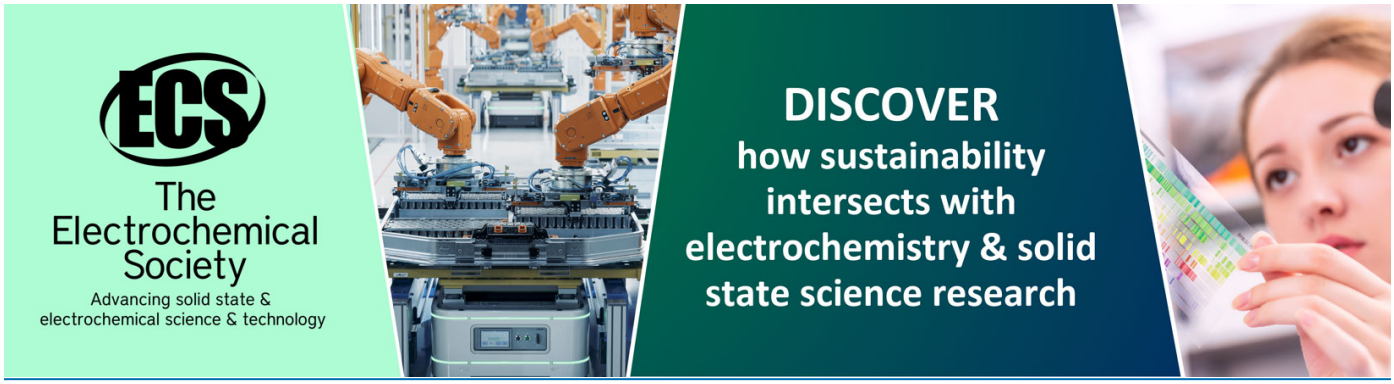
Typology of resource regions by the level of innovative potential: fuzzy approach



Typology of resource regions by the level of innovative potential: fuzzy approach

E S Kagan [1,2], S G Gutova[2] and E S Chernova[2]

[1]Russia Federal Research Center of Coal and Coal Chemistry, Siberian Branch of the Russian Academy of Sciences, 18 Sovetskiy ave, Kemerovo, 650000, Russia
[2]Kemerovo State University, 6 Krasnaya street, Kemerovo, 650000,

E-mal: kaganes@mail.ru

Abstract. The paper discusses a new approach to developing a typology of resource regions based on their readiness for comprehensive exploitation of mineral resources and the level of innovative development. The use of fuzzy clustering apparatus is explained by the fuzzy boundaries for defining classes as it allows improving the quality of the typology.

1. Introduction

The mineral resource complex of Russia is the main driver of economic development and a source of budget revenues, which determines many socio-economic indicators of the country's development, including the current and potential level of people's welfare. At present, such "resource" development model is gradually exhausting itself and there is an urgent need to change the development paradigm of the resource complex of Russia and its mining regions. The basis of the new paradigm is the mining regions' ability to move from extensive use of resources to comprehensive exploitation of mineral resources, which, according to academician K. N. Trubetskoy, assumes full and low-waste high-performance and economically justified extraction of mineral resources. The transition to comprehensive exploitation of mineral resources is impossible without active innovation. Comprehensive exploitation of mineral resources involves the use of resource-saving technologies; involvement of all associated natural resources in the process of extraction and processing, while increasing their useful qualities; respect for the subsoil and the environment. Comprehensive exploitation of mineral resources will focus on the combined technological solutions, allowing to create a closed technological cycle and to maintain the ecological balance in the territories of mineral resource exploitation [3, 9, 14, 16].

Despite the fact that in all Russian mining regions the resource specialization is steadily being developed, they are extremely heterogeneous in terms of development, the share of extractive industries in the regional GRP, innovation potential, income level, etc. But most importantly, the regions have different degrees of readiness to move to comprehensive exploitation of mineral resources. This fact should be taken into account in the development of their strategic and long-term development programs. Under these conditions, it is extremely important to develop new approaches to the qualitative assessment of regional differences, while the typology of regions (the division of regions into groups according to the set of qualitative characteristics) becomes an important tool for analysis [1, 2, 4, 7, 8, 10, 11].

2. Data and methods

The complexity of the typology of mining regions is explained by two factors: the lack of generally accepted approaches (qualitative and quantitative features and criteria) to the allocation of mining (resource) regions, and the lack of a universal approach to the typology of Russian regions as a whole. This is manifested in the predominance of the rating approach based on a small number of criteria.

In the present study, the selection of criteria for the typology of regions was carried out from the position of assessing their readiness for comprehensive exploitation of mineral resources. At the initial stage of this study, a group of 36 regions specializing in oil, gas and coal production was identified from the entire list of Russian regions. Therefore, the first criterion for clustering was the level of the region's resource dependence. To assess resource dependence, the share of extractive industries in the GRP of the region was determined [12]. The indicator characterizing resource dependence was presented as a coefficient calculated by the ratio of the share of extractive industries in the GRP of the region to the share of extractive industries in the GDP of the Russian Federation. For the studied group of regions, the value of this indicator ranged from 0.107 (Republic of Ingushetia) to 6.05 for (Khanty-Mansiysk Autonomous Okrug) [5, 18].

The implementation of comprehensive exploitation of mineral resources requires a qualitative leap, a sharp increase in the level of the regions' innovative development. The lag in innovation is seen as one of the main threats to national security. Innovative development is a determining factor that affects the formation of the level of the regions' competitiveness. Innovations should cover all stages of the production and technological cycle, from exploration and production of raw materials to processing and transportation of its products and processing [17]. There-fore, the second criterion characterizing the readiness of the region for the comprehensive exploitation of mineral resources is the level of innovative development. The level of the regions' innovative development was estimated through the value of an integral indicator calculated on the basis of the approach developed by the National Research Institute Higher School of Economics [15]. In the calculation of this indicator requires the information about the values of the four indices, characterizing different aspects of innovation development: "Socio-economic conditions for innovative activity", "Scientific and technical potential", "Innovation activity", and "Quality of innovation policies". For the studied group of regions, the value of the innovation development index ranged from 0.173 (Nenets Autonomous Okrug) to 0.575 (Republic of Tatarstan).

Traditionally, the problem of dividing objects into classes basing on a group of features can be solved in two ways.

1. Splitting objects into groups using cluster analysis methods. Yet, the cluster analysis for objects whose values differ significantly from the others even during the preliminary procedure of standardization leads to the fact that the cluster analysis does not identify the differences be-tween the objects, considering them insignificant compared to the abnormal results. The initial attempt to use the cluster analysis procedure to classify regions did not show positive results. Thus, for example, in the course of this procedure, regions with a low level of innovative development and medium resource dependence, as well as regions with an average level of innovative development and low resource dependence, fell into one cluster.

2. The typology of regions is carried out on the basis of the set boundaries (levels) of indicators. The disadvantage of this approach is the lack of a common view on the setting of such boundaries. In a number of works [15] such boundaries are set by the results of the previously conducted cluster analysis, the shortcomings of which were described above. At the same time, the boundaries of indicators belonging to different clusters can overlap.

In our opinion, a more productive approach to dividing regions into groups reflecting their readiness to comprehensive exploitation of mineral resources is the approach based on the use of fuzzy clustering algorithms. The use of fuzzy intervals and overlapping ranges will reduce uncertainty in setting cluster boundaries and improve the quality of classification.

3. Results and discussion

At the initial stage, the criteria were presented in the form of linguistic variables (LVs) with the corresponding term sets: "level of the region's innovative development" {T1-low, T2-medium, T3-high} and "level of the region's resource dependence" {T1-weak, T2-medium, T3-high} [13, 6]. Table 1 presents the expressions for the membership functions (MFs) of the corresponding terms of these two criteria.

Table 1. Membership functions of the terms of linguistic variables.

LV "Level of the region's innovative development"	LV "Level of the region's resource dependence"
$\mu(T1)=\begin{cases}1, & x\le 0,2\\ 1-\dfrac{x-0,2}{0,2}, & 0,2<x\le 0,4\\ 0, & x>0,4\end{cases}$	$\mu(T1)=\begin{cases}1, & x\le 0,15\\ 1-\dfrac{x-0,15}{0,65}, & 0,15<x\le 0,8\\ 0, & x>0,8\end{cases}$
$\mu(T2)=\begin{cases}0, & x\le 0,2\\ \dfrac{x-0,2}{0,1}, & 0,2<x\le 0,4\\ 1, & 0,4<x\le 0,5\\ 1-\dfrac{x-0,5}{0,2}, & 0,5<x\le 0,7\\ 0, & x>0,7\end{cases}$	$\mu(T2)=\begin{cases}0, & x\le 0,15\\ \dfrac{x-0,5}{0,65}, & 0,15<x\le 0,8\\ 1, & 0,8<x\le 1,5\\ 1-\dfrac{x-1,5}{1,5}, & 1,5<x\le 3\\ 0, & x>3\end{cases}$
$\mu(T3)=\begin{cases}0, & x\le 0,5\\ \dfrac{x-0,5}{0,2}, & 0,5<x\le 0,7\\ 1, & x>0,7\end{cases}$	$\mu(T3)=\begin{cases}0, & x\le 1,5\\ \dfrac{x-1,5}{1,5}, & 1,5<x\le 3\\ 1, & x>3\end{cases}$

Table 2 presents a fragment of the table with the initial (crisp) and fuzzy values of the criteria for the studied group of regions.

The fuzzy clustering procedure included two stages. Firstly, the possible number of clusters was determined. Since the criteria have three levels, the maximum possible number of clusters is nine. Then a reference point was defined for each cluster. For example, for a cluster that characterizes the regions with the medium level of resource dependence and medium level of innovative development, the reference point will have fuzzy coordinates:{(0,1,0);(0,1,0)}. In fuzzy clustering, three options are possible.

1. The region belongs to only one cluster if the coordinates of the region match the reference point of the cluster (the region's MF of each indicator for a certain term equals one). For example, Nenets Autonomous Okrug has a low level of innovative development (MF of LV terms equals (1;0;0) and a high level of resource dependence (MF of LV terms equals (0;0;1), so this region will belong only to the cluster, which is characterized by a low level of innovative development and high resource dependence, and will be the reference region for this cluster.

2. The region belongs to two adjacent clusters if the region's MF of only one indicator for a certain term equals one. For example, Tomsk Region has a medium level of innovative development (MF of LV terms equal (0;1;0)). However, MFs of LV terms "Level of the region's resource dependence are: T1=0; T2=0.246; for T3=0.754. Therefore, the degree of Tomsk Region's belonging to two clusters will be determined: 1) with the medium level of innovative development and a medium level of

resource dependence ((0;1;0), (0;1;0)); 2) with a medium level of innovative development and high level of resource dependence ((0;1;0), (0;0;1)).

3. The region belongs to four adjacent clusters, if none of the region's MF indicators equals one. For example, for the Republic of Tatarstan the level of innovative development is estimated as "medium" with the MF value equaling 0.724, and as "high" with the MF value equaling 0.376. At the same time, resource dependence for this region is estimated as "medium" with MF equaling 0.716 and "high" with MF equaling 0.274. Therefore, the extent of this region's membership in four cluster-frames will be evaluated: 1) with the medium level of innovative development and the medium level of resource dependence; 2) with the high level of innovative development and the medium level of resource dependence; 3) with the medium level of innovative development and the high level of resource dependence; 4) with the high level of innovative development and the high levels of resource dependence.

Table 2. Fragment of the table with crisp and fuzzy values of the criteria.

Region	Level of the region's innovative development				Level of the region's resource dependence			
	Crisp value	T1	T2	T3	Crisp value	T1	T2	T3
Amur Region	0.237	0.816	0.185	0.000	1.467	0.000	1.000	0.000
….								
Kemerovo Region	0.334	0.332	0.668	0.000	2.284	0.000	0.477	0.523
Krasnoyarsk Kray	0.461	0.000	1.000	0.000	1.562	0.000	0.959	0.041
Nenets Autonomous Okrug	**0.173**	**1.000**	**0.000**	**0.000**	**6.008**	**0.000**	**0.000**	**1.000**
Republic of Bashkortostan	0.485	0.000	1.000	0.000	0.334	0.717	0.283	0.000
Republic of Buryatia	0.309	0.455	0.546	0.000	0.379	0.648	0.352	0.000
Republic of Tatarstan	**0.575**	**0.000**	**0.624**	**0.376**	**1.927**	**0.000**	**0.716**	**0.284**
…								
Tomsk Region	**0.464**	**0.000**	**1.000**	**0.000**	**2.631**	**0.000**	**0.246**	**0.754**

The basic concept of cluster analysis is that of the distance between objects. In the fuzzy clustering the concept of fuzzy similarity between objects in some parameter can be used for calculating the distance between objects. The convergence between two objects A and B is determined by the formula: $d_{AB} = \frac{1}{2}\sum_{i=1}^{k}|\mu_{iA}(x) - \mu_{iB}(x)|$, where k is the number of LV terms. Then the distance between two objects by *n* criteria is counted as: $r_{AB} = \frac{1}{n}\sum_{i=1}^{n} d_{AB}$. The degree of belonging to a cluster is defined as $Cl_j = 1 - r_j$.

Thus, the typology of regions according to two selected criteria is developed according to the following algorithm. The distance from each region to the reference point of the cluster and the degree of its belonging to all clusters are determined. If the cluster does not contain any element, it can be excluded from further consideration (in this study, such a cluster is the cluster with the high level of innovative development and the low resource dependence). If the fuzzy coordinates of the region coincide with the coordinates of the reference point, this region is considered a reference for this cluster, which is another advantage of this approach. Table 3 shows a fragment of the results of the dividing the regions into clusters with indication of the degree of their belonging to some cluster.

Table 3. Fragment of the results of dividing regions into groups.

		Level of the region's resource dependence		
		T1-low	T2-medium	T3-high
Level of the region's innovative development		…	…	…
	T2-medium	**((0;1;0),(1;0;0))** Arkhangelsk Region (0.6), Volgograd Region (0.6), Kaliningrad Region (0.47), Kursk Region (0.35), Republic of Bashkortostan (0.86), Republic of Buryatia (0.6), Republic of Karelia (0.31), Khabarovsk Kray (0.74), Chechen Republic (0.53)	**((0;1;0),(0;1;0))** Amur Region (0.59), Arkhangelsk Region (0.33), Astrakhan Region (0.53), ***Belgorod Region (1),*** Volgograd Region (0.57), Transbaikal Kray (0.6), Irkutsk Region (0.65), Kaliningrad Region (0.22), Kemerovo Region (0.57), Krasnoyarsk Kray (0.98), Kursk Region (0.8), Magadan Region (0.4), Murmansk Region (0.88), ***Perm Kray (1),*** Republic of Bashkortostan (0.64), Republic of Buryatia (0.45), Republic of Karelia (0.71), Republic of Tatarstan (0.67), Republic of Tyva (0.6), Republic of Khakassia (0.59), Samara Region (0.99), Tomsk Region (0.62), Tyumen Region (0.97), Republic of Udmurtia (0.44), Khabarovsk Kray (0.76)	**((0;1;0),(0;0;1))** Astrakhan Region (0.53), Irkutsk Region (0.58), Kemerovo Region (0.6), Krasnoyarsk Kray (0.52), Magadan Region (0.62), Orenburg Region (0.76), Komi Republic (0.72), Republic of Sakha (0.85), Sakhalin Region (0.85), Republic of Tatarstan (0.45), Tomsk Region (0.88), Tyumen Region (0.47), Republic of Udmurtia (0.44), Khanty-Mansiysk Autonomous Okrug (0.79), Chukotka Autonomous Okrug (0.64), Yamalo-Nenets Autonomous Okrug (0.89)
	T3-high	**((0;0;1),(1;0;0))**	**((0;0;1),(0;1;0))** Republic of Tatarstan (0.55)	**((0;0;1),(0;0;1))** Republic of Tatarstan (0.33)

Yet, researchers at National Research Institution Higher School of Economics argue that in 2015, compared to the previous years, the difference between regions regarding "Socio-economic conditions" and "Scientific and technical potential" indices was smaller than the difference regarding the "Innovation activity" and "Quality of innovation policies" indices [15]. Table 4 presents the descriptive statistics for the four innovative indices calculated based on 2015 data.

At the second stage of the study the typology of regions was developed based on the modified Level of innovative development calculated basing on only two indices: "Innovation activity" and "Quality of innovation policies". The descriptive characteristics for the "Level of innovative development (modified)" are presented in the last line of table 4.

Table 4. Descriptive statistics of the indices reflecting the regions' innovative development in 2015.

	Descriptive statistics (innovative development)					
	Medium	Minimum	Maximum	Lower Quartile	Higher Quartile	Statistical deviation
Level of innovative development	0.322	0.173	0.575	0.249	0.371	0.090
"Socio-economic conditions" index	0.383	0.225	0.557	0.320	0.446	0.077
"Innovation activity" index	0.232	0.000	0.590	0.149	0.307	0.124
"Quality of innovation policies" index	0.389	0.000	0.811	0.310	0.487	0.180

"Scientific and technical potential" index	0.295	0.133	0.464	0.234	0.338	0.076
Level of innovative development (modified)	0.311	0.038	0.7	0.218	0.371	0.133

The analysis of the results presented in table 5 leads to the conclusion that the use of the modified coefficient significantly changes the typology of the regions, especially for classes with a high level of innovative development.

Table 5. Division of regions into classes based on the Level of innovative development (modified).

		Level of the region's resource dependence		
		T1-low	T2-medium	T3-high
Modified Level of the region's innovative development (modified)	T1-low	**Cluster 1: ((1;0;0),(1;0;0))** Arkhangelsk Region (0.74), Volgograd Region (0.36), Kaliningrad Region (0.88), Kursk Region (0.14), Republic of Buryatia (0.58) ***Republic of Ingushetia (1),*** Republic of Kalmykia (0.98), Republic of Karelia (0.41) ***Chechen Republic (1)***	**Cluster 2: ((1;0;0),(0;1;0))** Amur Region (0.98), Arkhangelsk Region (0.47), Astrakhan Region (0.49), Volgograd Region (0.33), Transbaikal Kray (0.96), Irkutsk Region (0.51), Kaliningrad Region (0.63), Kemerovo Region (0.4), Kursk Region (0.59), Magadan Region (0.25), Murmansk Region (0.68), Republic of Buryatia (0.43), Republic of Kalmykia (0.52), Republic of Karelia (0.81), Republic of Tyva (0.84), Republic of Khakassia (0.95), Samara Region (0.55), Tyumen Region (0.62), Republic of Udmurtia (0.64)	**Cluster 3: ((1;0;0),(0;0;1)** Astrakhan Region (0.49), Irkutsk Region (0.45), Kemerovo Region (0.42), Magadan Region (0.47), ***Nenets Autonomous Okrug (1),*** Orenburg Region (0.72), Komi Republic (0.92), Republic of Sakha (0.55), ***Sakhalin Region (1),*** Tyumen Region (0.12), Republic of Udmurtia (0.65), Khanty-Mansiysk Autonomous Okrug (0.78), Chukotka Autonomous Okrug (0.96), Yamalo-Nenets Autonomous Okrug (0.66)
	T2-medium	**Cluster 4: ((0;1;0),(1;0;0))** Arkhangelsk Region (0.53), Volgograd Region (0.67), Kursk Region (0.41), Republic of Bashkortostan (0.82), Republic of Buryatia (0.57), Republic of Karelia (0.19), Khabarovsk Kray (0.72)	**Cluster 5: ((0;1;0),(0;1;0))** Amur Region (0.52), Arkhangelsk Region (0.26), Astrakhan Region (0.51), ***Belgorod Region (1),*** Volgograd Region (0.64), Transbaikal Kray (0.54), Irkutsk Region (0.55), Kemerovo Region (0.58), Krasnoyarsk Kray (0.95), Kursk Region (0.86), Magadan Region (0.53), Murmansk Region (0.82), ***Perm Kray (1),*** Republic of Bashkortostan (0.61), Republic of Buryatia (0.42), Republic of Karelia (0.59), Republic of Tyva (0.66), Republic of Khakassia (0.55), Samara Region (0.95), Tomsk Region (0.62), Tyumen Region (0.88), Republic of Udmurtia (0.35), Khabarovsk Kray (0.73)	**Cluster 6: ((0;1;0),(0;0;1)** Astrakhan Region (0.53), Irkutsk Region (0.49), Kemerovo Region (0.6), Krasnoyarsk Kray (0.49), Magadan Region (0.75), Orenburg Region (0.78), Komi Republic (0.58), Republic of Sakha (0.95), Tomsk Region (0.88), Republic of Udmurtia (0.36), Khanty-Mansiysk Autonomous Okrug (0.72), Chukotka Autonomous Okrug (0.54), Yamalo-Nenets Autonomous Okrug (0.84)

T3-high	**Cluster 7: ((0;0;1),(1;0;0))** Republic of Bashkortostan (0.39), Khabarovsk Kray (0.27)	**Cluster 8: ((0;0;1),(0;1;0))** Krasnoyarsk Kray (0.51), Republic of Bashkortostan (0.18), Republic of Tatarstan (0.86), Khabarovsk Kray (0.28)	**Cluster 9: ((0;0;1),(0;0;1))** Krasnoyarsk Kray (0.05), Republic of Tatarstan (0.64)

4. Conclusion

The approach to the typology of regions based on the application of fuzzy sets, considered in the article, has the following advantages. Firstly, it makes attribution the region to a particular class more grounded, which reduces the uncertainty in the setting of their boundaries of clusters. Secondly, in most classes the most typical regions (reference points) can be distinguished, and the degree of similarity of the other group of regions with the reference regions can be estimated through the distance to the reference point. This approach allows changing the structure of clusters, specifying the qualitative and quantitative criteria for the classification of regions to a particular type. In this study, it allowed changing the composition of the clusters showing a high level of innovative development. Finally, the developed approach to the typology of regions opens up quite interesting prospects for further research and evaluation. So, at the next stage the given typology can be used to create an expert system for the formation of a fuzzy base of rules for assessing the resource regions' readiness for comprehensive exploitation of mineral resources.

Acknowledgements

The article was prepared with the financial support of the Russian Science Foundation, under the agreement No. 16-18-10182 "Formation of organizational and economic mechanisms for comprehensive exploitation of mineral resources in resource-type regions on the basis of the partnership of science, government and business".

References

[1] Boots B et al. 2002 *Typology of Russian Regions* (Moscow) p 130
[2] Golyashev A V and Grigoriev L M 2014 *Types of Russian Regions: Sustainability and Shifts in 2003-2013* (Moscow: Analytical Center under the President of the Russian Federation) p 47
[3] Guriev S, Plekhanov A and Sonin K 2010 *Issues of Economics* **3** 4–23
[4] Ilyina I N 2013 *Public Administration Issues* **2** 91–102
[5] Kagan E S and Goosen E V 2017 *High Tech. of Dev. and Use of Mineral Res.* **3** 163–170
[6] Kagan E S 2012 *Izvestiya of Altai State University Journal* **1(1)** 160–3
[7] Kondratyev V 2015 *Theoretical and Practical Aspects of Management* **6** 20–7
[8] Lapaev S P 2014 *Vestnik of Orenburg State University* **8(169)** 100–5
[9] Levin S N, Kagan E S and Sablin K S 2015 *Journal of Institutional Studies* **3(7)** 92–101
[10] Mikheeva N N 2009 *Region: Economics and Sociology* **2** 23–42
[11] Orlov V P 2007 *Mineral Recourses of Russia. Economics and Management* **2** 3–5
[12] Official website of the Federal Service of State Statistics http://www.gks.ru
[13] Pegat A 2013 *Fuzzy Modelling and Management* (Moscow: Binom. Laboratory of Knowledge) p 798
[14] *Development of Resource Saving and Resource Reproducing Geotechnologies for Complex Exploitation of Mineral resource Deposits* 2014 Trubetskoy K N ed. (Moscow: Institute for Comprehensive Exploitation of Mineral Reources of the RAS) p 196
[15] Abdrakhmanova G et al *National Research University Higher School of Economics* Gokhberg L ed. (Moscow: HSE) p 260
[16] *Resource Regions of Russia in the "New Reality"* 2017 Kuleshov V V ed. (Novosibirsk: IEOIP SB RAS) p 308
[17] Eder L et al 2017 *Drilling and Oil* **5** 20–9
[18] Kagan E S and Goosen E V *IOP Conf. Series: Earth and Environmental Science* **84** 012016