PERIÓDICO TCHÊ QUÍMICA
CASE STUDY

FONTE DE MATÉRIA PRIMA DE HIDROCARBONETOS DA ZONA ÁRTICA DA RÚSSIA

RAW MATERIAL SOURCE OF HYDROCARBONS OF THE ARCTIC ZONE OF RUSSIA

СЫРЬЕВАЯ БАЗА УГЛЕВОДОРОДОВ АРКТИЧЕСКОЙ ЗОНЫ РОССИИ

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Received 15 June 2020; received in revised form 18 September 2020; accepted 15 October 2020

RESUMO

O estudo do potencial de hidrocarbonetos do Ártico está sendo considerado na Rússia como a direção mais importante na preparação de uma nova base de matérias-primas de petróleo e gás, que substituirá as reservas extraídas nas áreas tradicionais de desenvolvimento durante o segundo trimestre desse século. A queda acentuada nos preços globais de hidrocarbonetos levou a uma redução nos custos de pesquisa e exploração, especialmente em áreas de difícil acesso e reservas de difícil recuperação, bem como na necessidade de determinar a contribuição para o equilíbrio de combustível e energia do país a partir do desenvolvimento da zona do Ártico, incluindo a superfície, sem a qual é impossível planejar e desenvolver novos projetos caros. Uma avaliação justa do potencial de petróleo e gás com base em um conjunto de ideias sobre os processos de formação de bacias sedimentares e processos de geração de petróleo e gás contribuiu para a obtenção de novas informações geofísicas sobre os resultados do trabalho sísmico executado na zona ártica da Federação Russa entre 2010 e 2020. Foi realizada uma avaliação quantitativa dos recursos de petróleo e gás, utilizando o método de analogias geológicas (para áreas geológicas e geofísicas bem estudadas) e o método genético-volume (para bacias menos estudadas). Foram verificadas diferenças significativas em relação às avaliações mais conhecidas do Ártico, tanto em termos do volume total de hidrocarbonetos quanto de sua composição de fases. Concluiu-se que existe ambiguidade na avaliação do potencial das zonas de águas profundas dos mares do Ártico e, por isso, é importante estudar áreas costeiras e rasas, especialmente o teor de óleo

Palavras-chave: *potencial de hidrocarbonetos do Ártico russo, métodos de avaliação de recursos, método de analogias geológicas, método de avaliação de sistemas de hidrocarbonetos, composição de fases de hidrocarbonetos.*

ABSTRACT

The study of the hydrocarbon potential of the Arctic is being considered in Russia as the most crucial direction of preparing a new raw material base of oil and gas, which will replace the extracted reserves in traditional areas of development during the second third of this century. The sharp fall in global hydrocarbon prices has led to a reduction in research and exploration costs, especially in hard-to-reach areas and hard-to-recover reserves as well as the need to determine the contribution to the country's fuel and energy balance from the hydrocarbons development of the Arctic zone, including the shelf, without which it is impossible to plan and develop new expensive projects. A fair assessment of oil and gas potential, based on a set of ideas about the processes of formation of sedimentary basins and oil and gas generation processes, contributed to obtaining new geophysical information on the results of seismic work executed in the Arctic zone of the Russian Federation between 2010 and 2020. A quantitative assessment of oil and gas resources was performed using geological analogies (for well-studied geological and geophysical areas) and the volume-genetic method (for less studied basins). It showed significant differences from the most well-known assessments of the Arctic, both in terms of the total volume of hydrocarbons and their phase composition. It was concluded that there is ambiguity in assessing the potential of deepwater zones of the Arctic seas. Because of that, it is important to study coastal and shallow areas, especially oil content.

Keywords: *hydrocarbon potential of the Russian Arctic, methods of resource assessment, method of geological analogies, the evaluation method of hydrocarbon systems, phase composition of hydrocarbons.*

DOI: 10.52571/PTQ.v17.n36.2020.521_Periodico36_pgs_506_526.pdf

АННОТАЦИЯ

Изучение и подготовка к освоению углеводородного потенциала Арктики рассматривается в России как важнейшее направление развития новой сырьевой базы нефти и газа, которая заменит добываемые запасы нефти и газа в традиционных районах освоения во второй трети текущего столетия. Резкое снижение мировых цен на углеводороды привело к сокращению затрат на исследования и разведку, особенно в труднодоступных районах и применительно к трудноизвлекаемым запасам, а также к необходимости более внимательного определения возможного вклада в топливно-энергетический баланс страны от освоения углеводородов Арктической зоны, в том числе Арктического шельфа, без чего невозможно планирование и подготовка к реализации новых дорогостоящих инвестиционных проектов. Адекватной оценке перспектив нефтегазоносности, основанной на совокупности представлений о процессах формирования осадочных бассейнов и процессах нефтегазообразования, способствовало получение новой геофизической информации по результатам сейсморазведочных работ, выполненных в Арктической зоне Российской Федерации в период с 2010 по 2020 годы. Проведена количественная оценка ресурсов нефти и газа с использованием метода геологических аналогий (для хорошо изученных геолого-геофизическими методами районов) и объемно-генетического метода (для менее изученных частей бассейнов). Она показала существенные отличия от наиболее известных оценок ресурсов Арктики как по общему объему углеводородов, так и по их фазовому составу. Сделан вывод о наличии неоднозначности в оценке потенциала глубоководных зон арктических морей и, в связи с этим, о важности изучения прибрежных и мелководных районов на продолжении в акваторию осадочных бассейнов, преимущественно нефтеносных и содержащих скопления газоконденсата.

Ключевые слова: *углеводородный потенциал Арктики России, методы оценки ресурсов, метод геологических аналогий, метод оценки углеводородных систем, фазовый состав углеводородов.*

1. INTRODUCTION:

The increased interest in the development of the Arctic region, shown in recent years by the international community, is caused by energies and economic and geopolitical factors. The development of the Arctic for Russia is not only a matter of national and energy security in the long term but also one of the most potent drivers for the development of innovation, science, high-tech production, and technology, comparable to the ambitious project for space exploration in the USSR (a comparison of academicians E.P. Velikhov and A.E. Kontorovich) (Kontorovich, 2015).

By its synergistic effect, is likely to be on a par with such events that provided a breakthrough in the country's economy in the last century, such as the space program mentioned above, the creation of the science campus, which determined scaling up scientific research, that led to tremendous progress in technology and the industrial development of the oil and gas potential of Western Siberia (Prischepa *et al*., 2019), which allowed making the country one of the leading economies in the world. Despite the wide variety of oil and gas basins in Russia, the generally accepted perspective is that the most significant part of the territories and water areas promising for gas is located in the Arctic zone. Its oil potential remains somewhat uncertain.

The Arctic territories provide more than 80% of gas production in Russia and about 12% of the production of liquid hydrocarbons (HC) (Table 1) (Pavlenko, 2013; Prischepa *et al*., 2019; Prischepa *et al*., 2020; Carayannis *et al*., 2019; Cherepovitsyn *et al*., 2018). In official government documents of the Russian Federation (Strategy of social and economic development, 2013; Bases of public policy, 2020; Draft of strategy, 2020, Research of the Analytical Centre, 2015) it is designated as an essential element for the implementation of the Arctic projects such as “intensification of geological exploration for oil and gas”.

The implementation of the strategic plans of development of the Russian Arctic is only possible if the adequacy of the oil and gas potential of the Arctic and the task of creating conditions and mechanisms ensuring the development of the Arctic regions and the favorable market of hydrocarbons and transportation, which directed the efforts of the state support (Kontorovich, 2015).

2. LITERATURE REVIEW:

2.1. State of the Arctic zone resource base

The basis for the quantitative assessment of the oil and gas potential is the geological understanding of the development of sedimentary basins, the characteristics of the strata, the reserves of already identified deposits, seismic data determining both regional, zonal and local features of the region, and a whole series of oil and gas potential criteria (Bogoyavlensky *et al*., 2019, Carayannis *et al*., 2019; Tcvetkov *et al*., 2020). The official result of the oil and gas potential is assessing the total in-situ resources (TIR) of oil and gas, carried out and approved by the state authority of the Russian Federation - the Federal Agency for Subsoil Use. It covers all promising and gas-bearing basins and, accordingly, includes the Russian Federation (Kaminsky *et al*., 2018; Prischepa *et al*., 2019, 2020).

Numerous land-based companies and two state-owned companies - Gazprom PJSC and Rosneft PJSC - which have exclusive rights to work on the Arctic shelf, are conducting their hydrocarbon potential studies. However, they often relate exclusively to existing licenses or promising licensed areas, which companies consider a priority for their development. The results of the official quantitative assessment of the resources of the Arctic waters and territories have been published more than once (Kontorovich, 2015; Vorotnikov *et al*., 2019; Kaminsky *et al*., 2016; Kaminsky *et al*., 2017; Suprunenko *et al*., 2016; Suprunenko *et al*., 2012; Kaminsky *et al*., 2018; Prischepa *et al*., 2019, 2020) and in this report an attempt is made to compare them with the most well-known independent estimates and those of Western experts.

There are serious concerns that the official estimate of resources to a significant extent, reflects current trends indicated by the official point of view about the Arctic's considerable potential. First of all, this conclusion is based on the fact that a comparison of the potential estimates of the least studied part of the Arctic shelf indicates a steady increase, often not confirmed by an increase in exploration, new significant discoveries or the identification of fundamentally new directions for increasing the raw CHC material base (Kontorovich, 2015; Kaminsky *et al*., 2018; Prischepa *et al*., 2019).

For example, the total hydrocarbon resources of the richest West-Arctic shelf as of 01.01.1993 were estimated at 75.3 billion tons of fuel equivalent. The next assessment (as of 01.01.2002) showed their increase (by 256 million tons of standard fuel equivalent in Pechorsky, by 1,860 million tons of technical equivalent in the Barents and 5,096 million standard tons in the Kara Sea) in the amount of 7.2 billion tons of standard fuel equivalent. The next assessment (as of 01.01.2009) showed an additional increase in resources (17.5 billion tons of standard fuel) and the achievement of a total resource estimate of more than 100 billion tons of fuel equivalent, and a preliminary (state) estimate (as of 01.01.2019) also showed a slight increase in the amount of up to 103 billion tons of fuel equivalent. It led to a paradoxical situation of a significant decrease in the indicator of exploration of oil and gas reserves against the background of an increase in geological and geophysical knowledge (Varlamov, 2018; Skorobogatov *et al*., 2019, 2020).

This is especially surprising in the Pechora Sea water area. The discovery of new deposits dates back to the period between 1993 and 2002. A significant increase in the resource estimate occurred when there was practically no increase in reserves in 2002-2009. These discrepancies make us more attentive to the estimates obtained later (Chanysheva *et al*., 2019).

The oil and gas potential of the Russian sector of the Arctic is unique both in volume and in composition diversity. It is proved by numerous discoveries of unique, giant, and large oil and gas deposits on its mainland (more than 50 giant and large deposits have been identified) and gas reserves in the waters of the seas of the Arctic Ocean (Prischepa *et al*., 2019). Below, the author considers the most famous assessments and their potential of the Arctic performed by the following organizations and researchers: U.S. Geological Survey (USGS), Arctic Council, Mackenzi, UN; Gazprom VNIIGAZ LLC, VNIGNI, VNIGRI, VNIIOkeangeologiya, Russian Academy of Sciences, Kenneth J. Bird, Ronald R. Charpentier, Donald L. Gautier, David W. Houseknecht, Timothy R. Klett, Janet K. Pitman, Thomas E. Moore, Christopher J. Schenk, Marilyn E. Tennyson, Craig R. Wandrey (Neville, 2017; Durbano *et al*., 2015, Energy Futures, 2013; Mulrooney *et al*., 2017; Llopart *et al*., 2019; Lerch *et al*., 2016; Houseknecht *et al*., 2018; Harada, 2020; Galloway *et al*., 2018; Dewing, 2019; Kontorovich, Kaminsky *et al*., Suprunenko *et al*., 2016; Yurchenko, 2018; Blumenberg, 2016; Sobolev, 2016; Skorobogatov, Prischepa *et al*., 2020; Otmas *et al*., 2017; Tolstikov, 2018).

The international community of experts (Geological Survey of the USA (USGS) in 2008; Wood Mackenzie, 2006; Resources to Reserves, 2013; Research and Development, 2010) in the oil and gas industry is making attempts to assess the hydrocarbon potential of the Arctic, including its international and Russian segments.

2.2 State of the Arctic zone resource base

The best-known estimates were made by the consulting companies Wood Mackenzie and Fugro Robertson in 2006 and the Geological Survey of the USA (USGS) in 2008. They conducted two individual studies of the Arctic hydrocarbon potential (Schenk, 2012; Houseknecht *et al*., 2012).

Before discussing and comparing the results of these assessments, it should be noted that the research areas, according to USGS, were limited to those located north of the Arctic Circle. Suppose for water areas, and this approach is not entirely different from that used in Russia for the Arctic shelf, then for land areas (territories). In that case, the Arctic regions' assignment is regulated in Russia by specific documents. These territories differ significantly from those estimated in USGS's work (Decree of the President of the Russian Federation of May 2, 2014). Therefore, the assessment's given comparison must be adjusted, taking into account this condition (Ivanitskaya *et al*., 2019). Simultaneously, all Arctic water areas are unambiguously comparable with international experts' assessment areas (Figures 1 and 2). (Arctic Environmental Protection Strategy, 1991; Oil and gas exploration in the Arctic; Fundamentals of the state policy of the Russian Federation in the Arctic, 2020; Research of the Analytical Centre under the Government of the Russian Federation, 2015)

USGS estimates include 6 Arctic land areas of Russia - the northern part of the Timan-Pechora and West Siberian sedimentary basins, the Yenisei-Khatanga, and Leno-Anabarsky basins, the extreme North-Eastern fragment of the Lena-Vilyui basin and the Zyryan basin. At the same time, the Northern part of the Lenno-Tunguska NGP, including areas north of the Arctic Circle, was not evaluated. Since some subjects, for example, Yamal-Nenets Autonomous Okrug are completely included in the ADR, the borders of the ADR are expanded to areas south of the Arctic Circle. It does not coincide with the areas of USGS, 2008, Mackenzie (Ivanova *et al*., 2019; Shemin, 2019; Proceedings of the All-Russian Scientific-Practical Conference, 2013).

The report of Wood Mackenzie and Fugro Robertson was based on a detailed analysis of geophysical and seismic data in various Arctic basins. According to a Future of the Arctic - A New Dawn for Exploration (Geological Survey, 2008) study, new oil and gas resources in the Arctic are estimated at 233 billion barrels of oil equivalent, or more than 30 billion tons (conversion factor of 5.35 trillion cubic feet to 1 billion barrels of oil equivalent was used). At the same time, 85% of explored reserves and 74% of expected (resources) are gas. In 2008, USGS US Geological Survey prepared a report, Assessment of the Unexplored Oil and Gas Reserves of the Arctic North of the Arctic Circle (Wood Mackenzie, 2006).

In USGS study, the main emphasis was made on probabilistic geological analysis and identification of those areas that have a chance to contain relatively large reserves of oil or gas (more than 50 million tons of oil equivalent). According to USGS study, the total unexplored oil and gas resources of the entire Arctic is about 413 billion BOE (barrel of oil equivalent), or about 22% of the total unexplored reserves of traditional hydrocarbons in the world (which is about twice as high as the estimates made by Wood Mackenzie/Fugro Robertson). Novel oil resources are estimated at approximately 90 billion barrels (or 13 billion tons of about 7% of global resources), gas - 1,700 trillion cube feet of gas (about 47 trillion m^3), and 44 billion barrels of natural gas condensate (about 5.5 billion tons). The total assessment of the Arctic hydrocarbons is about 65 billion tons (USGS, 2008).

At the same time, the share of traditional oil (including liquid fractions of natural gas, NGL) accounts for about 134 billion barrels or about 18 billion tons, which corresponds to 13-15% of its global resources, and for traditional natural gas - the remaining 279 billion BOE, or slightly less than 30% of the total gas resources in the world (USGS**,** 2008)**.** About 80% of the Arctic's resources are located in the subsoil beneath the waters (offshore area); however, a significant part is concentrated in relatively shallow water (shelf) - at sea depths of less than 200-500 m. Moreover, according to USGS estimates, the probability of detection of any significant hydrocarbon reserves in the central part of the Arctic Ocean, as well as in the areas adjacent to them, are close to zero (USGS, 2008; Hansen *et al*., 2020; Research and Development in the Energy Sector, 2010).

Russia possesses approximately 70% of the total unexplored Arctic gas resources with the West Siberian basin (18.5 trillion m^3). It includes the southern part of the Kara Sea and the East Barents Sea basin (8.1 trillion m^3), located entirely in the eastern part of the Barents Sea, in the Yenisei-Khatanga basin (2.5 trillion m^3), the Laptev Sea (0.83 trillion m^3) and in the deeper part of the Barents (0.67 trillion m^3) and the Kara seas (0.38 trillion m^3) (Figures 3 and 4) (Kontorovich, 2015; Kaminsky, 2018; Prischepa, 2019). It is interesting to estimate that, in general, in the Arctic, more than 80% of oil resources are concentrated on the shelf. For Russia, this share is determined at 70%, while the Norwegian and Greenland oil-bearing regions of the Arctic are almost entirely located in the seas (Pak *et al*., 2019).

According to USGS, about 65% of non-NGL oil resources, concentrated in the North American sector of the Arctic zone: approximately 30 billion BOE (barrels of oil equivalent) accounts for Arctic Alaska (the USA), almost 10 billion BOE - to the so-called Amerasian basin (north of the coast of Canada) and another 9 billion BOE - on the shelf of Greenland (mainly on its eastern rift zone).

Russia, according to USGS (USGS, 2008) has about 30 billion BOE (33% of Arctic oil resources) with a distribution of 7.4 billion BOE - in the southeastern part of the Barents Sea, 5.6 billion BOE - in the Yenisei-Khatanga basin, 3.7 billion BOE - in the West Siberian NGB, 3.1 billion BOE - in the Laptev Sea NGB, 2.0 and 1.8 billion BOE - in the deepwater part of the Barents and the Kara seas and another 1.9 billion BOE - in Leno-Anabar and 1.6 billion BOE - in the Timan-Pechora oil-and-gas bearing basin. With the addition of NGL resources (3.7 billion tons), the share of liquid hydrocarbons in the Russian Arctic is growing significantly - up to 41% of the total Arctic resources (Zharov, 2019).

Thus, the total recoverable resources of the Russian sector of the Arctic are estimated by USGS at about 40 billion tons of oil equivalent tons, of which about 4.3 billion tons are oil, more than 32 trillion m^3 is gas and about 3.7 billion tons is condensate (USGS, 2008; UN Convention on the Law of Sea, 1982). The potential of hydrocarbons in the Russian Arctic is estimated even more modestly and less optimistically by experts from the International Energy Agency (IEA) that believes that geological resources amount to about 76.3 billion tons BOE. Simultaneously, the recoverable part (probably it is a question of technical availability) of oil in the Russian sector does not exceed 9.6 billion, and gas resources in the Arctic region of Russia are estimated at a modest 21.4 trillion m^3. The total estimate of recoverable resources for the Russian Arctic (without condensate) is 31 billion tons.

In the same study, data are presented that a total of 61 large oil and gas fields have already been discovered north of the Arctic Circle, and of these, 43 – in Russia (today here are already more than 50), 11 – in Canada, 6 – in Alaska and 1 – in Norway.

According to researches of UN (UN Convention on the Law of Sea, 1982) the geological oil resources of the Arctic regions are estimated at 140-180 billion tons, of which almost 40% are in the eastern part of the area, and about a third lie between the North Pole and the American continent. UN experts stated that given the enormous technical difficulties that companies will have to face in the industrial development of these resources, projects' economic feasibility raises great doubts (UN Convention on the Law of Sea, 1982).

The noted imbalances in the structure of real discoveries and assessing the potential of the Arctic indicate the insecurity of the experts themselves, probably caused by the lack of experience in such work with shallow exploration degrees (Prischepa, 2019).

3. MATERIALS AND METHODS:

An adequate assessment of the Arctic region oil and gas potential is necessary for long-term planning and expansion of research projects and appropriate management decisions.

One of the existing contradictions and disagreements when choosing promising areas and objects of exploration is that official estimates accepted for approval by state structures in the Russian Federation are based on regulatory and methodological documents that are based on principles that allow comparing the potential of poorly studied areas with fairly well-studied ones. Companies primarily use basin modeling technology or compare many criteria for oil and gas content on the weakest link principle. Comparison of such approaches leads to paradoxical results, when areas with a significant amount of estimated forecast resources are unclaimed by companies when placing the corresponding sites for licensing, and when, on the contrary, companies show interest in small areas that have significant prospects in their opinion (Zharov, V. and Zharov, N., 2019; Kleshchev *et al*., 2000, Tcvetkov *et al*., 2020; Sobota *et al*., 2020).

3.1. Methods of the quantitative forecast of oil and gas potential

Methods of the quantitative forecast of oil and gas content meet the purpose of determining the total value and distribution of hydrocarbon resources (by phase composition, the content of associated components, size, depth, timing to prospective complexes).

These tasks are solved based on projects by setting dependencies between the concentration of reserves and geological, geophysical, geochemical, and other parameters; and establishing dependencies between the indicators of the discoveries dynamic and the reserves movement and the volume indicators of geological exploration. Analogy methods provide for establishing dependencies and quantitative measures of similarity between reference and calculated areas. They are combined in two ways - the technique of comparative geological analogies and the volume genetic method.

The application of the method of comparative geological analogies in "pure form" (by average specific densities per unit area or volume of a sedimentary complex or its prospective part), consists in comparing the calculated area with the reference one based on a set of oil and gas content criteria, which primarily include accumulative and conservation characteristics. The volume genetic method of assesment is based on the results of the separate counting of the hydrocarbon fluids generated and emigrated from oil and gas bearing strata (OGBS) and the number of scattered on the migration routes and in the areas of accumulation in rocks and waters.

The assessment of the total oil and gas potential of sedimentary strata is based (Larchenko *et al*., 2020) on the statement of the universality of the processes of oil and gas formation in the sedimentary shell of the Earth. Thus, to determine the quantitative value of forecast resources, a complex calculation of the main parameters of sedimentary strata is carried out using the volume genetic method: the conditions for accumulation of organic matter and sediment (Kruk *et al*., 2020; Grigorev *et al*, 2020; Sabukevich *et al*., 2020).

In the first group of sedimentation basins associated mainly with large platform areas formed by powerful strata of Paleozoic, Mesozoic and Cenozoic age, with a high volume rate of sedimentCnfhation (> 14 thousand km^3/million years), the value of specific reserves of HC contained in 1 km^3 of sedimentary rocks is more than 14 thousand tons/km^3. In the second group of relatively large basins, where the rate of sedimentation is characterized by a volume rate of 4 to 14 thousand km^3/million years and the value of specific hydrocarbon reserves contained in 1 km^3 is 8-14 thousand tons/km^3. The third group consists of basins with an average volume rate of sedimentation: 1.5-4 thousand km^3/million years and with the value of specific hydrocarbon reserves in the range of 3-8 thousand tons/km^3. The fourth group includes small basins with an average sedimentation rate of less than 1.5 thousand km^3/million years, with the value of specific hydrocarbon reserves: less than 3 thousand tons/km^3 (Egorov, 2018).

The maps of the thermal clay of maternal thicknesses and the cards equal to the content of bitumoids in rocks are designed to perform the calculation. The method is to identify oil and gas bearing strata, to study the history of its development (the structure of organic matter, the degree of metamorphism, thermal history), to determine the most optimal for oil and gas generation areas (centers of oil and gas generation), assessment of track losses from centres of generation to areas of accumulation (dissipation, the restoration of the forms of iron and sulfur), and most importantly – in the assessment of the possible generated quantities of oil and gas in a particular center (emigration rates) and quantities in the areas of accumulation (accumulation coefficient). Up to this main stage, all the indicators used for calculating resources are quite correct, although not very accurate. However, the emigration coefficient's determination, especially for gas and the accumulation coefficient for gas and oil (the desired forecast resources), introduces significant uncertainty in the calculations.

Changes in the volume and density of resources on the reference standards caused by new discoveries and deposits both on land and in the water area and a significant refinement of the strata of the main oil and gas complexes in the water area due to regional seismic surveys are the basis for refining resource assesment for poorly studied Arctic territories and water areas.

In connection with the above, it is useful to compare the results of refining the quantitative assessment of oil and gas resources using the method of geological analogies with the approach to assessing the potential of oil and gas accumulation zones as elements of oil and gas systems. It allows to an evaluation of both approaches critically, differentiates heterogeneous promising objects by significance. It offers subsurface users previously unclaimed objects for further study and entire exploration areas that were not yet involved in the geological study. The analysis of oil and gas systems is applied, which determines the possibility of accumulation of generated hydrocarbons in the zones of oil and gas accumulation of individual complexes dissected by regional fluid traps.

One of the important aspects of the quantitative assessment of the present study of resources in neglected areas is the comparison of the reference to the investigated area with more or less similar geological conditions with the unexplored – valued (for the method of geological analogy), and volumetric-genetic recoverability of the history of diving and paleotemperature in the presence of oil and gas source strata, based on the thermal and geochemical data.

In general, the quantitative prediction methods of oil and gas content meet the goal of determining the total amount and distribution of hydrocarbon resources (by phase composition, the content of associated components, size, depth, confined to prospective complexes). These tasks can be solved based on establishing relationships between the concentration of reserves and geological, geophysical, geochemical parameters, establishing dependencies between the dynamics of discoveries and movement of resources, and the volume indicators of geological exploration, and expert evaluation.

The essence of the geological analogies used in this study consists of successive steps compared to the geological parameters of reference well-studied by geophysical methods and drilling sites with identified accumulations of hydrocarbons estimated areas with forecast potential. Crucial when using the geological analogy method becomes correctness (adequacy) indicators of oil potential backed by relatively homogeneous oil and gas formation conditions, which is possible only within single complexes and areas of similar geological structure.

An alternative assessment was made considering the modeling of oil and gas formation processes performed in the Temis software package of BaicipFranlab (Petroleum System Analysis and Basin Modeling) based on the geochemical data of VNIGRI (Prischepa, Bazhenov) and VNIIOkeangeologiya. The main stages of assessment and creation of geological models were (1) creation of a structural framework (construction of structural maps for the main seismostratigraphic horizons based on the results of regional seismic surveys); (2) creating maps of the strata of seismic facies complexes with their transformation into lithic facies complexes (based on the dismemberment of seismic sections and linking them with good data); (3) creation of maps of the total organic matter content of Sorg and the hydrocarbon potential of rocks HI; (4) creating maps of temperature and paleotemperature conditions (creating maps of paleo depths and paleotemperature of the water environment and maps of thermal flows using trends in changes in these parameters in geological time); and (5) restoration of the history of the sinking of selected oil and gas-bearing strata, determination of the time and possibility of generation of hydrocarbons, their migration and accumulation in natural reservoirs.

As the geological framework, the maps built-in VNIGRI over the North of the Timan-Pechora sedimentary basin and its offshore continuation, as well as over the waters of the Chukotka and the Bering seas, the maps of VNIIOkeangeologia in the Barents and the Kara seas, the maps SNIIGGIMS over the waters of the Laptev Sea, and the works of INGG of A.Trofimuk of Russian Academy of Sciences over the North of Western Siberia and the southern part of the Kara sea are used.

A team made assessments by the method of geological analogies of authors with the participation of employees of VNIGRI, VNIIOkeangeologia and VNIGNI. The most significant and comparable geological characteristics are (1) the thickness of the oil and gas complex or its part corresponding to the natural reservoir (the proportion of reservoir rocks-sandiness); (2) lithological-facies uniformity (variability); (3) reservoir properties of rocks; (4) area of accumulation of hydrocarbons (regional and zonal – structural factor or structure — bearing, specific area of traps); (5) depth of the complex; (6) quality of the layer (thickness, lithology); and (7) connection with the focus of oil and gas formation (distance, regional inclines).

Based on comparing these indicators on the calculated area and a well-studied standard, correction coefficients are introduced. The analogy coefficients were determined based on a comparison of the values of certain specific geological parameters (total thickness of complexes, the area occupied by positive structures (shafts, elevations, bridges, local objects), the proportion of possible reservoirs in the section (terrigenous and carbonate), and a qualitative assessment when comparing such parameters as the quality of fluid pores, the quality of connection with oil and gas formation and their potential. The total coefficient of analogy is defined as the product of the partial coefficients of analogy based on the fact that the range of values of these partial coefficients can vary from 0.5 to 2. (Methodological recommendations for quantitative assessment of VNIGNI resources, 2000).

Based on these indicators, a summary coefficient of analogy is derived, obtained as the product of all correction coefficients and reflects the ratio of resource density in the calculated area and the standard. The specific densities of reserves and resources on the standard can be represented by values per unit area, per unit volume, or per averaged structure. The estimated area's resources are defined as the product of the specific density of reserves on the standard by the summary coefficient of analogy.

The sequence of steps for conducting an assessment using comparative geological analogies for large forecasted oil and gas accumulation zones: 1. Clarification of oil and gas-geological zoning. 2. Dividing of the section into oil-and-gas-bearing and oil-and-gas-prospective complexes. 3. The mapping criteria of oil potential: – thickness systems; – structural maps in RH close to the surface of OGC; – lithofacies maps; – maps for collectors forecast; maps of layers development; – the maps of natural reservoirs; - maps of oil and gas-bearing zones; – maps of oil and gas generation areas; – maps of hydrogeological criteria of oil potential; – maps of the fund of local objects; – maps of identified oil and gas fields; - maps of geological and geophysical studies (seismic exploration and drilling); – maps of objects removed from drilling with negative results. 4. Allocation of well-studied areas within oil and gas complexes, where positive (identified deposits) and negative results of exploration (reference areas) were obtained. 5. Calculation of resource densities obtained at reference sites resulting from the addition of reserves and resources of local undeveloped structures with confidence coefficients divided by the area of the contoured reference site. 6. Allocation of calculated areas characterized by a common geological structure (most often parts of oil and gas-bearing areas) and small variations in the criteria of oil and gas content. 7. Sequential comparison of all parameters on the calculated and reference sections within the considered complex. 8. Receipt of partial coefficients of analogy to compare all the criteria (thickness, structureonly, the share of collectors, quality of layers, the distance from the source of generation, strata availability providing a migration, the presence of tectonic dislocations). 9. The calculation of the consolidated ratio of analogies by partial coefficients analogy. 10. Calculation of resource densities on the calculated plots obtained by multiplying the resource densities on the standard and the summary coefficient of analogy. 11. Calculation of the initial total resources obtained by multiplying the resource densities on the calculated plot and the calculated plot area.

4. RESULTS AND DISCUSSION:

The geological and geophysical exploration of the Arctic is extremely uneven. There are 13 large, medium, and small sedimentary basins prospective for oil and gas in the Russian Arctic, and only six of them have oil and gas deposits, five basins on land and two in the water area. The largest sedimentary basins in the Arctic are on land (or partially located on land, and partially in the water area) the Timan-Pechora, Western Siberia, Leno-Tunguska, Yenisei-Khatanga, Leno-Vilyuisky and Zyryansky (prospective); in the water area - the West Barents Sea, the East Barents, the South Kara, the North Kara, the Laptev, the East Siberian and the Chukotka (Zharkov, 2017; Matveeva, 2017; Vasiltsov, 2018).

The oil and gas potential of the Arctic shelf remains poorly explored. All discoveries (except the Pobeda deposit) were made more than 20 years ago. In recent years, geological exploration on the Arctic shelf for oil and gas has been reduced mainly to seismic exploration, which does not allow us to identify new or to explore previously discovered deposits. Although within the northern ends of the Timan-Pechora (Nenets Autonomous District - NAD) and West Siberian (Yamalo-Nenets Autonomous district - YNAD) provinces, the geological and geophysical exploration is significantly inferior to the exploration of the central and southern regions of these provinces. It can be called satisfactory and allowed to identify many oil and gas fields and have reliable estimates of resource potential (Prischepa, 2016).

The exploration of the Yenisei-Khatanga basin has grown significantly in terms of regional studies in recent years. Still, it remains extremely low, which also applies to the territories of the Lena-Vilyui and Zyryansk prospective basins. Both in the Yenisei-Khatanga and Leno-Vilyui basins, positive results of geological studies were obtained, which cannot be said about the Zyryan basin, the prospects of which remain extremely ambiguous. In the water area, the Barents and the Kara Seas' southern parts are relatively well studied. The water areas of the northern part of the Barents and Kara Seas, the Laptev Sea, the East Siberian and Chukotka Seas have not been sufficiently studied. The prospects for their oil and gas potential are not clear and not substantiated.

In total, about 750 thousand km of 2D seismic surveys of the 2D MOGT CDP 90 deep wells were drilled in the Arctic shelf (Suprunenko *et al*., 2012; Kaminsky *et al*., 2018). At the same time, the main volumes of seismic exploration (over 630 thousand km) fall on the West Arctic seas, where the average density of seismic exploration reaches 0.5 km/km^2 in the Barents Sea (together with the southern part of the Pechora Sea) and 0.2 km/km^2 in the Kara Sea. Seismic density does not even provide a regional study level in the East Arctic seas and varies from 0.02 to 0.06 km/km^2. In recent years, the study has been reduced to regional seismic surveys, concentrated mainly within the shallow water transit zones and areal seismic surveys (including 3D), performed at Gazprom and Rosneft's licensed sites.

Within the land of the Russian Arctic, more than 350 oil and gas deposits have been identified (Figure 5), of which oil reserves were accounted for in 265 deposits (mainly oil or mixed), and gas reserves - in 189 (from purely gas, gas condensate to mixed oil and gas condensate). The most significant number of oil and gas deposits were identified within Yamalo-Nenets Autonomous Area the territory of which belongs to the West Siberian oil and gas production. It also revealed the largest land deposits in the Republic of Azerbaijan (Larchenko *et al*., 2020).

The next entity in the Republic of Azerbaijan in terms of the number of discovered fields is NAD, where oil fields are predominantly established, and they are significantly inferior to them in terms of the number of deposits in the north of Krasnoyarsk Territory, north of the Republic of Sakha (Yakutia) and Chukotka Autonomous District. Within the Arctic waters, mainly gas-bearing basins are widely developed. The oil-bearing regions gravitate towards the southern parts of the seas - the territorial extensions of the land basins, where a significant part of Russia's oil potential is concentrated.

In the Arctic, oil and gas deposits have been identified within the Barents and the Kara Seas (Weniger, 2019). The identified oil reserves are concentrated mainly on the shelves of the Barents and the Kara Seas' southern parts. Oil reserves were recorded in 8 fields, gas – in 18. In the Barents and the Pechora Seas 8 fields were identified: 1 - oil (Prirazlomnoe) 1 - OGR (North-Gulyaevskoe), 3 - gas (Murmansk, North-Kildinskoe and Ludlovskoe) 3 - gas condensate (Pomeranian, Shtokman and Ledovoe). 13 deposits have been identified in the Kara Sea, partially or marine extensions of onshore fields: 1 - gas and oil (Pobeda), 1 oil and gas condensate - Yurkharovskoe, 4 gas (Kamennomyskoe-sea, Semakovskoe, Antipayutinskoe and Toto-Yakhinskoe) and 7 gas-condensate (Kruzenshternskoe, North-Kamennomyskoe, Rusanovskoe, Kharasaveyskoe, South Tambeyskoe, Leningrad and Chugoryakhinskoe).

In the mainly gas-bearing Western Arctic basins, a significant amount of condensate is predicted. According to the results of the estimates, the volume of forecast hydrocarbon resources (oil, free gas, condensate, and dissolved gas) of the Russian Arctic is estimated at about 250 billion tons of o. e. tons, including about 43 billion tons of oil and condensate (17% of all resources) and about 206 trillion m^3 of natural gas (Prischepa *et al*., 2019). The distribution of hydrocarbon resources within the oil and gas prospective territories and water areas of the Russian Arctic is very uneven (Figure 5). The former account for about 136 billion tons BOE (almost 55% of the total volume). The vast majority are gas-containing facilities located administratively in YNAD (120 billion tons BOE, including 97 trillion m^3 of gas). The remaining 42% are also predominantly gas dispersed within the Arctic shelf (Figure 6).

Note that in the estimates of the US Geological Survey, the share of land resources was estimated much more modestly (Nefedov, 2018). Simultaneously, the forecast of the hydrocarbon potential, as a whole, differ by more than six times (250 billion tons BOE and 40 billion tons BOE). Liquid - by more than five times (43 billion tons and 8 billion tons), gas - more than 6 times (206 trillion m^3 and 32 trillion m^3) Of course, even taking into account the fact that the southern regions of YNAD (West Siberian oil and gas field) and the north of the Lenno-Tunguska gas field were not included in the assessment of the geological service, the discrepancy between the estimates is more than obvious.

On land, the territory of YNAD is the most significant in terms of liquid hydrocarbons' potential. In the water area – the continuation of the Timan-Pechora and West Siberian provinces (Figures 7 and 8).

The most fundamental question concerns the prospects of the remote Arctic shelf (Figures 9 and 10). Judging by the cited and very ambiguous estimates (but extremely low), this region is estimated as promising solely out of geopolitical interest for Russia and is unlikely to be vital (economically) important even with a wide spread of work in the Arctic (Figures 11 and 12).

5. CONCLUSIONS:

Today, the Russian Arctic region's hydrocarbon potential is defined, in-demand and on its basis, the new production will be created in the long term. There are no technical or technological limitations for its development, which is proved by successful experience in commissioning such fields as Vankorskoe, Bovanenkovskoe and North-Kamennomyskoe. The involvement rate in development will depend solely on demand for hydrocarbon raw materials and companies' investment opportunities.

The development of the Arctic shelf will require fundamentally new technologies both in research and development. Today's technology allows for large-scale seismic exploration on land in transit strata and even in remote areas of the Arctic shelf. It is essential to understand that no matter how much the seismic equipment studies the Arctic waters, an idea of the real oil and gas potential can only be obtained if the wells are drilled and tested completely. The concessions to drilling exploration and justification of the categories of reserves provided for in recent methodological documents when calculating the reserves of the Arctic shelf, unfortunately, will not allow the formation of full-fledged and design documents that can become the basis for the active development of these fields.

The cost of exploratory drilling (an order of magnitude higher than on land) and the complexity of technology today make exploratory drilling in offshore regions of the Arctic economically practically prohibitive. Oil and gas potential is not fully studied. However, it is significantly studied by the Western expert community. The main uncertainty is the proportion of liquid hydrocarbons on the Arctic seas (Prischepa *et al*., 2019). The oil and gas potential of the Arctic shelf has not been fully studied. It is significantly lower according to the estimates of the international expert community than the official estimates of Russian estimations (Kontorovich, 2015; Vorotnikov *et al*., 2019; Kaminsky *et al*., 2016; Kaminsky *et al*., 2017; Suprunenko *et al*., 2016; Suprunenko *et al*., 2012; Kaminsky *et al*., 2018; Skorobogatov, Prischepa *et al*., 2020). The author's approach to assessing the Western Arctic's raw material base in this study shows that it is much higher than international estimates for liquid hydrocarbons but significantly inferior to official estimates for gas. The main uncertainty is the estimation of the share of liquid hydrocarbons on the Arctic seas' shelf.

The most viable strategy that has proven effective in Norway is a radial or creeping strategy for promoting projects as technology evolves from the southern latitudes to the more northern and from coastal to the more remote deep-sea.

The study and development of the Arctic's hydrocarbon potential may become one of Russia's main challenges in the second quarter of the 21st century, determining its innovative and scientific development.

6. ACKNOWLEDGEMENTS:

The publication has been prepared in the context of a government order of Russia on «Development of interdisciplinary trends in the complex development of the Earth's interior and nature preservation» № 075-03-2020-127\1.

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Table 1. *Assessment of hydrocarbon resources of the Arctic seas as of 01/01/2017 (Prischepa et al., 2020).*

Subject of the Federation	Stocks	Undiscovered resources, million tons of equivalent fuel equivalent	Total potential Geological / recoverable
Barents Sea	4777 4769	48881 41012	53658 45781
Pechora Sea	1637 548	19963 9468	21600 10017
Kara Sea	3392 2497	52433 45357	55824 47854
Kara Sea (southern part + North Pole)	3392 2497	45652 40636	49043 43133
Kara Sea (northern part)	0 0	6781 4721	6781 4721
Laptevih sea	0 0	13468 8839	13468 8839
ChukotkaSea	0 0	16160 0	16160 0
East-SiberianSea	0 0	19060 0	19060 0

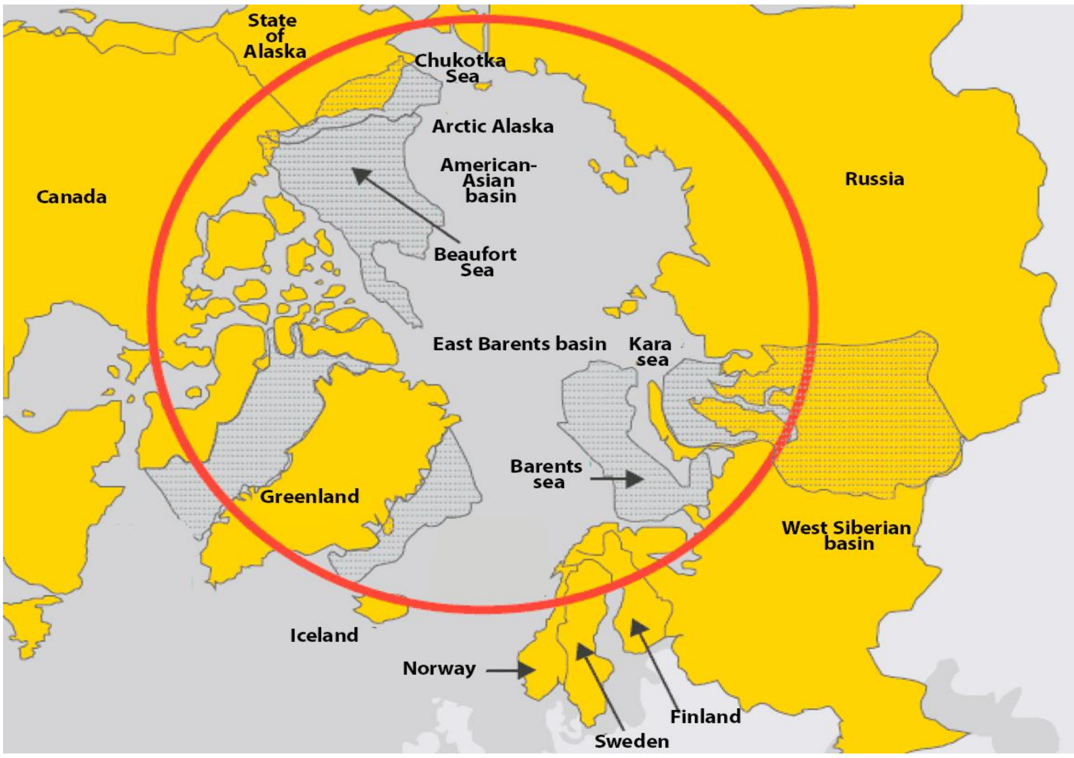
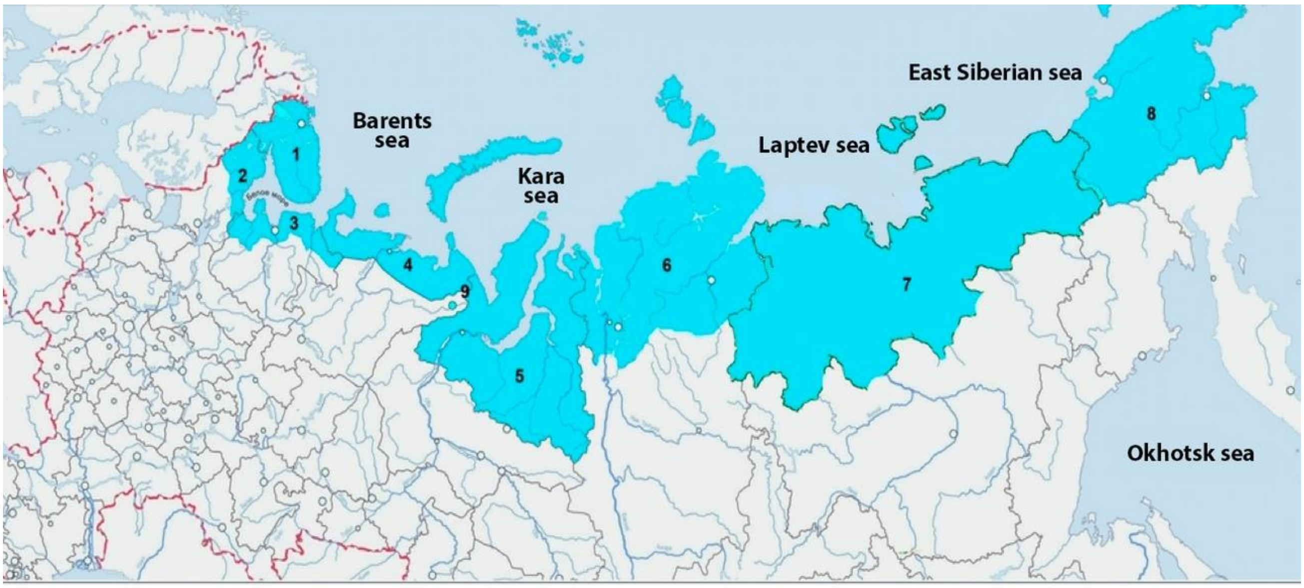


Figure 1. *Major oil and gas provinces in the Arctic according to the US Geological Survey (Geological Survey, 2008)*



1. Murmansk oblast,
2. Republic of Karelia (part of Louhsky, Kemsky and Belomorsky municipal Murmansk oblast, Republic of Karelia (part of Louhsky, Kemsky and Belomorsky municipal districts),
3. Arkhangelsk oblast (part of the Onega, Primorsky and Mezensky municipal districts and urban districts of Arkhangelsk, Severodvinsk and Novodvinsk, and administrative owned Arctic Islands),
4. Nenets Autonomous Okrug,
5. Yamalo-Nenets Autonomous Okrug,
6. Krasnodar Krai (part of the Taimyr (Dolgano-Nenets) municipal district, municipal district of Norilsk, a municipal formation of the town of Igarka Turukhansk municipal district,
7. Republic of Sokha (Yakutia) (as part of Abyisky, Allaikhovsky, Anabarsky, Bulunsky, Verkhoyansky, Zhigansky, Oleneksky, Nizhnekolymsky, Srednekolymsky, Ust-Yansky and Eveno-Bytantaysky uluses),
8. Chukotka Autonomous district,
9. Komi Republic (as part of the city district of Vorkuta)

Figure 2. *Arctic regions of the Russian Federation (Decree of the President of the Russian Federation of May 2, 2014).*

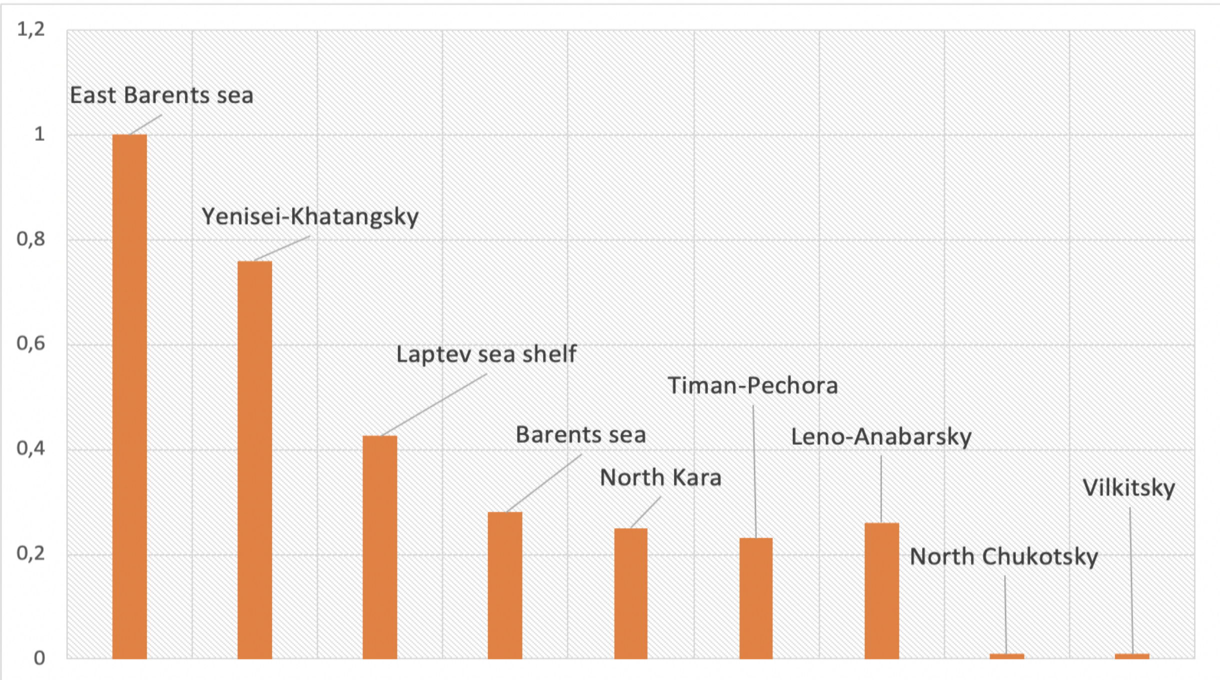


Figure 3. *Distribution of oil resources in Russia's Arctic basins (according to the US Geological survey), billion tons (Geological Survey, 2008).*

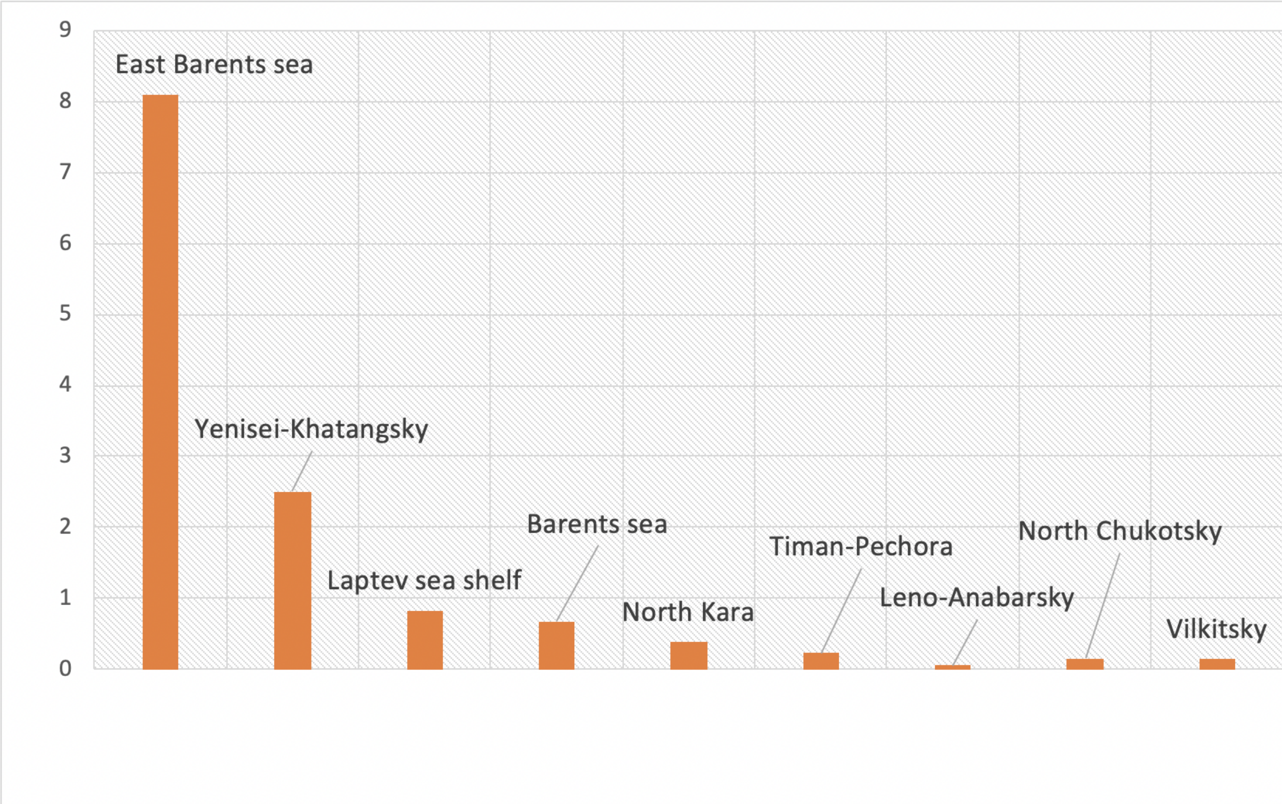


Figure 4. *Distribution of gas resources in Russia's Arctic basins (according to the US geological survey), trillion cubic meters (Geological Survey, 2008).*

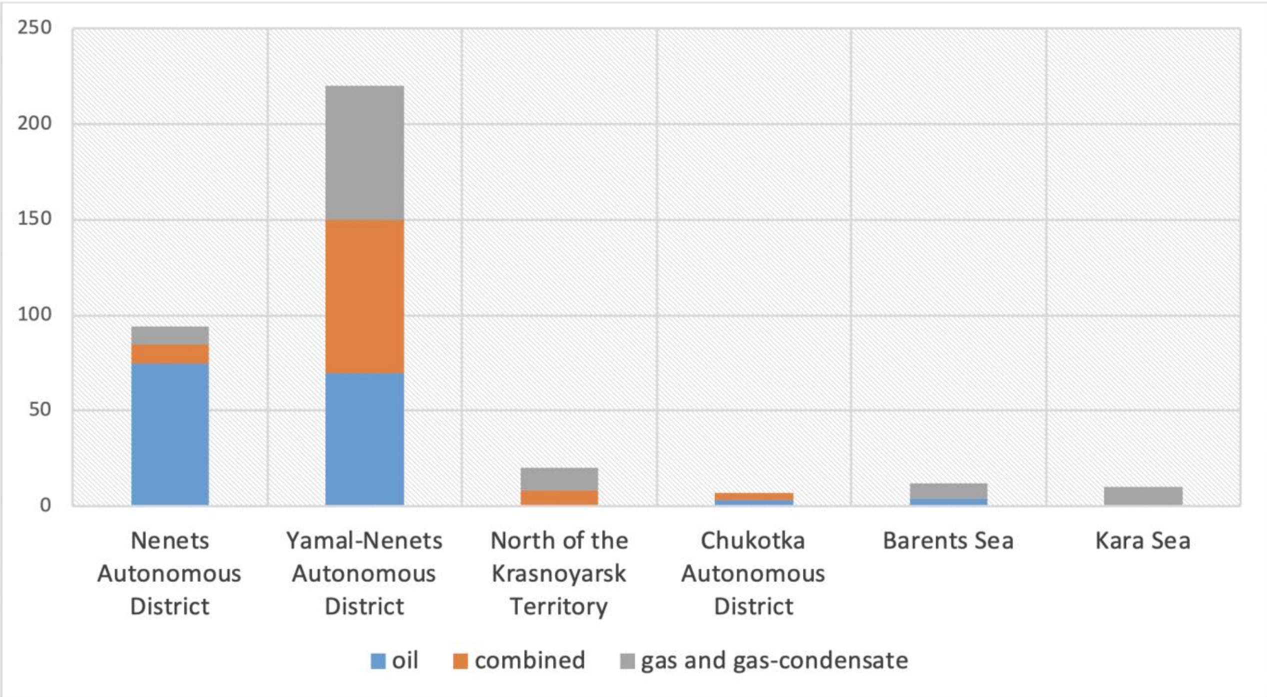


Figure 5. *Distribution of identified oil and gas fields in the Russian Federation's Arctic zone by subjects (Geological Survey, 2008).*

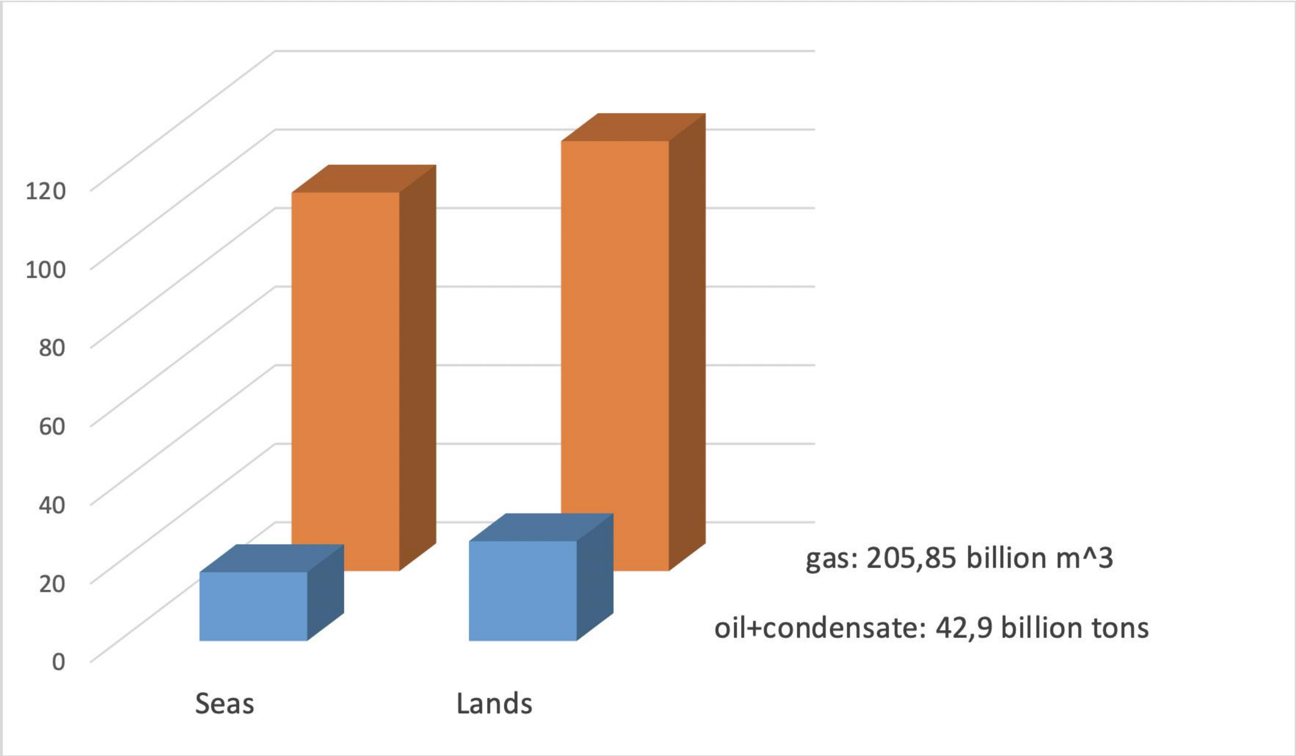


Figure 6. *Distribution of oil and gas resources in Russia's Arctic zone (according to the quantitative assessment as of 01.01.2018). Source: the author.*

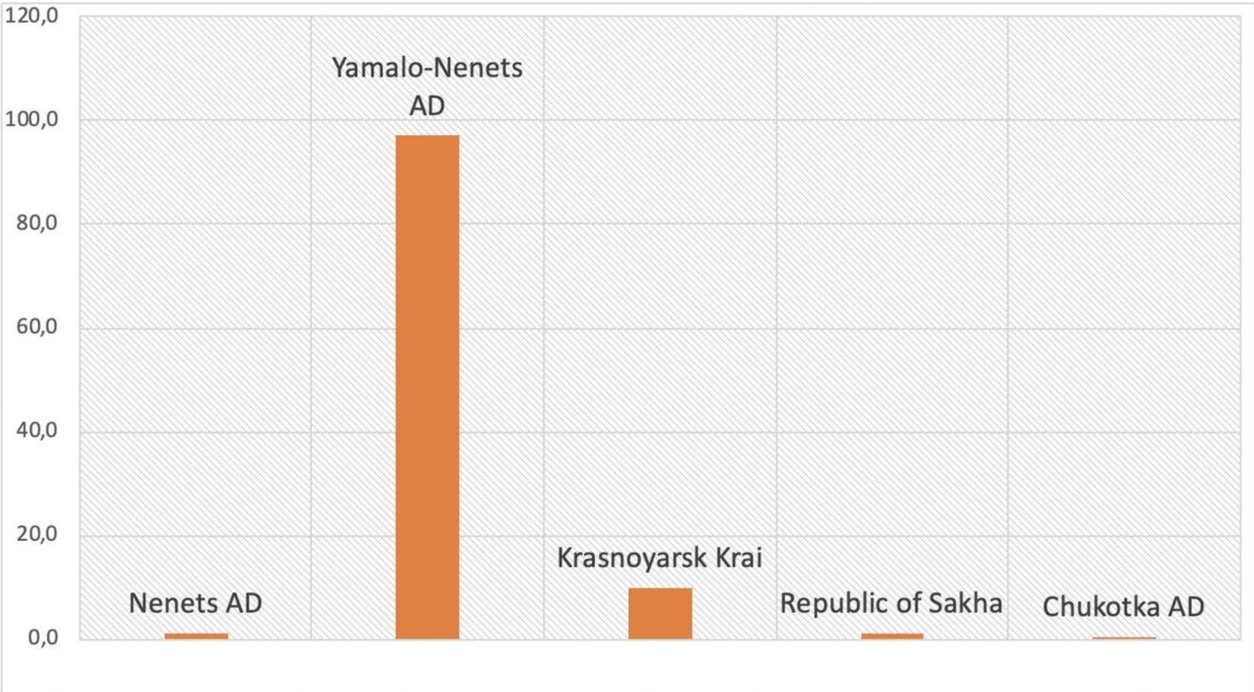


Figure 7. *Distribution of gas resources on land in the Arctic of the Russian Federation, trillion cubic meters. (Source: the author).*

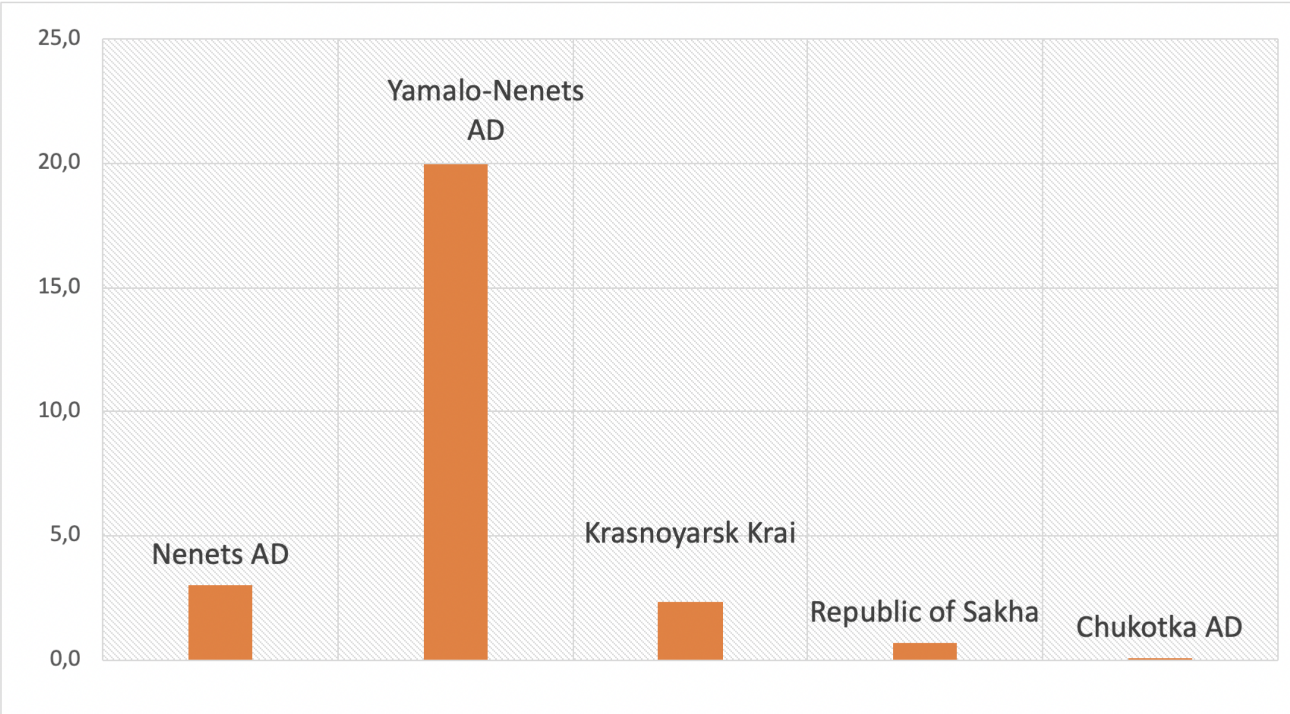


Figure 8. *Distribution of liquid hydrocarbon resources on land in the Arctic of the Russian Federation, billion tons. (Source: the author).*

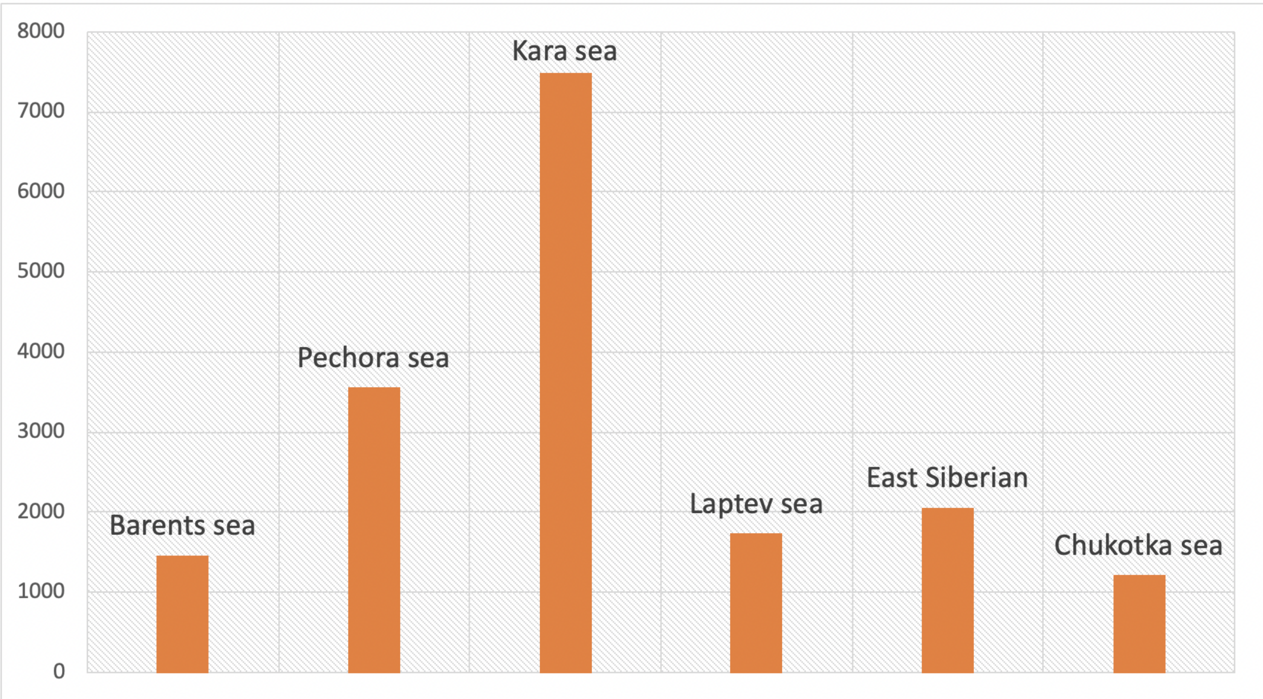


Figure 9. *Distribution of initial total resources oil+condensate of the Arctic seas of Russia (Source: the author).*

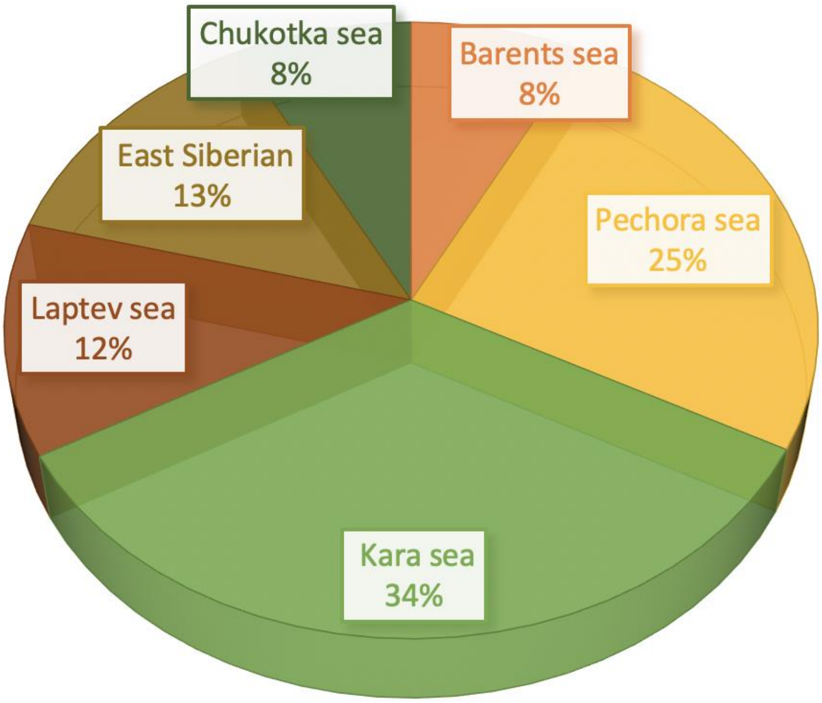


Figure10. *Distribution of initial total resources of the Arctic seas of Russia (Source: the author).*

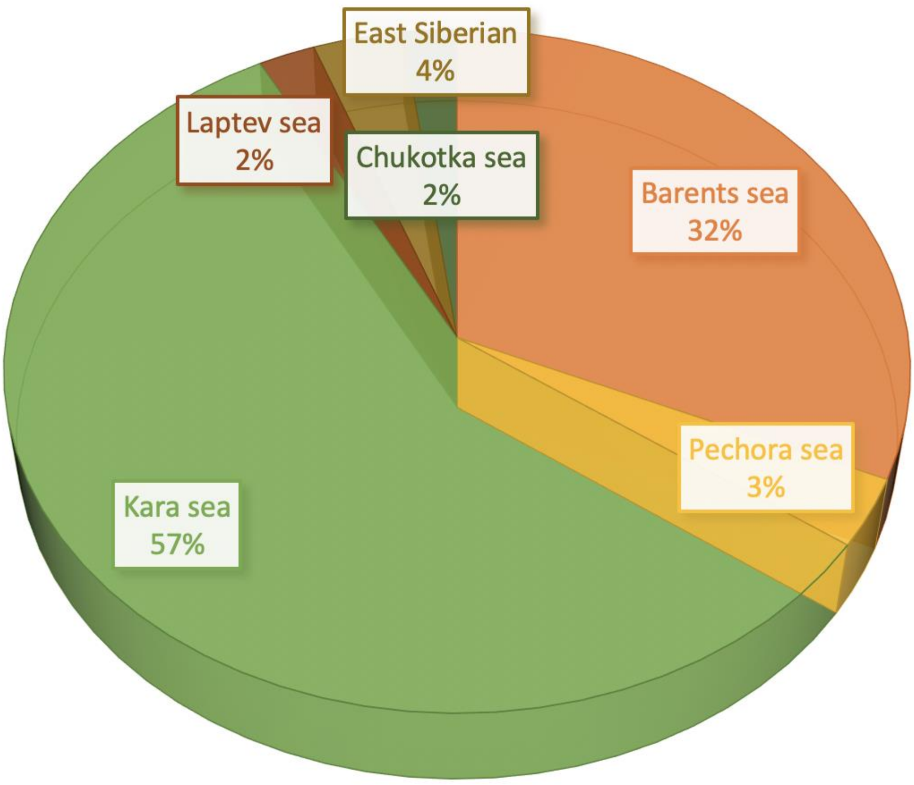


Figure 11. *Distribution of initial total free gas resources of Russia's Arctic seas, billion $m^{3.}$ (Source: the author).*

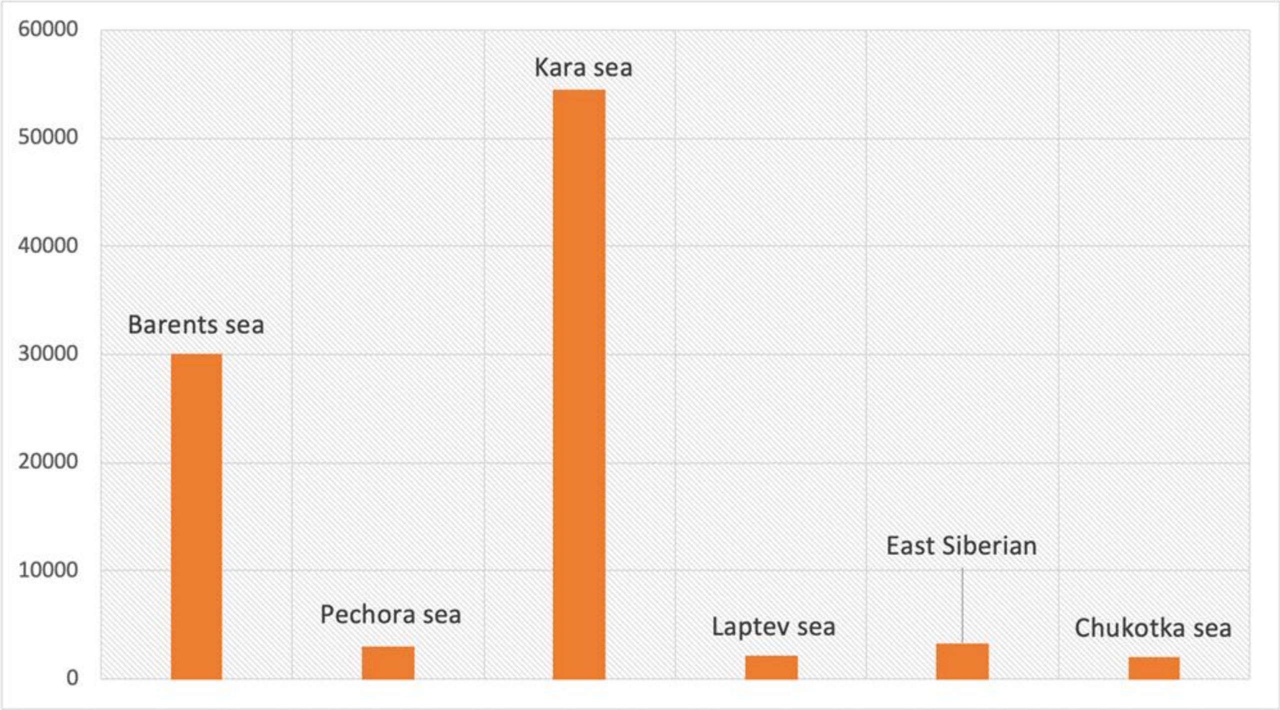


Figure 12. *Distribution of initial total free gas resources of Russia's Arctic seas, billion m^3 (Source: the author).*