) hidden layers, \( n \) input and \( m \) output variables. An effective projection of sustainable development would require 2-3 hidden layers and exactly 3 output variables, one for each considered dimension. A number of input variables is limited only by a researcher's wish and opportunities in search for input statistics. As for the threshold function, it is more practical to employ a sigmoid function \( F(x) = \frac{1}{1+e^{-x}} \). It is logically simple and produces quite accurate results. It is also worth noting that neural network models share one specific feature: there is no need for a researcher to estimate correlations among time-series early on, feeding input and output variables will suffice. This is fair logic but requires some elaboration. To ensure that the model analyzes input variables and provides required outcomes, it has to be properly built and trained. This need for training may be viewed as a downside of the given method since it consumes a lot of time and requires a wide range of training data [26].

If all the layers of the neural network in Figure 2 were to be considered as one block, the contents of training could be visually represented by the three interconnected blocks (fig.3). As the neural network has generated input variables, their values get to the error block, where the results obtained are compared with the results required; if they misalign or lack accuracy, they are sent to the training block which adjusts the work of the network itself, and the computational process is repeated until the outcome meets all the established criteria.

![Figure 3. Neural network training principle](image)

The aforementioned relative disadvantage is balanced out by significant advantages: the model can be built quickly and feature any predetermined number of hidden layers and input variables; it is scalable and allows for the possibility of almost indefinite data expansion.

5. Data
The built models of sustainable development were tested in the Murmansk region, where statistics was collected on indicators that characterize the economic, social, and environmental dimensions for the period of 30 years, from 1988 to 2018.

The economic dimension is assessed by the following indicators:

- Gross Regional Product
The social dimension is assessed by the following indicators:

- Human Development Index
- Number of hospitals and healthcare facilities for adults
- Number of hospitals and healthcare facilities for children
- Number of leisure centers per 1,000 people
- Number of schools and secondary-level educational establishments
- Number of secondary and higher vocational educational establishments
- Number of higher education institutions
- Development rate of traffic network as a percentage of the total number of territories
- Number of railways stations and airports
- Number of mobile telesystem users
- Number of Internet users.

The environmental dimension is assessed by the following indicators:

- Rate of CO2 emissions
- Atmospheric pollution
- Drinking-water pollution level
- Pollution level of drinking and recreational water resources
- Level of soil pollution in residential areas
- Percentage change in geological environment
- Percentage change in infant mortality
- Percentage in birth defects
- Average life expectancy
- Percentage change in morbidity
- Proportion of cancerous diseases
- Proportion of industrial enterprises to their total number
- Effective radiation dose
- Land-surface deformations
- Percentage of biodiversity loss.

The collected statistical data in the form of time series was tested for stationarity. In cases of non-stationarity, it was further tested for heteroscedasticity. To build a distributed lag model, the correlation and autocorrelation were assessed. The neural network was built with three hidden layers and trained for 100 iterations.

6. Results

Building an ADL-model resulted in the following system of interrelated equations with corresponding parameters:
\[
\begin{align*}
\{y_1^t &= f(0.98y_1^{t-1} + 0.23x_1^{t-5} + 0.45y_2^{t-1} - 0.87x_1^{t-1} + 0.69y_2^{t-1} + 0.85x_1^{t-1} - 0.25y_1^{t-1} + 0.11x_2^t) \\
y_2^t &= f(0.66y_1^t + 0.39y_2^{t-1} - 0.02x_2^t + 0.12y_2^{t-1}) \\
y_3^t &= f(0.79x_1^{t-1} + 0.58x_2^t + 0.36x_1^t + 0.55x_1^t + 0.88x_3^t - 0.24y_2^{t-1} + 0.67x_4^{t-5})
\end{align*}
\]

The resulting model was used to make forecasts for the years 2019 and 2020. The 2019 projection was made intentionally to compare it with actual data and analyze misalignments. The quality of forecasting was estimated using the MAPE method with a result of 9.8%, which is quite acceptable when building a linear model.

After training, the neural network model identified correlations automatically, but the results happened to be similar to those of the ADL-model. The results of weight distribution were also formulated into a system:

\[
\begin{align*}
\{y_1^t &= f(0.96y_1^{t-1} + 0.45x_1^{t-5} + 0.40y_2^{t-1} - 0.88x_1^{t-1} + 0.66y_3^{t-1} + 0.89x_1^{t-1} - 0.25y_1^{t-1} - 0.11x_3^t) \\
y_2^t &= f(0.506y_1^t + 0.33y_2^{t-1} - 0.08x_2^t + 0.12y_2^{t-1}) \\
y_3^t &= f(0.29x_1^{t-1} + 0.59x_2^t + 0.41x_1^t + 0.75x_1^t + 0.80x_3^t - 0.25y_1^{t-1} + 0.66x_4^{t-5})
\end{align*}
\]

The quality of forecasting amounted to 8.6%, which is better that that demonstrated by the ADL-model. Overall, the consistency of the obtained results proves the comparable precision of the suggested models, and therefore indicates the possibility for using both of them in projecting sustainable development.

7. Conclusion

Today, when the global economic system is highly unstable, it is imperative to ensure development of the domestic economy, and it is absolutely essential that this development be orderly, sustainable, and “projectable”. Only this will allow avoiding negative effects of adverse external factors. As technologies advance, it is becoming increasingly clear that adequate and accurate forecasting is not feasible without utilizing modern prognostic methods and innovative tools. Choosing effectively and building models of sustainable development constitute a fundamental premise for good management decision-making at the municipal, regional and federal levels. It is commonly recognized that particular consideration should be given to promoting the development of lagging regions, including those of the Russian Arctic. These preconditions determine the relevance of this study and provide a basis for further elaborating on the discussed issue. In the course of this research, the authors achieved the following results:

1) analyzing the key aspects of sustainable regional development;
2) investigating distinctive features of sustainable development in Far Northern regions;
3) examining country-specific approaches to implementing strategies for sustainable development in regions with similar climatic conditions;
4) describing most important groups of factors that characterize sustainable development and proposing methods to choose specific indicators;
5) considering and describing two options, two mathematical models most suitable for forecasting sustainable regional development;
6) introducing mathematically substantiated proposals for ensuring sustainable development in Arctic regions.

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