PRINCIPAL COMPONENTS APPROACH TO ESTIMATION OF ENVIRONMENTAL RESPONSIBILITY OF RUSSIAN REGIONS

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Abstract

The research reflects complex approach to assessment of Russian regional environmental sustainability. For each of 85 Russian region the index of environmental responsibility is calculated on the basis of generalized modified principal component analysis. The approach allows to avoid any expert assessments in construction of the rating. All data for calculation for the indicators are from official statistics. The rating takes into consideration 18 environmental indicators. The indicators are grouped into 3 subsets (pillars), that reflect definite attributes of environmental performance of a region. The decomposition of the aggregate index allows to trace the impact of these three groups of partial indicators on the environmental impact of the region. The research lays the foundation for regular analysis of the environmental factors of economic development and its dynamics in the regions of the Russian Federation. The rating is designed to meet the existing lack of appropriate indicator, assessing current state and potential of environmental responsibility of Russian regions, and can serve to improve regional ecological and economic policy.

Key words: principal components analysis, environmental impact, regional sustainability

JEL Code: C38, Q51, R11

Introduction and literature review

In accordance with the United Nations Rio Declaration on Environment and Development, the development and environmental needs of present and future generations should be met equitably. At the national level, everyone should have appropriate access to public information relating to the environment, in particular concerning hazardous materials and activities in the communities, and the opportunity to participate in decision-making processes. In accordance with the Constitution of the Russian Federation, the personal rights to a healthy and productive life in harmony with nature is the matter of primary cincern.

Thus, environmental protection should be an inevitable part of the development process and cannot be considered in isolation from it. Economic development should be implemented so as to

ensure that the needs of present and future generations are met together and the environment is preserved to the full extent.

By construction of the rating we make an attempt to reflect the current state of environmental management in the constituent entities of the Russian Federation. It is based on available data on environmentally significant development factors. In essence, the setup of the regional environmental index can be considered in a tight connection with the objectives and aggregate indicators of sustainable development.

In Russia there is a plenty of ratings that take into account primarily or exclusively environmental aspect of spatial development (see tab. 1). We can pay attention to the Environmental rating of regions of Russian Federation, quarterly composed by Russian public organization "Green patrol" and Ministry of natural resources and environment of the Russian Federation (http://greenpatrol.ru). The aim of this project is to implement public monitoring and comparative assessment of Russian regions in environmental sphere. The importance of each ecological event is estimated by an expert group. The jury assigns grades to events in ecosphere, technosphere and social sphere. Depending on a character of an event, values +1/-1 are given to a certain indicator or several indicators (where +1 is a positive and -1 – a negative assessment). Finally, the percentage of positive and negative judgements is estimated. The indices of the 85 regions being put together constitute the Environmental rating of Russian regions.

Tab. 1. Environmental Ratings in Russia

Rating	***Source***	***Origin***	***Features***
Environmental rating of regions of the Russian Federation	Public organization "Green Patrol"	Since 2008	Considers exclusively ecological aspect of spatial development
Ecological rating of regions and cities of Russia	Geographic faculty of Lomonosov Moscow State University	Since 1990	One of the oldest ecological ratings in Russia
Rating of economic and social situation of Russian territories	RIA Rating	Since 2011	Evaluates spatial development by the set of social and economic indicators
The quality of life rating of regions of the Russian Federation	RIA Rating	Since 2013	
Environmental, social and economic index of regions of the Russian Federation	Bobylev S.N., Minakov V.S., Solovyova S.V. and Tretyakov V.V.	2012	Uses adjusted net savings as an aggregate indicator of ecological sustainability

Source: composed by the authors based on: Environmental-ecological index of Russian regions. Methods and indicators, 2012 (https://wwf.ru/upload/iblock/dc8/index.pdf).

An important attempt in assessment of sustainable development of Russian regions was undertaken in 2012 when RIA and WWF released the Environmental, social and economic index of regions of the Russian Federation. The authors of the methodology (Bobylev et al, 2011) used the

World Bank's Adjusted Net Savings Index as an integral indicator that takes into account the environmental sustainability of Russia's regions in a broad context, including environmental, economic and social factors. Adjusted net savings show the need to compensate for the depletion of natural capital through increased investment in human and physical capital, a radical increase in energy efficiency, and increased savings in the funds of future generations. This index has revealed a number of patterns of development of Russian regions taking into account their economic orientation. The regions with the highest index belong to the group of agrarian regions. As a rule, these regions have a low level of economic development, but law harmful emissions into the environment. Also these regions have the largest areas of specially protected natural zones. Conversely, low index values are observed in regions where the economy is characterized by a significant share of the extractive sector. Also these regions are primarily the most important source of federal budget revenues.

As for international practices there exists a vast number of approaches to evaluation of environmental performance and regional policy. T. Beaussier, S. Caurla, V. Bellon-Maurel, and E. Loiseau analyze and compare the most promising methods of economic and environmental policies assessment (Beaussier et al, 2019).

The methodology of our research is based on principal component analysis (PCA), which is widely used in multidimensional statistics including environmental issues. For example, one can mention the research of Ff. Tan and Zh. Lu who applied PCA-VAR model to perform a qualitative and quantitative analysis of relations among society, economy and environment subsystems, and provide propositions for the future scenarios of regional development (Tan and Lu, 2015). Y.N. Gavrilets, M.V. Chernenkov and S.A. Nikitin use principal component analysis and data from sociological surveys as well as from official statistics for 47 Russian territories to calculate aggregate indices, that characterize the correspondence between regional economic growth and levels of population satisfaction and concern (Gavrilets, Chernenkov and Nikitin, 2019). T. Zhgun analyzes trends and quantitative characteristics of social dynamics on the basis of principal components analysis. Her algorithm is based not on the classical PCA, where information capacity of the calculated integral characteristic is set a priori, but on a variance criteria and the selected signal-to-noise ratio that characterize data variability (Zhgun, 2017). A.-I. Petrişor, I. Ianoş, D. Iurea and M.-N. Văidianu use principal components approach in conjunction with GIS modelling to build hierarchies of the adminstrative units and to identify 'hotspots', e.g. underdeveloped regions (Petrişor et al, 2012). Y. He, Y. Pang, Q. Zhang, Z. Jiao and Q. Chen constructe a comprehensive evaluation index for the level of clean energy development by considering policies, energy supply and consumption, environmental impact and other factors, carried out the correlation cluster analysis of

the index and use the rough set method to assign the weight of the principal components (He et al, 2018). J.T. Finley, A.O. Verenikin and A.Y. Verenikina use the modified principal component approach to make an assessment of environmental aspects of activities of Russian largest corporations (Finley, Verenikin and Verenikina, 2019).

1 Methodology, data and analysis

Environmental impact is a multidimensional characteristic that comprises a variety of indicators $X = \{x_i\}_{i=1}^{n}$ (n=18 in this case). Each, i-th indicator characterizes the performance of a j-th region (j=1,…,m; m=85 in this case). Overall we deal with a matrix of initial data $X = \begin{pmatrix} x_{11} & \cdots & x_{1m} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nm} \end{pmatrix}$.

The key issue is how to choose appropriate weighting coefficients for the particular social, economic and ecological activities x_i that will not rely on subjective judgments.

We use principal component approach - a multidimensional statistical technique allows to put together diverse, almost incomparable factors. It transforms a set of original variables into a set of artificial uncorrelated variables: $Z = \begin{pmatrix} Z_1 \\ \vdots \\ Z_n \end{pmatrix} = \begin{pmatrix} z_{11} & \cdots & z_{1m} \\ \vdots & \ddots & \vdots \\ z_{n1} & \cdots & z_{nm} \end{pmatrix} = LX$, where $Z_1,\ldots,Z_m$ are the first to m-th principal component vectors, $L = \begin{pmatrix} l_{11} & \cdots & l_{1n} \\ \vdots & \ddots & \vdots \\ l_{n1} & \cdots & l_{nn} \end{pmatrix}$ is the matrix of linear orthogonal transformation.

Principal component loadings are eigenvectors of the covariance matrix of initial data Σ: $(\Sigma - \lambda I)l_1^T = 0$. The corresponding characteristic equation $|\Sigma - \lambda I| = 0$ has n real-valued nonnegative roots $\lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_n \geq 0$ (eigenvalues of the covariance matrix Σ). The first principal component loadings are determined as the eigenvector that corresponds to the largest eigenvalue λ_1. The following principal components $Z_k = (z_{k1},\ldots,z_{km})$ use as component loadings other eigenvectors that correspond to successively smaller eigenvalues λ_k, k=2,…,n. λ_k is equal to variance of the k-th principal component. Total variance of principal components coincides with total variance of primary data, thus $\rho_k = \lambda_k \Big/ \sum_{k=1}^{n} \lambda_k$ is the share of total primary data variance explained by the k-th principal component.

The first principal component score z_{1j} is known to be used as an aggregate indicator of activity of the j-th economic actor. Unfortunately it explains only ρ_1 share of the variance of initial

data and thus yields a substantive loss in exposing capability.

We use the generalized principal component approach approved by our previous research (Verenikin and Verenikina, 2018) to calculate an aggregate measure of regional environmental impact as a weighted sum of all principal component scores: $I_j = \sum_{k=1}^{n} \rho_k y_{kj} = \sum_{k=1}^{n} \rho_k \sum_{i=1}^{n} l_{ki}^2 x_{ij}$.

Note that we use here modified principal component scores $y_{kj} = \sum_{i=1}^{n} l_{ki}^2 x_{ij}$ instead of ordinary principal components z_{kj} (Aivazian, Stepanov, Kozlova, 2006). This makes it possible to avoid negative principal component scores as constituting elements of the composite index. The modified principal components y_{kj} are weighted by the corresponding shares of explained variance ρ_k. There is no loss in variance of the considered data. The explaining capability of the proposed indicator is extended to the total variance of initial variables. The distinguishing feature of the proposed composite measure is that it is not sensitive to subjective preferences concerning the relative significance of specific factors of regional ecological responsibility.

The data are normalized within the range from one to ten. Besides the indicators that negatively influence environmental responsibility are inverted so as to obtain the uniform increasing impact of all the factors of concern on the level of the resulting aggregate index.

The analysis is focused on data from open official statistics, mainly Federal State Statistics Service (www.gks.ru). We had to analyze both annual state and regional reports, available in official web sites for the year 2017.

Original data were grouped into a number of subsets or *pillars* that reflect definite attributes of ecological performance of a region. The rating consider a number of indicators deal with human development, capital and environmental factors. They were grouped into 3 Pillars called: «Labour», «Capital» and «Land and Atmosphere» (see tab.2). Most of indicators from pillars A and B were weighted by gross regional product (GRP) to make data more compatible.

Expenses on human capital development represent the sum of regional expenses for education, health care and physical culture and sports (in mln rub.).

Tab. 2. Indicators and pillars

Pillar	Indicator
A. Labour	A1. Expenses on human capital development, % to GRP
B. Capital	B1. Investment in fixed capital, % to GRP
	B2. Industrial production index in mining and quarrying
	B3. Industrial production index in water supply; sewerage, waste management and remediation activities
	B4. Mining and quarrying, % to GRP
	B5. Water supply; sewerage, waste management and remediation activities, % to GRP
	B6. Environmental protection expenditures, % to GRP

	B7. Index of environmental protection expenses
C. Land and Atmosphere	C1. Change of wood reserves (mln. m^3)
	C2. Current expenditures for woods reproduction and afforestation (mln. rubles)
	C3. Water withdrawal from natural water reservoirs for practical use (mln. m^3)
	C4. Recycled and consistent use of water (mln.m^3)
	C5. Discharge of polluted sewage (mln.m^3)
	C6. CO emissions (thousand tones)
	C7. Emission of pollutants into atmosphere, % to the previous year
	C8. Share of atmospheric pollutants captured
	C9. Share of atmospheric pollutants neutralized
	C10. Share of specially protected natural territories

Source: composed by the authors.

2 Results and discussion

Sebastopol and Crimea are the leaders of the index (see tab.3). High indicators of the region are conditioned by significant growth of budget expenditures for education, health care, physical training and sports, availability of specially protected natural areas, as well as lack of extraction and law rate of land and air pollution.

The third and thourth place in the index were taken by Chechnya and Ingushetia. The regions exibit a high level of fixed capital accumulation, significant expenditures on social programs, and a large area of specially protected natural areas. However, one should take into consideration that these regions are subsidized from federal budget.

The 6th place of Altay Republic can be explained by the growth of forest resources stock, availability of specially protected natural areas, as well as relatively high budget expenditures for education, health care, physical training and sports. Altaisky Zapovednik and a buffer zone around Lake Teletskoye; Katunsky Zapovednik and a buffer zone around Mount Belukha belong to UNESCO World heritage site "Golden Mountains of Altai".

Yamal-Nenets Autonomous Area and Khanty-Mansi Autonomous Area –Yugra are the outsiders of the index. In these regions, the share of fossil fuels in the GRP structure is very high about 70%. However, it is necessary to emphasize that the territory of these districts, especially in Yugra, is one of the main stocks of the Russian oil reserves. Oil extraction remains one of the most important branches of the Russian economy and main sources of budget revenues which are distributed among donated regions of the country.

Nenets area and Sakhalin region, where mineral extraction and damage from harmful emissions is also high, are in the bottom of the rating, as well as Kemerovo region where the ratio of damage from harmful emissions to GRP is one of the highest in Russia.

Astrakhan region is closing the list of outsiders. Emissions of harmful substances into the atmosphere and water basins by industrial enterprises, as well as significant volumes of solid

household waste disposed of in unauthorized landfills, are the main sources of environmental pollution in this region. The environmental problems of Astrakhan are mainly the problems of any downstream ecosystem. Above the Volga River there are large industrial centers which pollute water, air and land of the region, produce harmful wastes. According to statistics, there are about 350 landfills in the region today, and most of them are unauthorized. Their total area is estimated at 1,300 hectares, and the volume of solid industrial and household waste stored on them is about 2.5 million tons.

Tab. 3. The overall rating of regional environmental impact: leaders and outsiders

Leaders		*Outsiders*	
Sebastopol	*1*	*Khakassia*	*71*
Crimea	*2*	*Daghestan*	*72*
Chechnya	*3*	*Orenburg Region*	*73*
Ingushetia	*4*	*Belgorod Region*	*74*
Tuva	*5*	*Udmurtia*	*75*
Altay Republic	*6*	*Saint Petersburg*	*76*
Amur Region	*7*	*Moscow City*	*77*
Pskov Region	*8*	*Krasnodar Territory*	*78*
Karachayevo-Chercassia	*9*	*Nenets Area*	*79*
Yakutia	*10*	*Sakhalin*	*80*
North Ossetia	*11*	*Novosibirsk Region*	*81*
Sverdlovsk Region	*12*	*Kemerovo Region*	*82*
Tver Region	*13*	*Yamal-Nenets Area*	*83*
Smolensk Region	*14*	*Yugra*	*84*
Ulyanovsk Region	*15*	*Astrakhan Region*	*85*

Source: composed by the authors

The overall index of environmental impact and responsibility is a linear combination of the whole set of modified principal component scores: $I_j = \sum_{k=1}^{n} \left(\lambda_k \sum_{i=1}^{n} l_{ki}^2 x_{ij} \right) \Big/ \sum_{k=1}^{n} \lambda_k$. So it can be considered as a composition of partial indices which sum up weighted modified principal component scores for each data pillar. These sub-indices generate the region's rankings with respect to particular pillars (see tab.4). They provide a glimpse of the factors of environmental impact and of the potential to improve it.

Also we obtained overall index for districts of Russian Federation by summing up final scores of regions included in the certain aggregate district (see tab.5). The predictable leader here is Central federal district.

Tab. 4. Pillars A. Labour, B. Capital and C. Land and Atmosphere: leaders and outsiders

	Labour		Capital		Land and Atmosphere	
Leaders	Sebastopol	1	Sebastopol	1	Sebastopol	1
	Pskov Region	2	Chechnya	2	Crimea	2
	Yakutia	3	Tuva	3	Chechnya	3
	Crimea	4	Crimea	4	Amur Region	4
	Amur Region	5	Ingushetia	5	Ingushetia	5
	Sverdlovsk Region	6	Altay	6	Altay Republic	6
	Smolensk Region	7	Pskov Region	7	Tuva	7
	Tatarstan	8	Karachayevo-Chercassia	8	Karachayevo-Chercassia	8
	Nenets Area	9	North Ossetia	9	Yakutia	9
	Bryansk Region	10	Sverdlovsk Region	10	Tver Region	10
	Mari El	11	Yakutia	11	Pskov Region	11
	Kursk Region	12	Bryansk Region	12	Leningrad Region	12
	Tambov Region	13	Smolensk Region	13	North Ossetia	13
	Tula Region	14	Buryatia	14	Mordovia	14
	Ulyanovsk Region	15	Ulyanovsk Region	15	Tambov Region	15
	Labour		**Capital**		**Land and Atmosphere**	
Outsiders	Kurgan Region	71	Stavropol Territory	71	Karelia	71
	Moscow Region	72	Belgorod Region	72	Nenets Area	72
	Udmurtia	73	Vologda Region	73	Krasnodar Territory	73
	Novosibirsk Region	74	Saint Petersburg	74	Moscow	74
	Belgorod Region	75	Novgorod Region	75	Khakassia	75
	Moscow City	76	Novosibirsk Region	76	Belgorod Region	76
	Novgorod Region	77	Moscow City	77	Saint Petersburg	77
	Mordovia	78	Kemerovo Region	78	Sakhalin	78
	Kalmykia	79	Daghestan	79	Udmurtia	79
	Astrakhan Region	80	Krasnodar Territory	80	Orenburg Region	80
	Khabarovsk Territory	81	Sakhalin	81	Yamal Nenets Area	81
	Krasnodar Territory	82	Nenets Area	82	Novosibirsk Region	82
	Daghestan	83	Yamal Nenets Area	83	Kemerovo Region	83
	Yugra	84	Yugra	84	Yugra	84
	Kamchatka	85	Astrakhan Region	85	Astrakhan Region	85

Source: composed by the authors

Tab. 5. The overall rating of environmental impact of districts: leaders and outsiders

Central Federal District	1
Volga Federal District	2
Siberian Federal District	3
Northwestern Federal District	4
Far Eastern Federal District	5
Southern Federal District	6
North Caucasus Federal District	7
Ural Federal District	8

Source: composed by the authors

Conclusion

Unlike most of the existing area ratings, our rating methodology reflects a comprehensive approach to assessing regional environmental policy. This rating provides an integral assessment of the

current state of environmental responsibility of Russian regions. An important point was an attempt to use only open official statistics published by federal agencies in order to avoid any expert assesments which require complex and expensive research. There are also some disadvantages due to the lack of sufficient statistical information.

In fact, our research lays the foundation for regular (once in 3-5 years) consideration of the environmental component of economic growth and its dynamics in the regions of the Russian Federation. Investigation of the factors that determine the positions of different regions in environmental responsibility ranking can serve to improve ecological and economic policy in Russian regions. It is obvious that in order to improve a regional environmental impact priority should be given to projects which maintain ecosystems and investments in them, sustainable forestry and agriculture, recreation, ecotourism, etc.

The availability of an aggregated indicator is important for decision-making in terms of taking into account the environmental factor in the development of the country. Such an indicator could be used to judge the degree of stability of the country and regions, ecological trajectory of development of individual territories.

As a matter of further research, the inclusion of new environmental, economic and social components in our index, can serve to improve the comprehensive index of sustainable development of Russian regions.

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