IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Application of multicriteria fuzzy clusterization approach to assess the arctic seas oil and gas field development prospects

To cite this article: K N Pivovarov *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **700** 012049

IOP Conf. Series: Materials Science and Engineering **700** (2019) 012049 doi:10.1088/1757-899X/700/1/012049

Application of multicriteria fuzzy clusterization approach to assess the arctic seas oil and gas field development prospects

K N Pivovarov[1,*] A B Zolotukhin[1,2,3] and V V Streletskaya[1]

[1] Gubkin Russian State University of Oil and Gas (National Research University), Leninsky prospect 65, Moscow, 119991, Russia
[2] Northern Arctic Federal University, Severnaya Dvina Emb. 17, Arkhangelsk, 163002, Russia
[3] The University of Stavanger, P.O. Box 8600 Forus N-4036 Stavanger, Norway

* Corresponding author: pivovarov_k@mail.ru

Abstract. The article describes a unified approach to the assessment of resources and business planning. As an example, the oil and gas resources of the Pechora Sea are considered in the paper. Based on the specifics of the problem (the quantity and quality of the available data and their nature), the methods of multicriteria fuzzy clusterization are used. The assessment of the prospects for the development of oil and gas fields was carried out using 3 criteria, namely: availability of resources (natural and climatic conditions of the region); hydrocarbon resources and their degree of exploration; economic assessment of the development. The results of such an analysis are presented in the form of maps of the Pechora Sea area, illustrating the most important and accessible areas and the sequence of their development. Such a stepwise development based on minimizing the risk and maximizing the benefits can be the basis for the successful and trouble-free development of the resources of the entire region.

1. Introduction

Currently, the oil and gas industry of Russia is actively entering a new phase of the development of offshore Arctic fields. The reserves of natural hydrocarbons in the zone of the Russian Arctic are truly enormous. The degree of involvement of these reserves in the development will affect the economic growth of Russia, as well as the stability of the development of many other countries of the world. The Arctic region has an extremely challenging climate and as its development requires the highest technical and technological level of development, it becomes clear that the relevance of systematization of data and forecasting methods for the development of the Arctic is estimated to be extremely high.

Human activities in the Arctic include shipping, fishing, extraction of minerals, fast growing tourism and offshore oil and gas field development. Large oil and gas fields are already reasonably explored and ready for development.

Evaluation of the arctic offshore fields' accessibility is illustrated for the Pechora Sea region and is based on multi-criteria approach represented by 3 main axes:

- Availability of resources (natural and climatic conditions of the region);
- Hydrocarbon resources and their degree of exploration;
- Economic assessment of the development.

The methodology of the forecast is based on a fuzzy sets approach.

2. Accessibility of resources (natural and climatic conditions of the region)

The availability of resources, in terms of climatic, geographical and ecological conditions, is one of the fundamental characteristics for the analysis of the offshore regions. This represents a multi-criteria parameter challenge, consisting of the following criteria:

- Weather conditions: This parameter is used for understanding the climatic severity of regions, including the complexity of the working conditions. This parameter considers the influence of the weather environment, both on offshore structures and on the conduct of many marine operations. In determining the values of this factor, a comparative descriptive characteristic of the sea areas is given, based on the analysis of long-term observations of scientists (Figure 1(a)).
- Ice conditions: This parameter includes the ice type, the average width of the ice and so on. Its main parameter that has an influence on the concept of field development (type of platform, well completion, storage and transportation), investment costs (platform type) and operation costs (ice conditions control). This parameter points to the technological solution for the development, including the level of protecting offshore structures and the need for competent and timely ice management (Figure 1(b)).
- Icebergs and their occurrence probability in the region: Icebergs, as one of the most dangerous ice formations, threaten not only shipping and operations of offshore oil and gas facilities, but also significantly increase the risks associated with the safe conduct of the production operation processes. This factor is based on the analysis of historical data of long-term observations of ice conditions. But it should be borne in mind that this approach cannot fully describe the probability of an iceberg colliding with the platform, since the total movement of many icebergs is sufficiently random and chaotic, depending on currents, winds and the Coriolis force (Figure 1(c)).
- Gas hydrates accumulations in areas can influence exploration and development: larger volumes of gas hydrates deposited under the sea bed bring additional challenges to the production of HC. Gas hydrate areas are dangerous because when thawing, 1 cubic meter of gas hydrates in this zone can release more than 160 m^3 of gas [1]. This mainly occurs when drilling and cementing a well, as too hot drilling fluid and cement can significantly increase the temperature in the near-wellbore zone and change the pressure established in the reservoir (Figure 1(d)).
- Duration of the ice-free period: this parameter has a strong impact on exploration drilling which is usually performed in the ice-free period. In the areas with short ice-free navigation period the cost of exploration drilling is significantly higher than in ice-free areas. Accordingly, there is an escalation of risks of non-fulfilment of drilling obligations on time, because of storms, strong winds and high seas as often occur during ice-free periods. All this complicates the work and hinders its implementation (Figure 1(e)).
- Sea depth (Figure 1(f)): this is the second most important criterion for the analysis. The type of marine facilities is heavily reliant on the sea depth. In theory, the problems associated with depth increase exponentially with its increase, but practice shows that at shallow depths and in coastal areas other difficulties arise: high environmental sensitivity, ploughing the bottom with the keel of ice ridges (representing problems for subsea pipelines and sub-sea equipment) and coastal erosion [2].
- Proximity to shore (Figure 1(g)): this is used as criterion to choose the transport type (as pipeline from field to shore). In addition, it is important for health and industrial safety issues (search and rescue of personnel). This parameter is estimated as the shortest distance from the field location to the coastline. Offshore areas are characterized by the lack of infrastructure, satellite coverage and the possibility of rapid emergency response. It is important to note that coastal

IOP Conf. Series: Materials Science and Engineering **700** (2019) 012049 doi:10.1088/1757-899X/700/1/012049

areas are more environmentally sensitive than offshore areas, in particular is the coastal erosion of concern.

- Remoteness from the supply base is discussed for preliminary estimation of efforts for providing necessary equipment, materials and man power (transportation, supports, evacuation, etc.). In the Arctic, the logistics component of the project is also among the most important and complex tasks: the distance between the field and the supply base plays a significant role in the preliminary assessment of work to secure continuous supply of equipment, materials and labour (Figure 1(h)).
- Flora & Fauna: this criterion is related to the number and variety of animals and plants. This parameter means ecological balance in a region. Diversity of flora and fauna of the Arctic seas is quite large, and several animals are even included in the Red Book of endangered species (narwhals, polar bears, white whales, Atlantic walrus, Greenland whale, etc.) (Figure 1(i)).
- Potential environmental impact due to oil spill: this criterion shows the damage of the ecological balance due to an oil spill disaster and the possibility to return this balance to normal (Figure 1(j)). In addition to considering quantitative and qualitative indicators of flora and fauna, this factor also depends on other criteria: currents in the region and their vectors, meteorological conditions, remoteness of the area from the coastline and from operation bases, ice conditions, etc. Inclusion of two environmental factors in a row in the overall analysis is due to the fact that the care for the extremely sensitive and fragile northern ecosystem and understanding of possible consequences of disturbing the natural balance are fundamental criteria for the diligent and responsible development of oil and gas resources in the Arctic seas.

A technology accessibility map is, furthermore, shown on Figure 2:

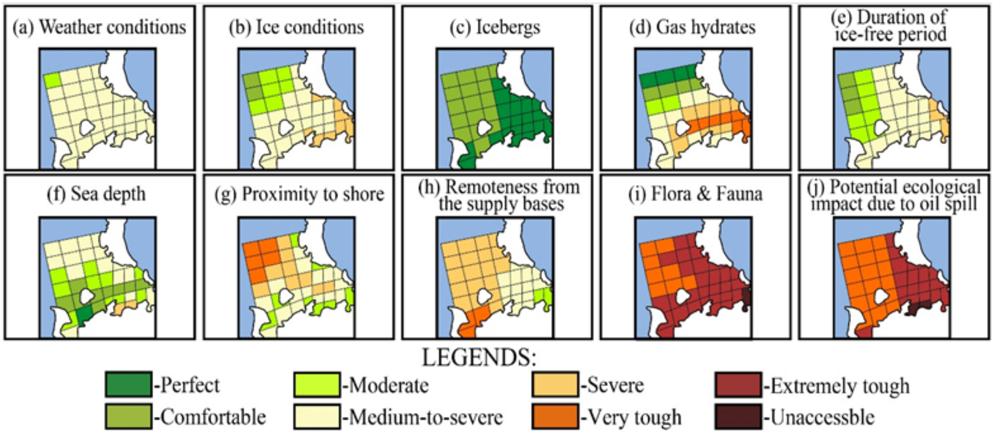

Figure 1. Features of the Pechora Sea

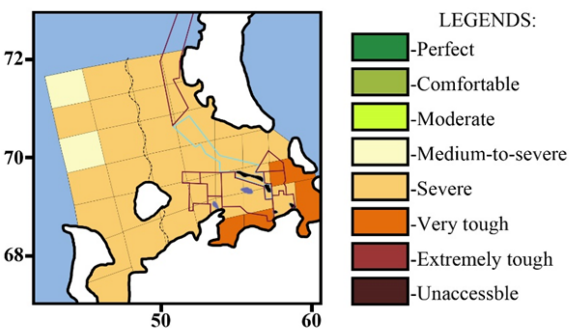

Figure 2. Map of technological accessibility

3. Hydrocarbon resources and their degree of exploration

The "Geological axis" shows the degree of exploration of the region in question and the region's reasonably assured oil and gas resources:

- The degree of exploration of the Pechora Sea region could be thought of as the density of the seismic exploration (lines per square kilometer) and the volume of the seismic survey (Figure 3)
- Resource assessment – oil, gas and condensate, expressed in tons of oil equivalent (TOE). It is based on the classification of structures (deposits) by the size of their reserves. Figure 4 shows the licensed areas of Rosneft and Gazprom, as well as the discovered deposits of the Pechora Sea. It depicts 6 fields, of which only the Prirazlomnoye field is currently in production.

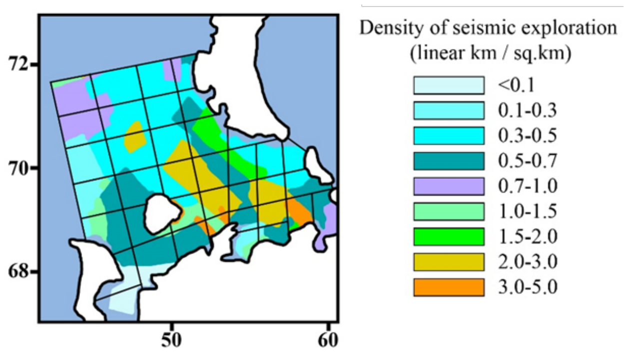

Figure 3. Density of seismic exploration, built on [3].

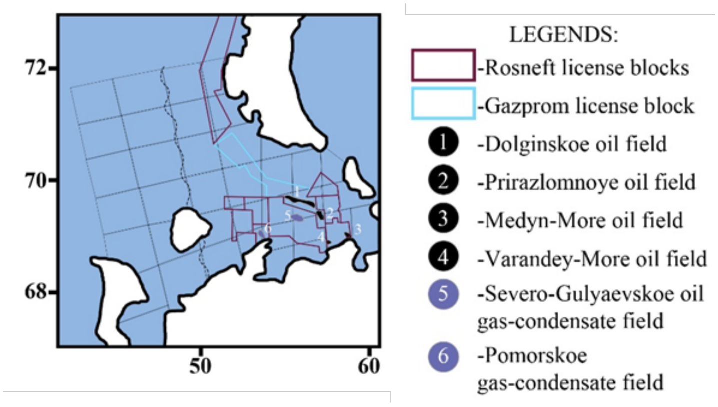

Figure 4. Discovered fields and license blocks.

It should be noted that the fields and license blocks fall into different zones, therefore their possible recoverable resources are spread over these zones proportional to the percentage ratio falling into one or another block. Such an approach enables us to present the zones as clusters of several sub-class deposits. It is possible, however, that some of the deposits, due to their size, are not profitable to be developed on a stand-alone basis. It is also possible that licensed blocks attributable to a specific zone will not contain commercial hydrocarbon reserves. For such blocks we assume that the degree of their exploration corresponds to a 50% probability (P_{50} value).

It is worth noting that the more sites there are and the smaller their sizes are, the more detailed will be the picture of the development of these sites and the need to use data averaging procedures will be reduced.

IOP Conf. Series: Materials Science and Engineering **700** (2019) 012049 doi:10.1088/1757-899X/700/1/012049

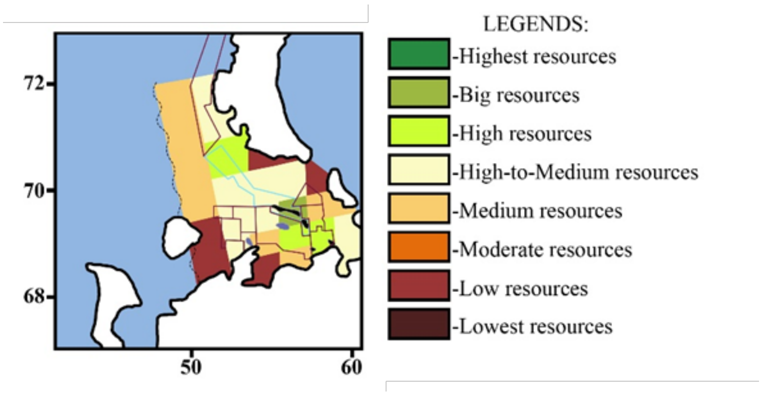

Figure 5. Map showing reserves

Because data on reserves or structures is not for the whole region, for the purpose of comparison, “empty” areas are excluded from further analysis (Figure 5). Combining the previous two parameters and using the fuzzy sets approach (see Section 5), we get a map of resources.

4. Economic assessment of the development

The "Economic assessment” is used as value development indicator:

- Possible revenue from a project is calculated as a product of the current price of the oil barrel and the preliminary estimated recoverable oil and gas reserves of a given territory (Figure 6). This economic indicator is not comprehensive and reflects only the very idea that an assessment of the economics of a block will allow a closer look at different territories in terms of their economic attractiveness.

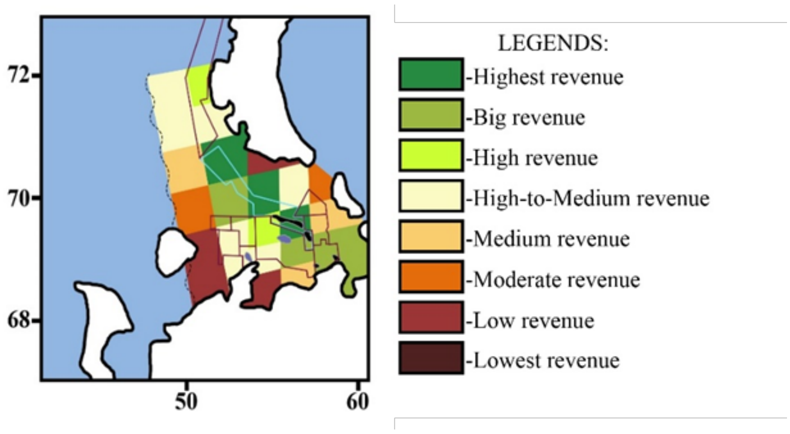

Figure 6. Economic assessment map.

5. Methodology

The methodology of the approach to assess the arctic seas oil and gas field development prospects is based on the fuzzy logic theory. The entire area of the Pechora Sea was divided into several zones. Those zones were studied and assessed by using the multi-criteria approach. The reason to use the fuzzy logic approach was that it enables us to operate with many parameters with limited knowledge of the subject and large uncertainty regarding the available data without any difficulty [4, 5].

In contrast to the Boolean logic, this approach differs from the standard binary logistic answers “true” or “false”. It allows us to reflect on the degree of incompleteness and uncertainty of our knowledge [6] and provides effective tools for building models that most adequately reflect the quantity and quality of the available data [7].

The multiple criteria approach in assessing the complexity of the conditions means simultaneous analysis of many factors. This approach is discussed in detail in [8], where the task of mapping the technical accessibility has been analyzed. Consequently, the approach is only briefly described herein. As explained above, three main axes were selected for building the map. A whole range of values for each criterion was mapped on the axis of the corresponding membership function, which was further divided into eight different classes, where the 1st class had the lowest and the 8th – the highest value.

Subsequently, each membership grade was described by well-defined numerical values selected from the interval (0, 1), which is divided into 8 subintervals of 0.125 widths each. To aggregate these characteristics in order to build an aggregated map, the authors with respect to the existing approaches to fuzzy systematization of data, chose the Weighted Geometric Mean method (WGM). This method is based on the method of aggregation of a multiple criteria objective function into a single criterion one by using the following rule:

$$\mu_{A_0} = \mu_1^{\omega_1} \cdot \mu_2^{\omega_2} \cdots \mu_n^{\omega_n} \tag{1}$$

Here μ_i is an estimate by the i-th criterion, ω_i is the coefficient of significance of the *i*-th criterion, *n* – the total number of criteria, participating in the assessment [9].

In addition to the clustering of considered zones, the fuzzy approach can be used for ranking of the zones, i.e., their grading according to the degree of attractiveness or complexity of the conditions for their development [10]. The fuzzy ranking consists of 3 consecutive stages of calculations.

The first step is to calculate a non-strict preference when comparing fields or production zones (one is preferable to no less than the other) according to the equation [10]:

$$\mu_R(i,j) = 1 - \sum_{k=1}^{n} \omega_k \cdot [\mu_k(j) \ominus \mu_k(i)] \tag{2}$$

Here *n* – number of parameters in the evaluation, *i, j* – indexes of compared fields / production zones, symbol $\ominus$ – limited subtraction, $\mu_k(j) \ominus \mu_k(i) = \max\{0, \mu_k(j) - \mu_k(i)\}$ [10].
The second step is based on the principle of strict preference on compared criteria [10]

$$\mu_P(i,j) = \mu_R(i,j) \ominus \mu_R(j,i) \tag{3}$$

The last step of fuzzy ranking is a link between the two previous steps which rank the fields according to the degree of complexity of their development. The following relationship is used for this purpose [10]:

$$\mu_\Phi(i) = \frac{1}{(n-1)} \left\{ \sum_{j \neq i} \mu_P(i,j) \ominus \sum_{j \neq i} \mu_P(j,i) \right\} \tag{4}$$

Here the first sum shows the fuzzy measure of the preference of the element *i* to all other elements *j*. The second sum shows the fuzzy measure of preference of elements $j \neq i$ to the element *i*. The map of approach to assess the Arctic Seas oil and gas field development prospects is shown in Figure 7.

Analysis of each zone according to the criteria described above made it possible to compile a summary table of the characteristics of all zones, which in turn made it possible to aggregate the multi-criteria assessment into a single-criterion one by aggregating all the criteria into the weighted geometric mean and construct an accessibility map that takes into account economic, technological and geological components (Figure 7). In addition to the division of production zones into clusters according to the levels of technical accessibility, degree of exploration and economic attractiveness, Figure 7 shows the ranking of territories.

It is easy to see that the Prirazlomnoye field is in the 1st ranking zone, which is confirmed by its industrial development. Organization of a systematic approach for the business planning enables creation of comprehensive and phased commissioning of oil and gas fields.

According to Figure 7, the next stage of the development of the region may well be the development of the Dolginskoye and Severo-Gulyaevskoye fields, then moving to the Varandey-More and Medyn-More fields. At the same time, it is necessary to continue exploration of license areas to identify promising structures and discover new deposits.

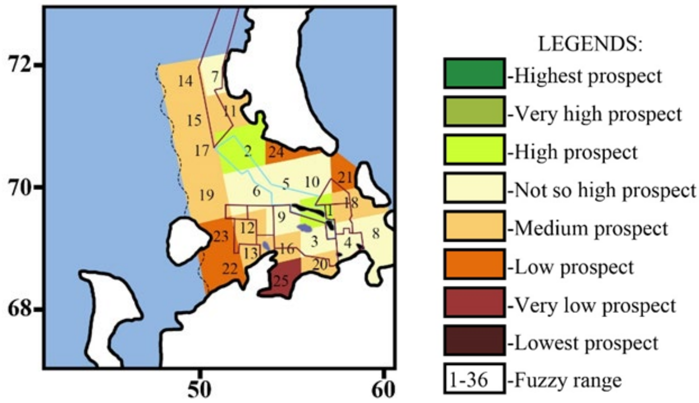

Figure 7. Fuzzy clustering and ranking of fields / production zones on 3 axes.

6. Conclusion

Pechora Sea is a region known for its environmental sensitivity and it is important to minimize negative anthropogenic impacts. Sequential field development planning allows a comprehensive approach to production optimization. The high commercial potential of the region and the uncertainty caused by the global climate change requires intensified research and development activities to achieve a stable and long-term development strategy. Due to the nature and intrinsic properties of fuzzy logic its application enables forecasting of development stages, based on changeable, incomplete and inaccurate information. Those specific mathematical properties allow us to assess potential development of oil and gas fields located in the arctic waters from different points of view, focusing either on a single parameter or conducting a comprehensive multi-criteria analysis.

It is worth noting that the example considered in the paper clearly demonstrates that the development of this area was started in the same manner as suggested by the system developed by the authors.

References

[1] Judzis A, Schofield TR and Yousif M 1997 Stabilization of In-Situ Hydrates Enhances Drilling Performance and Rig Safety *Proc. SPE Annual Technical Conf. and Exhibition (San Antonio)* Paper SPE 38568.

[2] Mørk K 2007 The challenges facing Arctic pipelines, design principles for extreme conditions, *J. Offshore Oil and Gas Magazine* **67** 9.

[3] Tkachenko M 2014 Geological structure and oil and gas potential of the Jurassic complex of the central part of the East Barents megaprogib (Moscow: FGBU VNIGNI).

[4] Zade L 1965 Fuzzy sets, *J. Inform. Control.* **8**(3), 338 – 353.

[5] Hurgin Ya 1995 Fuzzy methods in the oil and gas industry (Moscow: I. M. Gubkin State Academy of Oil and Gas), 131.

[6] Leonenkov A 2005 Fuzzy simulation in the MATLAB and fuzzyTECH (Saint-Petersburg: BHV Petersburg), 736.

[7] Golunov R, Dli M and Kruglov V 2001 Fuzzy logic and artificial neural networks (Moscow: Fizmatlit), 201.

[8] Zolotukhin A, Nesic S, Pivovarov K and Streletskaya V 2017 Mapping the main risks for offshore operations in the Pechora Sea *Int. Conf. on Safety and Security Engineering (Rome) SAFE*, **174**, 69–80.

[9] Zolotukhin A and Pivovarov K 2018 Use of multicriteria approach and methods of fuzzy mathematics for estimating development conditions of arctic seas in terms of the south-eastern part of the Barents Sea, *J. Arctic: ecology and economy,* **3**(31), 100–111.

[10] Zolotukhin A 2007 Engineering methods in petroleum science (Stavanger: Stavanger University) *Preprint* Lecture notes on the master's course MPE 140.