Hard-to-recover oil reserves as a factor of socio-economic growth of resource regions

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Abstract. The article considers the main classification features of the category of hard-to-recover oil reserves. The analysis of changes in the dynamics of production of hard-to-recover oil in Russia is carried out. The relationship between the development parameters of the oil and gas complex and the level of socio-economic development of resource regions using the method of hierarchical cluster analysis is investigated.

1. Introduction
Over the past two decades, the oil and gas complex Russia has played a key role in the country's economy. Favorable pricing conditions on world energy markets since the early 2000s contributed to the expansion of the geography of oil and gas production in the country [1]. The development of the oil and gas potential of the Lena-Tunguska oil and gas province in the regions of Eastern Siberia and the Republic of Sakha (Yakutia) has begun, large-scale exploration work has begun on the shelf of the Arctic Ocean, especially within the Kara and Barents Seas, unique transport projects have been implemented - oil pipelines have been put into operation “Eastern Siberia – Pacific Ocean”, “Zapolyarye – Purpe – Samotlor”, “Power of Siberia” gas pipeline, a new port infrastructure has been created - the Kozmino spemornefteport, “Sabetta” and a number of other large projects, including international, of strategic importance for the development of the oil and gas complex of Russia and the country's economy as a whole [2].

One of the important trends in the development of oil and gas complex, which developed during the period of high oil prices, but also in many respects naturally caused, along with the expansion of the geography of production, is the development of hard-to-recover oil reserves [3]. The largest fields of traditional oil production centers (West Siberian oil and gas production, Volga-Ural oil and gas production, Timan-Pechora oil and gas production), which provide more than 85% of oil production in the country, are at a late stage of development and are characterized by a high degree of depletion and water cut [4, 5]. New increases in oil reserves are associated with the discovery of small and minute deposits in these territories, or the development of oil reserves of deeper horizons, with worse mining and geological conditions of occurrence, or special physicochemical properties. Such oil reserves are
generally classified as “hard to recover” [6]. Basically, there are several categories of hard-to-recover oil reserves:

- with special physicochemical properties;
- occurring in difficult geological conditions;
- in regions with missing or poorly developed infrastructure.

Oils with abnormal physicochemical properties include heavy, viscous, sulphurous, paraffinic, resinous oils with high or low gas saturation [7]. Difficult bedding conditions include low permeability reservoirs, reservoirs with low porosity, large depths, high or low reservoir temperature, and a high degree of water cut.

In modern scientific literature, the discussion continues on the interpretation of the term “hard to recover” oil reserves. However, there is a need to account for oil production from the so-called “hard to recover” reserves. Such monitoring allows us to predict the parameters of sustainable development of the Russian oil and gas complex, evaluate the cost of preparing and extracting raw materials, and plan state revenues from extractive industries. Therefore, in practice, the category of “hardly recoverable” oil includes that part of the extracted raw materials, which is taxed on mineral extraction (MET) with decreasing ratios or benefits [8, 9] in accordance with the Tax Code of the Russian Federation, chapter 26. Mineral extraction tax (introduced Federal Law of 08.08.2001 N 126-FL, as amended on 12.27.2019, as amended on 01.28.2020).

In 2018, oil production from hard-to-recover reserves amounted to 246 million tons, which is 18% more than the previous year. The production of “hardly recoverable” oil in Russia in 2018 amounted to 50% of oil production in Russia (figure 1).

![Figure 1. Dynamics of production of hard-to-recover oil.](chart.png)

Providing benefits to subsoil users engaged in the extraction of hard-to-recover oil, the state maintains the level of oil production in the country and stimulates the development of new regions. At the same time, technologies are developing for the development of complex reservoirs or the production of highly viscous, bituminous oil, as well as the search, assessment and exploration of hard-to-recover categories of reserves and resources [10, 11]. A positive socio-economic effect is also observed at the level of oil production regions - an increase in the population and employed, an increase in per capita incomes.

However, due to the fact that the main taxes from the oil and gas complex - the tax on extraction of mineral resources (oil, natural gas, gas condensate) and export customs duty - are received in full to the federal budget, the regions receive only the tax on extractive industries from the regional budget profit, property tax and personal income tax. Therefore, the multiplier effect for the regions is not
determined solely by tax revenues and under the current tax system, the regions are more interested not in financial returns from OGCs, but in social and innovative effects [11, 12]. Therefore, the purpose of this study is to analyze and evaluate the impact of the oil and gas complex on the economy of the producing regions. The authors set themselves the task of determining the effect of the growth of hard-to-recover oil reserves on the parameters of the socio-economic development of producing regions. The feasibility of such a study is due to the need to understand the motivation and incentives for the development of regional support to subsoil users, as well as the ability of oil and gas companies to generate a positive multiplier effect on the regional economy [13-15].

2. Materials
As an object of study, 32 oil-producing regions of Russia are accepted. In order to assess the current state of the socio-economic development of the resource regions relative to each other, we selected indicators such as gross regional product per capita, per capita cash income, investment in fixed assets per capita, and the degree of depreciation of fixed assets at the end of the year (table 1).

| Region                                 | GRP per capita, thousand rubles | Average per capita cash income per month, thousand rubles | Investments in fixed assets per capita, thousand rubles | The degree of depreciation of fixed assets at the end of the year, % |
|----------------------------------------|---------------------------------|----------------------------------------------------------|--------------------------------------------------------|-----------------------------------------------------------|
| Nenets Autonomous District             | 5 822                           | 70.1                                                     | 3 233                                                  | 45.6                                                     |
| Yamal-Nenets Autonomous District       | 3 670                           | 71.7                                                     | 2 014                                                  | 56.8                                                     |
| Khanty-Mansi Autonomous District - Ugra| 1 852                           | 44.8                                                     | 571                                                    | 70.7                                                     |
| Sakhalin District                      | 1 576                           | 48.7                                                     | 613                                                    | 49.2                                                     |
| The Republic of Sakha (Yakutia)        | 904                             | 39.8                                                     | 399                                                    | 45.0                                                     |
| Komi Republic                          | 641                             | 31.2                                                     | 153                                                    | 47.1                                                     |
| Tyumen region                          | 632                             | 28.3                                                     | 195                                                    | 50.3                                                     |
| Krasnoyarsk region                     | 616                             | 28.0                                                     | 148                                                    | 41.4                                                     |
| Republic of Tatarstan                  | 500                             | 31.7                                                     | 164                                                    | 45.2                                                     |
| Tomsk region                           | 452                             | 24.5                                                     | 88                                                     | 60.3                                                     |
| Irkutsk region                         | 443                             | 22.4                                                     | 107                                                    | 48.3                                                     |
| Perm region                            | 414                             | 28.7                                                     | 97                                                     | 64.1                                                     |
| Samara Region                          | 398                             | 27.0                                                     | 79                                                     | 56.3                                                     |
| Novosibirsk region                     | 391                             | 25.3                                                     | 63                                                     | 49.7                                                     |
| Orenburg region                        | 388                             | 22.7                                                     | 92                                                     | 62.8                                                     |
| Krasnodar region                       | 364                             | 33.1                                                     | 87                                                     | 37.2                                                     |
| Udmurtia                               | 356                             | 23.9                                                     | 53                                                     | 65.1                                                     |
| Astrakhan region                       | 332                             | 22.5                                                     | 142                                                    | 50.1                                                     |
| Republic of Bashkortostan              | 330                             | 28.4                                                     | 64                                                     | 54.5                                                     |
| Omsk region                            | 317                             | 25.2                                                     | 51                                                     | 49.2                                                     |
| Volgograd region                       | 293                             | 21.4                                                     | 75                                                     | 51.3                                                     |
| Saratov region                         | 264                             | 19.8                                                     | 59                                                     | 57.6                                                     |
The highest GRP per capita belongs to the Nenets Autonomous District, in 2017 it amounted to 5,822 thousand rubles. The Yamalo-Nenets and Khanty-Mansi Autonomous Districts also entered the top three per capita GRP. The smallest GRP per capita among resource regions in 2017 belonged to the Republic of Kalmykia - 201 thousand rubles at the national level of 472 thousand rubles.

The highest level of average per capita cash income of the population in 2017, which was achieved in the Yamalo-Nenets Autonomous District, amounted to 71.7 thousand rubles per month. The Nenets Autonomous District in this indicator was in second place. The size of the average per capita cash income of the population in 2017 amounted to 70.1 thousand rubles. Closes the top three indicators of the Sakhalin region, where revenues amounted to 48.7 thousand rubles. The Republic of Kalmykia also ranked last in terms of average per capita income - 14.7 thousand rubles. The level in Russia in 2017 amounted to 31.4 thousand rubles.

In investments in fixed assets per capita, the Nenets Autonomous Okrug also became a leader, where the value of this indicator in 2017 was 3,233 thousand rubles. The second place was taken by the Yamalo-Nenets Autonomous Okrug. Here, investment in fixed assets per capita amounted to 2,014 thousand rubles. With a significant margin in terms of indicator value, the Sakhalin Oblast entered the top three - 613 thousand rubles. The lowest investment value is 38 thousand rubles in 2017, it was in the Republic of Kalmykia.

The minimum value of depreciation of fixed assets at the end of 2017 was related to the Krasnodar Territory - 37.2%, which is 13.7 percentage points below the value at the level of Russia. The greatest wear at the end of 2017 was indicated in the Khanty-Mansi Autonomous Okrug. Depreciation of fixed assets in this region amounted to 70.7%, which exceeds the Russian level by 19.8 percentage points.

3. Methods
To study the relationship of socio-economic indicators of the development of Russian regions and the development parameters of the oil and gas complex, the method of hierarchical cluster analysis, which includes the following stages:

- Statement of the problem, task, working hypotheses;
- Choosing a method for measuring distance;
- Choice of cluster analysis method;
- Deciding on the number of clusters;
- Description of clusters;
- Interpretation of the results obtained;
- Assessment of the reliability of clustering.

Let us consider the first stage - the formulation of objectives, the implementation of which is provided in this paper.

The quality of the raw material base of the regions was described by three groups of factors – raw material characteristics, production factors, and fluid properties. The total recoverable reserves, the share of small and smallest deposits, the average size of the deposit, and the degree of exploration (initial) were included as raw material factors. Fluid properties include three factors such as the proportion of dense, sulphurous and viscous oil. The fishery characteristics of the raw material base are indicated through water cut and depletion.

Through this clustering, it is possible to assess the impact of the oil and gas complex on the socio-economic indicators of resource regions. As indicators of NGC, several groups of factors were identified.
First group – mining industry characteristics. This includes total recoverable reserves, cumulative production for 2007-2017, the share of people employed in the extraction of minerals from the total number of employees, the share of the extraction of minerals in gross value added and the factor in the share of crude oil and natural gas production in the volume of shipped goods of own production performed works and services in-house in the mining industry. The last factor shows the importance of the oil and gas sector in the region’s mining industry.

The second group of factors is represented by four socio-economic characteristics: per capita cash income, gross regional product per capita, investment in fixed assets per capita, and the degree of depreciation of fixed assets.

The second stage of cluster analysis is the choice of distance measurement method. Based on the measured distance between the objects, a decision will be made to combine them into one group. If the factors by which the division of objects is required are interval values, then measures of distance such as the Euclidean distance or the square of the Euclidean distance are used. Euclidean distance is calculated by the formula (2.1):

\[
D(x_i, x_j) = \left[ \sum_{l=1}^{k} (x_{il} - x_{jl})^2 \right]^{1/2}
\]

where \(D(x_i, x_j)\) – Euclidean distance between objects \(x_i\) and \(x_j\) (i, j = 1, 2, …, N), \(N\) – total number of cluster analysis objects, \(x_{il}\) – value of the 1-th characteristic for the object i (l = 1, 2, …, k).

At the initial stage of hierarchical agglomerative analysis, each object represents a separate “cluster” and the distance between them is calculated by the selected metric. At the next stage, when objects close in distance formed clusters, the question arises of how to determine the distances between formed clusters or individual objects and formed clusters. To do this, at the third stage, a cluster analysis method or a combination method is selected.

Among the most famous methods, the Ward method stands out. Its difference from other methods is the use of analysis of variance. In this procedure, the distance between the clusters takes the increase in the sum of the squares of the distances of the objects to the centers of the clusters, obtained as a result of their union. At each step, those clusters are subject to unification, which lead to a minimum increase in the intragroup sum of squares. This method was proposed in 1963 by J. Ward [Ward, 1963].

Since the clustering process is time-consuming, various statistical packages and programs are currently used for its implementation. In this work, the statistical program Stata was used.

The next step is a description of the clusters. Clusters are described using the average values of each trait (factor) in the cluster. In addition to the average values, in order to be more demonstrative, the description may include the minimum and maximum values of the characteristic for the group, standard deviation, etc.

4. Results and discussion

The result of clustering was the division of regions into four clusters depending on the scale of the mining industry in the region and the effectiveness of socio-economic development. In this case, we say that a region is more efficient if it has a large GRP per capita, average per capita cash income of the population, and investment in fixed assets per capita. Since the Khanty-Mansi Autonomous District was defined as an outlier during clustering from resource regions, it was removed (table 2).

The first cluster is represented by the Nenets and Yamalo-Nenets Autonomous Districts. Their distinguishing features in comparison with other resource regions are the high share of the mining industry in gross value added (GVA) – in the Nenets Autonomous District – 75%, in the Yamalo-Nenets – 55%. 88% of revenue in this industry relates to revenues from oil and natural gas. Also, about a fifth of those employed are in the mining industry. These regions can be called mono-industry
due to the high impact of production, which determines their specificity in the socio-economic situation.

The second cluster consists of twelve regions with low production impact and low efficiency. The cluster is characterized by a low level of production, the average share of employees in production is 0.9%, the average share of production in gross value added reaches 7%. At the same time, the regions that fell into this cluster are characterized by the lowest values of factors of socio-economic development.

The third cluster is represented by five regions with high production impact and high efficiency - the Tyumen region, the Republic of Sakha, Sakhalin region, Krasnoyarsk Region and Tatarstan. This cluster differs from cluster No. 1 in a smaller share of production workers (up to 10% of employees), a smaller but still high share of production in the GVA (19-54%). At the same time, the values of indicators of socio-economic development for these regions are an order of magnitude lower than the revenues generated in the first cluster. The average per capita cash income is less by 50%, the average GRP per capita is less by 80%, the average investment in fixed assets per capita is 90% less than in cluster No. 1. But compared with other resource regions (clusters No. 2 and No. 4), these indicators reach high levels, so we can talk about the high efficiency of this cluster.

**Table 2.** Clustering of regions according to the characteristics of oil and gas complex and socio-economic development.

| №  | Region                        | Cluster                                      | Cluster description                                                                 |
|----|-------------------------------|----------------------------------------------|-------------------------------------------------------------------------------------|
| 1  | Nenets Autonomous District   | Cluster No. 1 - Regions with High Production Impact and Ultra High Efficiency | High proportion of people employed in mining 55-75% share of production in the GVA The highest values of indicators of socio-economic development |
| 2  | Yamal-Nenets Autonomous District |                                | Lowest mining share Low GVA production The lowest values of indicators of socio-economic development |
| 3  | Krasnodar region             | Cluster No. 2 - Regions with low production impact and low efficiency |                                                                                   |
| 4  | Republic of Kalmykia         |                               |                                                                                   |
| 5  | Kirov region                 |                               |                                                                                   |
| 6  | Saratov region               |                               |                                                                                   |
| 7  | Ulyanovsk region             |                               |                                                                                   |
| 8  | Novosibirsk region           |                               |                                                                                   |
| 9  | Tyumen region                |                               |                                                                                   |
| 10 | Astrakhan region             |                               |                                                                                   |
| 11 | Irkutsk region               |                               |                                                                                   |
| 12 | Omsk region                  |                               |                                                                                   |
| 1  | Komi Republic                | Cluster No. 3 - Regions with High Production Impact and High Efficiency | 20-50% of GVA relates to mining High values of indicators of social and economic development |
| 2  | Republic of Tatarstan        |                               |                                                                                   |
| 3  | Krasnoyarsk region           |                               |                                                                                   |
| 4  | The Republic of Sakha (Yakutia) |                               |                                                                                   |
| 5  | Sakhalin Oblast              |                               |                                                                                   |
| 1  | Republic of Bashkortostan    | Cluster No. 4 - Regions with medium production impact and low efficiency | High reserves and production Low mining share Up to 35% of GVA relates to mining Average values of indicators of socio-economic development |
| 2  | Samara Region                |                               |                                                                                   |
| 3  | Udmurtia                     |                               |                                                                                   |
| 4  | Orenburg region              |                               |                                                                                   |
| 5  | Perm region                  |                               |                                                                                   |
The fourth cluster consists of six regions with medium production impact and low efficiency. The influence of the mining industry in this cluster should be called medium rather than low, since the share of production in the GVA varies from 4% to 35%. The share of the population employed in the industry does not exceed 5%. The effectiveness of this cluster can be called low, since in general the values of indicators of socio-economic development are comparable to indicators of cluster No. 2.

The main conclusions of this clustering can be formulated as follows. The highest average per capita incomes, GRP per capita and investment in fixed assets per capita are observed in clusters with a high influence of the mining industry in the regional economies - cluster No. 1 and cluster No. 3. In clusters with a low impact of production, that is, more diversified economies, show an order of magnitude lower indicators of income, product created and investment in fixed assets. This is cluster No. 2 and cluster No. 4. Cluster No. 4 is characterized by much larger oil production than cluster No. 2, but despite this, the average per capita income of the population is close.

5. Conclusion
The conducted cluster analysis on the factors of the quality of the raw material base and the factors of the socio-economic situation revealed the special position of the Yamalo-Nenets and Nenets Autonomous Districts in relation to the values of the factors chosen to take into account socio-economic development. This fact required additional study and cluster analysis on the characteristics of the oil and gas complex of the regions. Some patterns were identified among which:

- Regions with high reserves and a low degree of hard-to-recover oil reserves on average show a higher level of socio-economic development than regions with high reserves and a high degree of hard-to-recover oil reserves;
- Regions with small reserves and a low degree of hard-to-recover oil reserves have, on average, a higher socio-economic position than with small reserves and a high degree of hard-to-recover oil reserves;
- The highest average per capita incomes, GRP per capita and investment in fixed assets per capita are observed in clusters with a high influence of the mining industry in the regional economy;
- In clusters with a low impact of production, that is, more diversified economies, show an order of magnitude lower indicators of income, product created and investment in fixed assets.

Thus, the factor of difficult to extract showed a negative impact on the level of socio-economic situation in the region, i.e. At present, the mechanism of transferring the effect of the development and implementation of technological innovations to regions with hard-to-recover oil reserves has not yet been fully developed. This is largely due to the imbalance in the location of centers with innovative and raw materials potentials. However, using the positive experience of combining these potentials with the Republics of Bashkortostan and Tatarstan, it is possible to accelerate spatial development in the context of the shift of oil and gas production centers to remote regions that need comprehensive development, including innovative.

The factor of monopolization of the economy (low diversification) by the mining industry had a positive impact on the socio-economic situation of resource regions. This is largely due to the higher social responsibility of mining companies in the regions of their monopoly presence. For example, the relationship between Gazprom and the cities of the Yamalo-Nenets Autonomous Okrug - Nadym, Novy Urengoy, Pangody, Rosneft and the Sakhalin Oblast and Komsomolsk-on-Amur, etc. However, these effects can be traced in traditional mining regions, where urban and regional infrastructures were formed back in Soviet times. While the modern strategy for developing new oil-producing regions is mainly based on the shift method, which weakens the socio-economic effects for the regions.
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