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ASSESSMENT OF THE ECO-EFFICIENCY OF THE DEVELOPMENT OF THE REGIONS OF NORTH ASIA BASED ON IMPACT DECOUPLING

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Abstract: In modern conditions, the problem of preserving the natural environment in implementing economic growth is becoming increasingly acute. The need to balance these development vectors determines the relevance of developing methods for assessing the contingency of economic growth and environmental impact. In this paper, we propose a methodology for assessing the eco-efficiency of regional economic development. A systematic approach was developed based on impact decoupling using the Data Envelopment Analysis (DEA) method. Calculations were made based on data from 25 Russian regions located in North Asia. The results obtained indicate a high inter-regional differentiation of this indicator. Based on the dynamics of indicators, the regions were grouped in the direction of the ecological and economic development trend.

Keywords: Sustainability, eco-efficiency, impact decoupling, Data Envelopment Analysis, North Asia.

Introduction

At the present stage of development, society is faced with a dilemma of choice between the continuation of extensive economic growth and the need to preserve the natural environment. The need for a transition to sustainable development, put forward in 1992 at the Second International Conference of the United Nations on Environment and Development in Rio de Janeiro, is now recognised throughout the world and is reflected in the strategies of most countries (UN, 1992; OECD, 2009; European Commission, 2019).

Most of the goals and objectives of sustainable development have been included in the strategic and program documents of the Russian Federation (The Accounts Chamber of the Russian Federation, 2020; Analytical Center for the Government of the Russian Federation, 2020). Under these conditions, the assessment of socio-economic development's conformity with sustainable development principles acquires special significance.

One of the first indicators developed in this area was the system of sustainable development indicators of the UN Commission on Sustainable Development, calculated since 1996 (UNSD, 2020). By now, almost all major international organisations-the UN, the World Bank, the OECD, and the EU-have their systems of sustainable development indicators (Eurostat, 2022; The World Bank Group, 2022; OECD, 2022). At the same time, it should be noted that the assessment using a system of indicators has several disadvantages: A significant number of indicators that often show conflicting trends and a lack of a clear relationship between indicators. To correct these shortcomings in the assessment, reduced indicator systems are being developed more often. For example, the list of more than 130 UN sustainable development indicators has been reduced by more than two times (UNSD, 2007).

The most promising, in our opinion, is the approach to building an assessment methodology based on an integral indicator, which makes it possible to judge the degree of stability of the territory and the environmental friendliness of its development trajectory. Since the 1990s many methodological approaches have been developed to assess sustainability based on integral indicators, such as the index of sustainable economic well-being (Sanches *et al.*, 2020; Zhu *et al.*, 2020), true savings rate (Bazhanov, 2022), society sustainability index (Witulski *et al.*, 2020), Ecological Footprint (Thornbush, 2021), Inclusive Development Index (Kurniawan *et al.*, 2021). It is especially worth highlighting the concept of "environment carrying capacity" as a great concern of research interest. This approach is often used for more sustainable spatial management, especially in residential development (Świąder *et al.*, 2020).

Increasingly, researchers are using the eco-efficiency indicator as an integral indicator of compliance with the principles of sustainable development. This term was proposed in 1989 by S. Schaltegger and A. Sturm and was defined by them as the ratio of economic value added to added environmental impact (Schaltegger & Sturm, 1989).

Eco-efficiency reflects the relationship between environmental impact and economic value. The fundamental challenge of development is how to continue the economic growth required to improve the quality of life and meet the basic needs of its inhabitants while reducing the pressure on environmental carrying capacity. The eco-efficiency assessment is based on the concept of decoupling. OECD identifies decoupling environmental pressures from economic growth in its Environmental Strategy for the First Decade of the 21st Century as one of its five goals in sustainable development. "Decoupling" occurs when a given form of the environment grows more slowly than the driving force (economic activity, population growth or other measures of human activity) over time. Incorporating eco-efficiency concepts into development planning and policymaking is critical to ensuring that the heaviest pressures on the environment are alleviated and that this happens on a large enough scale to ensure that the heaviest environmental pressures are relieved and that takes place on a broad enough scale to ensure that growth does not exceed environmental carrying capacity.

Subsequently, this concept was recognised by the World Business Council for Sustainable Development, the European Environment Agency, the UN and many other international organisations. In our work, we adhere to the formulation of this OECD concept: "the efficiency with which environmental resources are used to meet human needs" (OECD, 1998). Eco-efficiency has been adopted by ESCAP "as a key element in promoting fundamental changes in how societies produce and consume resources" and has been identified as the main indicator for measuring progress in green growth (UN. ESCAP, 2009).

In recent years, the analysis method of the functioning environment Data Envelopment Analysis (DEA) has become widespread in assessing the eco-efficiency of economic development. This method is based on the use of classical linear programming tools. The essence of the method is to build an effective boundary against which the efficiency of the analysed objects is measured. Under the DEA method, efficiency is understood as the ratio of the weighted sum of output parameters (obtained results) to the weighted sum of input parameters (resources used).

This article aimed to expand the methodology for studying regional eco-efficiency by analysing the operating environment, using the example of the Russian regions of North Asia.

Materials and Methods

The development of DEA dates back to 1978, when A. Charnes, V. V. Cooper, and E. Rhodes (Charnes *et al.*, 1978), based on the developments of M.J. Farrell (Farrell, 1957) first proposed it. This method was first used for analysis at the microeconomics level. (Charnes, 1989; Barr *et al.*, 1993; Athanassopoulos, 1995), but later, the scope of its application has expanded significantly, and it is currently used both in the practice of macroeconomic analysis and to assess the eco-efficiency of the economic development of regions and countries (Moutinho *et al.*, 2020; Bianchi *et al.*, 2020; Xiao *et al.*, 2021; Kiani Mavi & Kiani Mavi, 2021; Puertas & Marti, 2021). It should be noted that the use of this method in Russia to assess the environmental efficiency of regions has not yet become widespread. S.V. Ratner was one of the first in Russia to use this method to solve the problem of assessing the eco-efficiency of regions (Ratner, 2017). He monitored the ecological and economic efficiency of the economic activity of regional economic systems on the example of the regions of the Central Federal District of the Russian Federation using the Charnes-Cooper-Rhodes model (CCR model) with input orientation, aimed at minimising the input parameters, while the output parameters may either remain at the original level or increase. The CCR model belongs to the radial type of DEA models, which, in the process of determining the effectiveness, proportionally reduce the number of inputs and outputs, and according to some researchers, this model can be used in cases where there are proportional changes in the inputs or outputs of the model (Tone, 2017). Another model often used in DEA is the radial Banker-Charnes-Cooper model (BCC model), which, unlike the CCR model, considers the variable scale effect but, like the previous one, does not distinguish between desirable and undesirable outputs/ inputs (Lissitsa & Babieceva, 2003). Unlike radial models, non-radial models such as the slacks-based measure model (SBM model) do not process proportional changes in inputs or outputs but specific values for each input or output (Tone, 2001). According to researchers, this model is the most adequate for measuring efficiency when input and output data change disproportionately (Chen *et al.*, 2021; Du *et al.*, 2021; Zhang & Chen, 2022).

Based on the analysis of methodological approaches to assessing the eco-efficiency of regional development, two approaches to selecting indicators as input and output variables of the DEA model were identified.

One approach to selection is based on the traditional representation of the production function, in which the main factors of production from an economic point of view are land, labour and capital. Indicators characterising the consumption of these resources are used as input variables, and as an output, the gross domestic or regional product is considered as a desirable output, and environmental pollution indicators as undesirable (Golany & Roll, 1989; Scheel, 2001; Demiral & Saglam, 2021).

Another approach is guided by the effect of impact decoupling as a basis for selection. Impact decoupling is a mismatch between economic growth and negative environmental impacts (UNEP, 2011). Within the framework of this approach, environmental impact indicators are used as input variables of the model, and indicators characterising economic growth are used as output variables (Tyteca, 1997; Zhang *et al.*, 2008; Yin *et al.*, 2011; 2014; Egilmez *et al.*, 2013; Liu *et al.*, 2016; Guo & Xu, 2016; Ratner, 2017; Bobylev *et al.*, 2019; Zemtsov *et al.*, 2020). For example, in a study analysing the eco-efficiency of industry in the six central provinces of China, the authors considered the volume of wastewater discharges, emissions and energy consumption as input variables and the value added of the industry as the output variable (Guo & Xu, 2016).

In our opinion, the second approach most accurately reflects the principles of sustainable development as maintaining the balance of two vectors of regional development: Economic growth and environmental conservation (Lubsanova *et al.*, 2022). When developing the assessment methodology, this approach to selecting indicators was used.

A DEA-based methodological approach was developed using an undirected SBM model to assess the eco-efficiency of regional development. The SBM is a performance calculation model based on remaining reserves (slacks).

The efficiency of each of the objects (regions) is evaluated, each of which o_j, $j = \overline{(1, n)}$ is described by two vectors (x_j, y_j). The vector $x_j = (x_{1j}, \ldots, x_{mj}) > 0$ is a vector of m input variables for j the -th object. Vector $y_j = (y_{1j}, \ldots, y_{sj}) > 0$– vector s of output variables for j the -th object. The dimension $m * n$ matrix $X = x_j$

contains the input data for all *n* objects, and the $Y = y_j$ dimension matrix $s * n$ contains the output data for all *n* objects. The SBM model is formulated as

$$\min \rho = \frac{1-(1/m)\sum_{i=1}^{m} s_i^- / x_{i0}}{1+(1/s)\sum_{r=1}^{s} s_r^+ / y_{r0}} \quad (1)$$

s.t.

$$x_0 = X\lambda + s^-$$

$$y_0 = Y\lambda + s^+$$

$$\lambda \geq 0, s^- \geq 0, s^+ \geq 0$$

where s^- , s^+ are reserves and represent the cost surplus (input variables) and the output deficit (output variables), respectively.

ρ - a measure of the efficiency of the *j*- th object, while $\rho \in (0; 1]$;

λ - the degree of similarity of the -th object to other objects of the studied population in terms of the ratios of the values of the variables.

The problem is solved for each object, i.e. n times. An object (region) is effective if the following condition is met: $\rho = 1$.

Following the recommendations in the field of measuring the effect of decoupling (European Commission *et al.*, 2014), the input variables are indicators of the impact "pressure" on the environment, and the output variables are indicators of the "driving force" that leads to the above impact, that is, reflecting macroeconomic aggregates (in particular, the volume of GRP and the number of permanent population). As input variables, we determined indicators characterising the consumption of natural capital and ecosystem services as output variables-the gross regional product and the number of resident populations, which allows us to consider the environmental, economic and social aspects of regional development in the model (Figure 1). The indicators were chosen due to their fundamental importance and the availability of sufficient data for evaluation.

As noted in many studies on the assessment of eco-efficiency based on DEA, similar indicators of environmental impact, as well as indicators of "driving force" are widely used to determine the eco-efficiency and sustainability

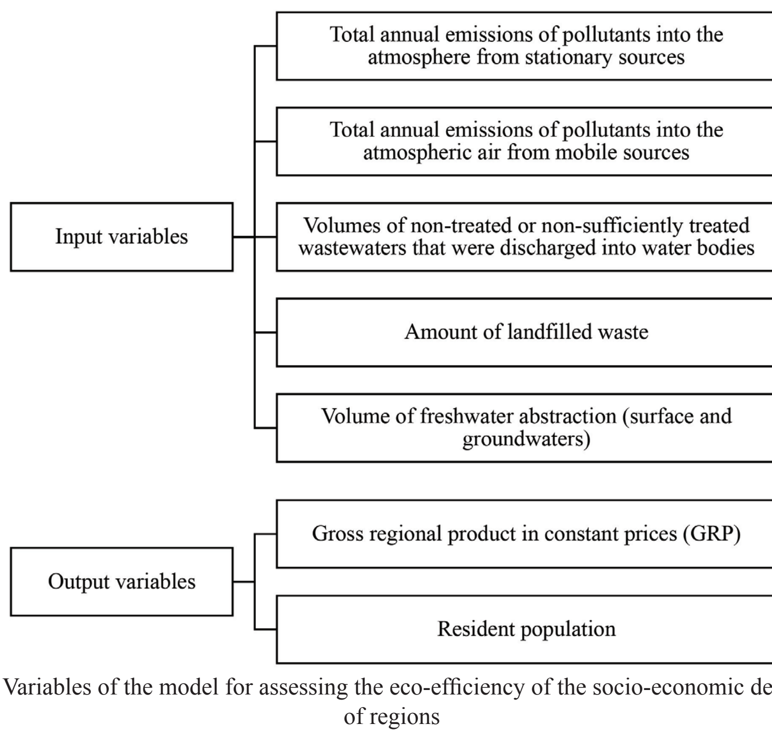

Figure 1: Variables of the model for assessing the eco-efficiency of the socio-economic development of regions

of development (Golany & Roll, 1989; Tyteca D., 1997; Scheel, 2001; Zhang *et al.*, 2008; Egilmez *et al.*, 2013; Guo & Xu, 2016; Ratner, 2017; Demiral & Sağlam, 2021). It should be noted that the environmental impact indicators methodologically in the DEA refer to undesirable outputs. But, if radial models are used for estimation, they are often referred to as inputs to avoid model limitations. In our study, through the use of a non-radial SBM model, we were able to attribute these impact indicators (discharges, emissions, and waste) to negative outputs and the "driving force" indicators (in particular, GRP and resident population) to inputs, which corresponds to a meaningful understanding eco-efficiency as ensuring the increasing effect of the scale of the growth of the economy and population, exceeding the development of the negative environmental impact.

The choice of the object for testing the methodology was due to the growing importance of the macro-region of North Asia in modern transregional and international interactions in the context of the intensification of economic and political cooperation between Russia and the countries of Central Asia and the Asia-Pacific region. The North Asia macro-region includes 25 Russian areas, within 3 Federal Districts: Ural, Siberian, and the Far Eastern. Calculations were made to assess the eco-efficiency of the socio-economic development of 25 Russian regions located in North Asia. For the calculations, the open-source DEA (OSDEA) package was used; the open data of the Federal State Statistics Service and the Ministry of Natural Resources and Ecology of the Russian Federation were used as data sources.

Results and Discussion

The results of the assessment of the environmental efficiency of the socio-economic development of North Asian regions for 2010-2019 are presented in Figure 2 and Table 1. A value equal to 1 indicates that the development of the area can be considered environmentally efficient. In this case, the relative increase in output parameters (GRP and population) is greater than the relative increase in negative environmental effects produced due to economic and population growth. A value less than 1 means that the growth rate of the economy and population is lower than the rate of increase in the negative environmental impact.

The results show eco-efficiency (value greater than 1) from 2010-2019 are consistently characterised as regions with large agglomerations and a relatively diversified economy, such as the Sakhalin region, and regions with highly efficient extractive industries, such as the Tyumen region. At the same time, certain regions characterised by a high share of agriculture and the public sector are also effective: The Republic of Altai and the Republic of Tyva. The number of eco-efficient regions decreased from 9 in 2010 to 8 in 2019.

The lowest values of the level of eco-efficiency were determined mainly in the regions specialising in the mining and metallurgical industries and characterised by high specific

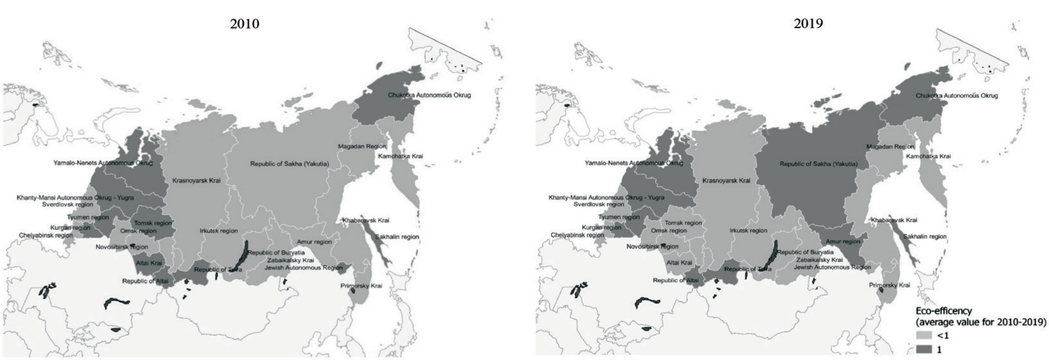

Figure 2: Eco-efficiency of socio-economic development of the regions of North Asia from 2010-2019

Table 1: Eco-efficiency of socio-economic development of the regions of North Asia from 2010-2019

Regions	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Average Value for 2010-2019
Altai Krai	1.000	0.661	0.661	1.000	1.000	1.000	1.000	0.754	0.711	0.340	0.813
Amur region	0.503	0.507	0.507	0.450	0.596	0.505	0.631	0.562	0.700	1.000	0.596
Jewish Autonomous region	1.000	1.000	1.000	0.540	0.488	0.446	1.000	1.000	1.000	0.783	0.826
Zabaikalsky Krai	0.315	0.320	0.320	0.391	0.402	0.325	0.353	0.328	0.337	0.414	0.351
Irkutsk region	0.253	0.237	0.237	0.227	0.472	0.327	0.338	0.551	0.356	0.370	0.337
Kamchatka Krai	0.535	0.563	0.563	0.414	1.000	0.469	0.563	0.413	0.414	0.224	0.516
Kemerovo region	0.267	0.258	0.258	0.253	0.266	0.203	0.205	0.212	0.196	0.215	0.233
Krasnoyarsk Krai	0.288	0.292	0.292	0.274	0.539	0.298	0.332	0.384	0.412	0.244	0.335
Kurgan region	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.776	1.000	0.978
Magadan region	0.307	0.305	0.305	0.311	0.310	0.303	0.287	0.297	0.279	0.110	0.281
Novosibirsk region	0.745	0.770	0.770	0.626	1.000	0.543	1.000	0.553	0.557	0.572	0.714
Omsk region	0.622	0.537	0.537	0.602	0.723	0.529	0.684	1.000	1.000	0.668	0.690
Primorsky Krai	0.355	0.379	0.379	0.377	0.395	0.313	0.333	0.400	0.428	0.419	0.378
Republic of Altai	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Republic of Buryatia	0.399	0.362	0.362	0.317	0.268	0.223	0.241	0.257	0.250	0.263	0.294
Republic of Sakha (Yakutia)	0.613	0.506	0.506	0.552	1.000	1.000	1.000	1.000	0.477	1.000	0.765
Republic of Tuva	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Republic of Khakassia	0.379	0.423	0.423	0.479	0.467	0.428	0.461	0.446	0.319	0.467	0.429
Sakhalin region	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Sverdlovsk region	0.313	0.364	0.364	0.317	0.340	0.309	0.338	0.383	0.435	0.468	0.363
Tomsk region	1.000	1.000	1.000	0.815	1.000	0.610	1.000	1.000	0.845	0.370	0.864
Tyumen region[1]	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Khabarovsk Krai	0.569	0.518	0.518	0.572	0.461	0.419	0.417	0.477	0.456	0.380	0.479
Chelyabinsk region	0.288	0.328	0.328	0.384	0.392	0.281	0.307	0.358	0.343	0.460	0.347
Chukotka Autonomous Okrug	1.000	1.000	1.000	1.000	1.000	1.000	0.519	1.000	1.000	1.000	0.952

*Data presented for Tyumen Oblast together with Khanty-Mansi Autonomous Okrug - Yugra and Yamalo-Nenets Autonomous Okrug emissions and energy consumption: Magadan Region (0.110 in 2019), Kemerovo Region (0.215), and Krasnoyarsk Krai (0.244).

In general, for the regions of North Asia for the period 2010-2019 there is a decrease in the level of eco-efficiency of socio-economic development. The interregional differentiation of this indicator for the period under review remained high, and an unstable increase in the coefficient of variation was observed (Figure 3).

Our results are generally similar to the estimates of researchers from RANEPA (Zemtsov *et al.*, 2020). They also note that low eco-efficiency is typical for regions with energy-intensive and low-tech industries-the Kemerovo and Krasnoyarsk regions. At the same time, there are discrepancies regarding assessments of eco-efficient regions; these authors include the Sverdlovsk and Omsk regions. It is worth noting that previous studies of the eco-efficiency of Russian regions were carried out based on radial models, but in our study, a non-radial SBM model was used, which is the most adequate for measuring efficiency when input and output data can change disproportionately (Chen *et al.*, 2021; Du *et al.*, 2021; Zhang & Chen, 2022).

The largest decrease in the eco-efficiency index occurred in Altai Krai (from 1 in 2010 to 0.340 in 2019) and Tomsk region (from 1 to 0.370) due to increased environmental impact indicators. In the Altai Krai, the main impact was the emissions of pollutants into the atmosphere from road transport from 224.7 thousand tonnes in 2010 to 302.6 thousand tonnes in 2019. In the Tomsk region, there has been an increase in the volume of untreated and insufficiently treated wastewater discharged into surface sources from 14.22 million m^3 in 2010 to 180.67 million m^3 in 2019 (On the State and Protection..., 2020).

To determine the trend of the ecological and economic development of the regions, an assessment was made of the dynamics of eco-efficiency and economic development according to the data for 2010-2019. The growth rate of gross regional product per capita in constant prices (2010) indicated economic development. Based on the results, four groups were identified in the direction of the trend of the ecological and economic development of the regions (Figure 4):

- Sustainable direction (I) - there is a positive trend in both economic development and eco-efficiency regions;

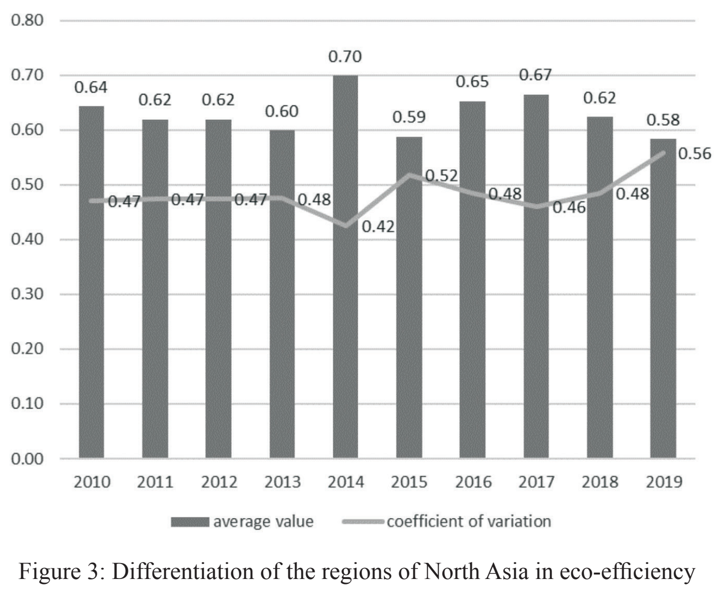

Figure 3: Differentiation of the regions of North Asia in eco-efficiency

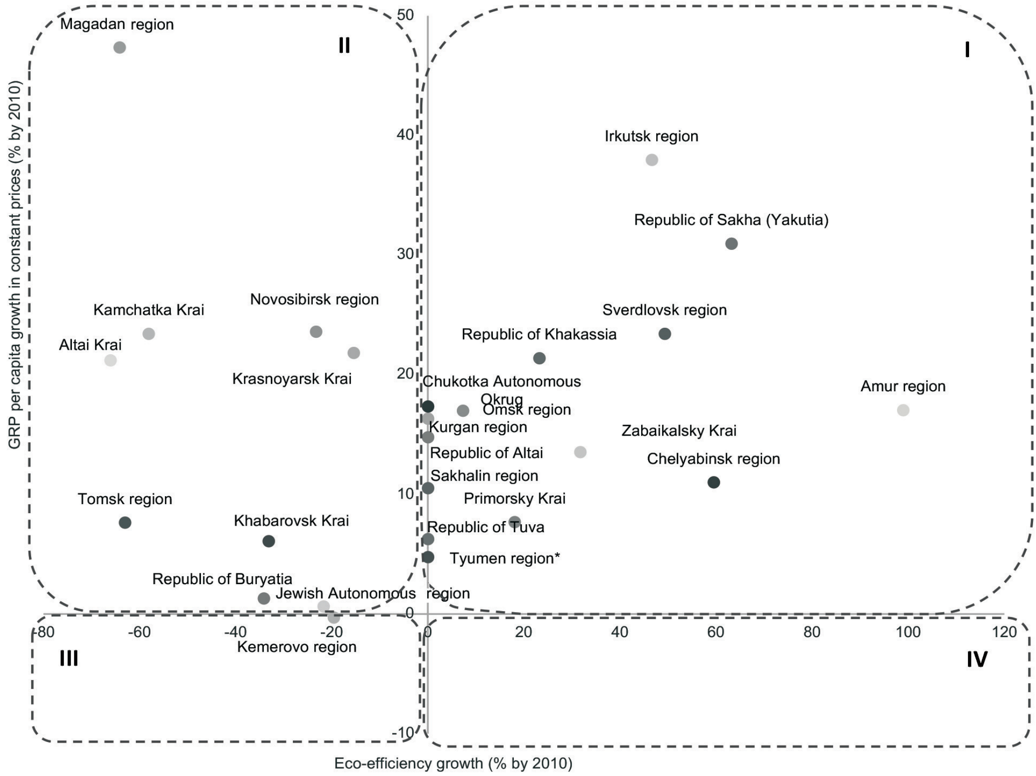

Figure 4: Groups of the regions of North Asia in the direction of the trend of ecological and economic development (according to data from 2010-2019)

- Positive dynamics of economic development characterise extensive direction (II), but negative dynamics of eco-efficiency, i.e. the extensive nature of economic development;
- Depressive direction (III) - in this group, there is both a decrease in economic growth rates and eco-efficiency;
- Economic degradation (IV) is a decrease in economic growth with increased eco-efficiency.

Group I included 15 out of 25 regions of North Asia: Republics of Sakha (Yakutia), Khakassia, Tyva, Altai, regions Irkutsk, Sverdlovsk, Amur, Omsk, Chelyabinsk, Kurgan, Sakhalin, Tyumen, Primorsky, Zabaikalsky Krai, and Chukotka Autonomous Okrug. These regions are characterised by economic growth, the largest increase was noted in the Amur region (17%). At the same time, the eco-efficiency of the regions included in this group was marked by a positive increase or remained at the same level, indicating a sustainable direction of the environmental and economic development trend. Group II, which included nine regions: Republic of Buryatia, Magadan, Novosibirsk, Tomsk regions, Kamchatka, Altai, Krasnoyarsk, Khabarovsk Krai, and Jewish Autonomous Region was characterised by growth in economic indicators, but a decrease in the level of eco-efficiency. The increase in the negative environmental impact on the environment exceeds the growth of the economy, i.e. the development of these regions is extensive. Thus, the increase in the gross regional product of the Altai Krai amounted to 21.2%, while eco-efficiency fell from 1 in 2010 to 0.340 in 2019. Only the Kemerovo region is included in group III, the ecological and economic development indicators, which indicate a decrease in both economic and eco-efficiency indicators.

Limitations of the Research

The proposed study concludes the current state of the environmental trajectory of the socio-economic development of the regions of North Asia, but during the analysis, related questions arise about the quality of regional management and the effectiveness of government mechanisms that ensure the "greening" of regional development. In the future, we intend to expand the approach by including this aspect in the methodology.

It is also worth noting that the model used mainly considers the economic and environmental aspects of sustainability, and although the social aspect is present in the form of population, we would like to highlight the social dimension of sustainability in subsequent studies, including indicators reflecting the equality in the distribution of economic benefits, the priorities of the younger generation, etc.

The method was tested on the example of only the Russian part of North Asia; therefore, the study may lack some generalisation regarding the applicability of the results to other countries. In continuation of the study, it is planned to add to the study not only the Russian regions of North Asia but also the regions of Mongolia, Kazakhstan and China.

Despite these limitations and shortcomings, in our opinion, the methodological approaches and conclusions this study offers have scientific novelty and can be used by various stakeholders for application in public administration and by researchers in future developments.

Conclusions

For the 10 years 2010-2019 practically in all regions of North Asia, economic growth was observed, based both on the development of extractive industries and the development of industrial potential, agriculture, and the non-manufacturing sector. Many regions with high economic rates were able to maintain a stable development trend, mainly regions with a relatively diversified economy: Sverdlovsk, Chelyabinsk, Irkutsk, and Sakhalin regions; but also some areas with highly efficient extractive industries: Tyumen region, Republic of Sakha (Yakutia) and some poorly specialised regions: Republic of Altai, Republic of Tyva.

The proposed methodology evaluates the dynamics of the socio-economic development of regions in terms of implementing the sustainable development paradigm, balanced economic, demographic development, and environmental efficiency. The use of the method of analysis of the functioning environment makes it possible to evaluate eco-efficiency according to all criteria that affect the system as a whole based on an integral indicator that considers many different input and output parameters. In our opinion, the use of an unoriented SBM model, aimed at both minimising input and maximising output parameters, most adequately reflects the socioecological and economic dependencies of the regional economy.

The economic consequences of the pandemic and Western sanctions increase the likelihood of a change in the trend of the ecological and economic development of the regions to a depressive one, combining a contraction in the economy with a decrease in environmental efficiency, which was already observed after the introduction of the first sanctions in 2014.

At the same time, it should be noted that, although the eco-efficiency of the socio-economic development of regions largely depends on objective factors determined by the natural and geographical position, the current structure of the economy, but to a large extent it can be adjusted by state policy measures in the field of creating resource incentives. and energy saving, reducing the negative impact on the environment. As noted by many researchers, the introduction of resource-saving technologies, in addition to environmental effects, also contributes to an increase in the productivity and competitiveness of regions. In these conditions of the growing role of the state, new opportunities are created to increase the eco-efficiency of the regional economy and structural transformation from a raw-material type to a green economy.

The proposed approach to evaluating eco-efficiency using the analysis of the operating environment can become a tool for measuring the degree of sustainability and environmental friendliness of economic development. The results and conclusions obtained can be used to make managerial decisions in the regional ecological and economic development field.

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Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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