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Energy Resources Exploitation in the Russian Arctic: Challenges and Prospects for the Sustainable Development of the Ecosystem

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Abstract: According to the forecasts made by IEA, BP, and Total in early 2021, the demand for hydrocarbons will continue for decades, and their share in the global energy balance will remain significant. Russia, as a key player in the energy market, is interested in maintaining and increasing hydrocarbon production, so further exploitation of the Arctic energy resources is an urgent issue. A large number of onshore oil and gas projects have been successfully implemented in the Arctic since the 1930s, while recently, special attention has been paid to the offshore energy resources and implementation of natural gas liquefaction projects. However, the implementation of oil and gas projects in the Arctic is characterized by a negative impact on the environment, which leads to a violation of the ecological balance in the Arctic, and affects the stability of its ecosystem, which is one of the most vulnerable ecosystems on the planet. The main goal of the present study is to understand how the implementation of oil and gas projects in the Arctic affects the ecosystem, to assess the significance of this process, and to find out what the state and business could do to minimize it. In the article, the authors analyze energy trends, provide brief information about important oil and gas projects being implemented in the Arctic region of Russia, and investigate the challenges of the oil and gas projects' development and its negative impacts on the Arctic environment. The main contributions of this paper are the identification of all possible environmental risks and processes accompanying oil and gas production, and its qualitative analysis and recommendations for the state and business to reduce the negative impact of oil and gas projects on the Arctic ecosystem. The research methodology includes desk studies, risk management tools (such as risk analysis, registers, and maps), brainstorming, the expert method, systematization, comparative analysis, generalization, and grouping.

Keywords: ecosystem; sustainable development; oil and gas projects; energy; environmental risks; Arctic; project risk management; state; business

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1. Introduction

The year 2020 has become a great challenge for countries around the world [1]; due to the rapid spread of the coronavirus pandemic (COVID-19), authorities in most countries were forced to take tough isolation measures, which led to a decrease in production activity and living standards of people, a reduction in the service sector, and an increase in unemployment [2]. The systemic crisis caused by the coronavirus pandemic negatively affected the economy, as well as many industries, including the energy sector [3]; a sharp decline in business activity led to a reduction in air traffic, cargo transportation, and affected the work of industrial enterprises, which, according to BP Statistical Review of World Energy 2021, caused a decrease in global energy demand by 4.3% [4]. The oil and gas sector experienced the greatest negative impact, where the demand for oil fell by a record 9.6% and natural gas consumption decreased by 2.3%, while the demand for alternative energy continued to grow [4,5]. However, many experts believe that the consumption of renewable energy will not grow significantly in the long term, even with the introduction of stricter climate regulation [6]. Various scenarios for the development of the world energy sector, formed by various companies and organizations, predict that the role of hydrocarbons, especially gas, in the global energy balance will remain significant for at least the next 30 years [7–10].

The partial lifting of restrictions, constant political support, and high vaccination rates have had a positive impact on global economic activity, which began to recover during 2021. It is expected that developing countries will stimulate final energy demand, which will lead to its growth by 4.6% according to the forecast that the International Energy Agency published in *The Global Energy Review 2021* [10].

Russia, as a key player in the global energy market, has an important role in meeting both external and internal energy demand in the short and long terms; therefore, the Arctic continues to be one of the promising areas for providing Russia with hydrocarbons [11]. The development of rich mineral resources in the Arctic has been of global interest for several decades for both business and scientific communities around the world [12–16], including Russia, since 30% of the Russian budget depends on oil and gas revenues [17], and about 12% of oil and 83% of gas is produced in the Arctic [18].

Some areas of the Arctic have been exploited for decades as sources of oil and gas. In recent decades, the Arctic region of the Russian Federation has attracted the attention of governments, private companies, and state bodies, which is explained by the beginning of the development of offshore reserves. On the Arctic shelf of Russia, 26 fields have been discovered with approximately 0.6 billion tons of total reserves of oil and 8.5 trillion cubic meters of gas [19]. The Russian government has formed a large-scale plan for the development of the Arctic region, according to which, about 5 trillion rubles will be invested in the Arctic by 2050 to implement about 150 projects. Intensive and effective development of the Arctic, especially the shelf zone, will multiply the resource potential of Russia and increase the competitiveness of the Russian economy at the global level [20–24].

However, the development of Arctic hydrocarbons is accompanied by a number of problems, including the key ones, as follows: low degree and high cost of geological exploration; high capital and operating costs; lack of necessary technologies due to the introduction of international sanctions; underdeveloped infrastructure; high environmental vulnerability; likelihood of causing harm to the environment. For the Arctic, the environmental problems of the development and transportation of hydrocarbons are more vital than for other regions. The Arctic region has unique natural and geographical features and it forms the climate of our planet; therefore, various environmental problems arising in the Arctic, especially on the shelf, can have catastrophic consequences at the global level [24–27].

Global warming is one of the main environmental problems in the Arctic, which has already led to the displacement of the boundaries of the forest zone, degradation of landscapes, melting of permafrost, and changes in the area and in the thickness of sea ice. According to experts, the greatest contribution to the disturbance of the ecological balance in the Arctic is made by oil and gas companies, which must transfer their activities to the path of sustainable development [28] in order to minimize its negative consequences and prevent possible consequences that could worsen the ecological situation in the region.

All of the above constitutes the goal of the present research—the investigation of the main factors of sustainable development of the Arctic ecosystem, during resources exploitation, and the required measures to overcome it—which is urgent and relevant. To achieve this goal, the authors need to answer the following research questions:

RQ1: What is the role of the Arctic development in the current and future energy supply of Russia?

RQ2: What aspects should be considered when addressing the impact of oil and gas projects on the Arctic ecosystem?

RQ3: What could businesses do to ensure the sustainable development of the Arctic ecosystem?

In order to answer the RQs we organized the paper as follows: firstly, we provide a brief literature review on issues of energy trends, Arctic resource potential, challenges of the oil and gas projects development, and factors affecting the Arctic ecosystem (risks and processes). Then, we identify the environmental risks and processes accompanying the implementation of oil and gas projects, form a register of risks and processes, and conduct a qualitative analysis of the environmental risks of oil and gas projects, using the expert method. As a result, we formulate general principles and recommendations for the state and businesses to ensure the sustainable development of the Arctic ecosystem, which will allow us to solve or avoid the problem that has arisen.

A large number of specialists and scientists are concerned about environmental problems, namely global climate change, environmental pollution, and impacts on natural systems, which result in an increase in natural disasters and temperature anomalies [29–37]. Due to the large-scale development of various projects, Arctic ecosystems are experiencing increasing stress and are subject to various threats that affect their urgent development. Destruction of landscapes, disruption of the migration processes of various animals, and pollution of air, water, biological resources, and noise are some examples of the negative impacts of oil and gas production on the environment [38–41].

Today, the new agenda for energy research, sessions and development takes environmental concerns into account. In the past few decades, there has been an increasing requirement to address the potential environmental consequences of developing energy projects at the beginning of the planning process, before the final investment decision is made, at the strategic level of both the state and companies [42].

The negative impact of oil and gas companies on the environment is widely discussed in scientific literature: some researchers investigate threats and anthropogenic impact on the Arctic ecosystem [43,44], others study the impact of oil pollution [45], considering the environmental perspectives of oil and gas projects [46].

Many scientists consider the impact on the Arctic from the point of view of a risk approach: they study the sustainability of risky oil and gas projects [47]; they carry out dynamic modeling of environmental risks [48]; they perform environmental, technical, and economic analyses [49]; they provide a detailed analysis of specific environmental risks and risks from various types of oil and gas activities [50–52]; they assess environmental risks [53–55]. However, experts understand the concept of "risk" in different ways, and many of them associate it with the processes that constantly accompany the stages of oil and gas production.

The main problem with studies on the impact of oil and gas projects on the Arctic ecosystem is that they are pinpointed—they lack a systematic approach. To fill these gaps, the authors propose an approach assuming that the activities of oil and gas companies are considered as a source of environmental risks on the one hand, and that negative processes accompany the production of hydrocarbons on the other hand. The novelty of the research lies in the fact that the authors have compiled a list of all possible environmental risks and processes accompanying oil and gas production; for these processes and risks, the authors clearly identify the source of occurrence and the consequences for the Arctic ecosystem and develop management methods, which should be used at the corporate and state levels to reduce the negative impact of oil and gas companies on the environment.

2. Materials and Methods

In Figure 1, the authors present the structure of the research.

Key research methods include desk studies, risk management tools (such as risk analysis, registers, and maps), brainstorming, the expert method, systematization, comparative analysis, generalization, and grouping.

Figure 1. The structure of the present research (created by the authors).

A desk study was carried out as a preliminary study, based on an academic literature review, focused on the Arctic resource potential, its relationship with the environment, the challenges and prospects for the development of oil and gas projects, and the environmental risks in the oil and gas sector. It was performed to provide an initial understanding of the subject, the situation around oil and gas projects, and their impact on the Arctic ecosystem.

The Scopus and ScienceDirect databases were used as the primary sources of information. As a theoretical basis for the study, we used the publications of experts in scientific printed and electronic journals—such as *Polar Journal*, *Marine Pollution Bulletin*, *Journal of Cleaner production*, *Marine Policy*, *The Journal of Marine Science and Engineering*, *Energies*, *The Environmental Science & Policy*, *The Journal of Mining Institute*, *Environmental Pollution*, *Energy Economics*, *Environmental Research*, and others—as well as government reports on the development of the Arctic region, federal laws, letters from Ministries, and reports on the sustainable development of Arctic companies.

The PMBoK guide on project risk management was used as a methodological basis. The PMBoK risk management algorithm is as follows: risk identification, qualitative analysis, quantitative analysis, risk response planning, and risk control [56].

To identify and carry out a qualitative analysis of the main environmental risks and processes accompanying the implementation of oil and gas projects, the authors used brainstorming and an expert method, based on questionnaires.

At a first stage of brainstorming (generation of ideas), based on literature review, the authors first compiled their own list of environmental risks and processes accompanying the implementation of oil and gas projects.

Then, an individual online expert method was used to form a correct and complete list of risks and processes. Ten experts were invited to the research.

The experts were representatives of energy companies (PJSC, Gazpromneft-2; PJSC Rosneft-1; PJSC Gazprom-1), as well as representatives of Russian universities and research centers (Saint-Petersburg Mining University-2; Saint-Petersburg Polytechnic University-1; Saint-Petersburg State University-1; Kola Scientific Center of the Russian Academy of Sciences-2), whose interests include the problems of extraction and production of energy resources.

To select experts for the working group, a documentary (based on socio-demographic data) method was used. The following criteria for the selection of experts were used: competence in the field under study, academic degree, scientific or practical work experience, official position, and objectivity.

Experts were asked by e-mail to fill out a form in which they needed to provide information about themselves, as well as to compile a list of risks and processes (Appendix B, Tables A2 and A3). The open question technique was used. The protocol of the expert response is presented in Appendix C (one example, Tables A4 and A5).

Then, as the next stage of the brainstorming technique (grouping, selection, and evaluation of ideas), the authors used the methods of systematization, generalization, and grouping of information from the expert's protocol. As a result, the authors have formed a list and register of environmental risks and processes accompanying the implementation of oil and gas projects.

Then, the experts were sent a list of risks and were asked to determine the risks in terms of the probability of occurrence and the scale of the consequences (Appendix D, Table A6). The closed question technique was used. The protocol of the expert response is presented in Appendix E (one example, Table A7). The processing of expert assessments was carried out by the method of determining the generalized assessment.

Finally, the experts were asked to rank the risks within one range of consequences and one range of probability. The processing of expert assessments was carried out by the method of pairwise comparisons. At the last stage of the research, using general risk response measures, examples of best practices in the industry, and existing knowledge and resources, the authors provided general recommendations for the state and business to prevent the negative impact of oil and gas activities on the ecosystem.

3. Results

3.1. Energy Trends and Forecasts for the Future

The coronavirus epidemic has become one of the main threats to the global economy and financial markets. COVID-2019 has led to the closure of many industrial enterprises, a decrease in production activity, a reduction in the service sector, and restrictions and bans on movement in both business tourism and entertainment [57,58]. The authorities of most countries restricted, up to a complete ban, the departure of people and travel by public transport. Numerous companies and educational institutions worked online [59,60]. Despite the easing of these measures, the travel ban remains, with some industries not operating at full capacity due to social distancing or lack of demand. The global lockdown situation in 2020 led to a 4.3% drop in the global economy, that is, 2.5 times more than during the global financial crisis of 2009 [61]. The contraction of the global economy had a significant impact on energy markets and led to a 4.3% drop in global energy demand, mainly due to carbon-intensive electricity generation, transport, and tertiary sectors [4,8,9] (Table 1).

Table 1. Energy consumption by fuel type (created by the authors, based on [4]).

Fuel	2019, Exajoules			2020, Exajoules			2020/2019, %
	Total	OECD	NON-OECD	Total	OECD	NON-OECD	
Natural gas	140.54	64.8	75.74	137.62	63.28	74.34	−2.1
Oil	191.89	90.16	101.73	173.73	78.52	95.21	−9.5
Coal	157.64	32.3	125.34	151.42	27.46	123.96	−3.9
Nuclear energy	24.93	17.78	7.15	23.98	16.67	7.31	−3.8
Hydropower	37.68	12.87	24.81	38.16	13.14	25.02	1.3
Renewables	28.82	16.56	12.26	31.71	18.04	13.67	10.0
Total	581.5	234.47	347.03	556.62	217.11	339.51	−4.3

Non-OECD (Organization for Economic Cooperation and Development) countries provided the bulk of energy demand, while the largest decline was driven by the OECD. By country, the US, India, and Russia contributed the largest declines in energy consumption [4]. The oil and gas sector suffered from a serious negative impact: oil demand fell by a record 9.6% or 9.1 million barrels per day (b/d) and natural gas consumption fell by 2.3% or 81 billion cubic meters (bcm) [4,60]. Amid declining demand and the absence of an agreement to cut oil production between Russia and OPEC (Organization of Petroleum-Exporting Countries), oil prices collapsed in the first half of 2020. Subsequently, Russia and OPEC came to an agreement to reduce supplies, which stabilized oil prices.

Continuous political support, high vaccination rates, and partial lifting of restrictions had a positive impact on global economic activity, which began to recover during 2021. However, according to the International Energy Agency, the energy crisis that emerged in October 2021 due to the failure of renewable energy sources, reduced gas supplies, high demand for gas from Asia, and a reduction in gas reserves in European underground storage facilities will cause a slowdown in global economic growth in the near future. Nevertheless, the demand for electricity will continue to grow.

According to [4,7,8] the new energy economy will be more electrified, efficient and clean. Thus, in 2021, Total presented two scenarios [7] for the development of world energy: a momentum scenario—a progressive scenario, according to which, by 2100, the temperature will rise by 2.2–2.4 degrees; and a rupture scenario—a backcast approach, according to which, global warming is limited to 1.7 degrees. In these energy scenarios (Figure 2a,b), global electricity demand is projected to grow by 18 and 9 percent, respectively, driven by population growth and improved living standards. As we can see from Figure 2a, according to the momentum scenario, an increase in gas demand and an increase in its share in the global energy balance are predicted, as well as a gradual, but not critical, drop in oil demand. According to the rupture scenario (Figure 2b), gas demand is also projected to grow, but at a slower pace than in the momentum scenario, while maintaining its share in the global energy balance.

According to a reference case, compiled by McKinsey and Company in the Global Energy Perspective 2021 [1], fossil fuels continue to play an important role in the energy sector.

In the world energy outlook [8] there are three scenarios for the development of world energy: and Net Zero Emissions by 2050 scenario (NZE), the Announced Pledges scenario (APS), and the Stated Policies scenario (STEPS), the most realistic of which is the STEPS scenario, showing that oil demand will decrease slightly by 2050 and natural gas demand will continue to grow by 2030 and beyond.

Thus, according to the scenarios for the development of the world energy sector, formed by various companies and organizations, the demand for oil and gas will remain, and the role of hydrocarbons, especially gas, in the global energy balance will remain significant at least in the next 30 years.

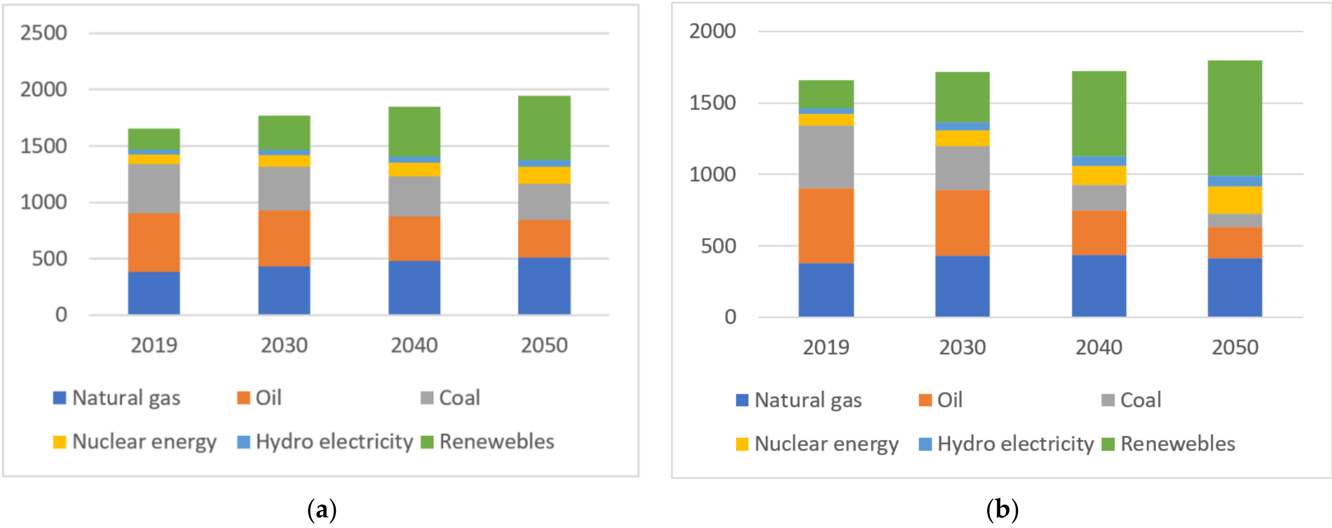

Figure 2. World demand for primary energy. (**a**) The momentum scenario, PJ/d; (**b**) The rupture scenario, PJ/d [7].

3.2. The Role of the Arctic in the Current and Future Energy Supply of Russia

The importance of the oil and gas complex for the stable development of the Russian economy is primarily due to the contribution of the oil and gas industry to the country's GDP, export revenues, and revenues of the consolidated state budget (Figure 3). Figure 3 shows that the share of oil and gas revenues in the federal budget has decreased, but still remains significant.

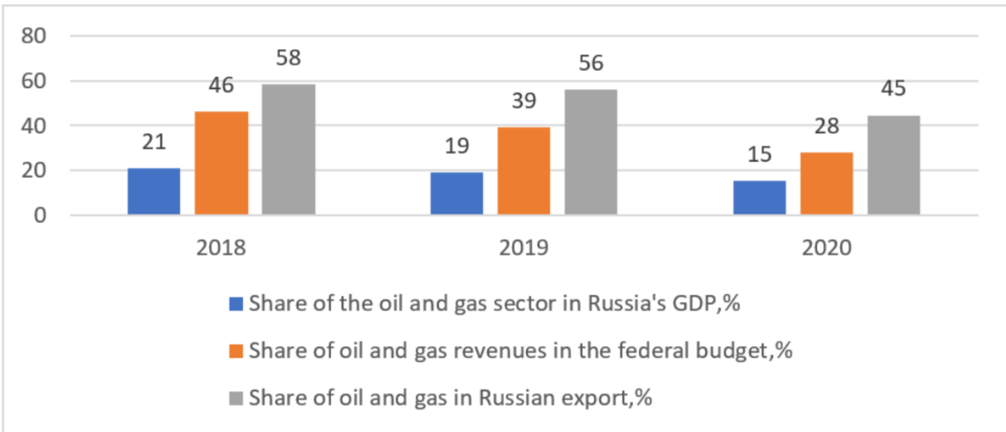

Figure 3. Contribution of the oil and gas industry to the Russian economy [62].

The oil and gas revenues of the Russian budget in 2020 amounted to 5.24 million rubles, which is 28% of all revenues, a decrease of 33.9% compared with 2019. The decrease in oil and gas revenues was caused by the reduction in the mineral extraction tax (MET) and export customs duties paid to the budget, which are closely related to the average price of a barrel of Urals crude oil ($43.3 in 2020; $63.9 in 2019).

To meet the needs of the domestic and foreign markets for energy resources, to ensure stable economic and social development, and to achieve the goals of the "Energy Strategy of the Russian Federation until 2035", the current level of oil production in Russia should be maintained in the medium term, the current level of gas production should be increased to 795–820 billion m^3 [63] in the medium term, and up to 860–1000 billion m^3 [63] in the long term. The current level of LNG production should be increased to 46–65 million t [63] in the medium term and up to 80–140 billion million t [63] in the long term.

However, due to the decrease in relatively easy-to-recover oil and gas reserves in traditional production areas, there is a need to develop hard-to-recover hydrocarbons.

According to the "Energy Strategy of the Russian Federation for the Period up to 2035" [63], the priorities for the development of the Russian oil and gas sector are the extraction of residual hydrocarbon reserves and the production of super-heavy oil, heavy oil, and shale oil; the increase in Russian hydrocarbon production should be driven by the development of the Arctic fields.

The Russian Arctic, occupying about a third of the world's Arctic area and 20% of the country's territory, is a zone of special strategic interests for Russia. The Arctic produces about 83% of natural gas and 17% of oil, and unique projects for the liquefaction of natural gas (LNG projects) [19,64] are being implemented, providing a significant share of national income and all-Russian exports. Significant oil and gas projects in the Russian Arctic are presented in Appendix A (Table A1) [64–71]. In Appendix A, the authors divided projects into three types: the first type—projects for the development of onshore hydrocarbon fields (all projects are in operation or completed); the second type—LNG projects (a fairly new initiative for the Russia Arctic, one project is in operation); the third type—projects for the development of offshore hydrocarbon fields (one project is in operation). Such division of project types was carried out to further identify the stage of hydrocarbon production at which an environmental risk arises.

Intensive prospecting for hydrocarbon deposits onshore in the Arctic began in the 1930s. The world's first Arctic oil field, Chibuskoye, was discovered in 1930. Onshore development in the Arctic has been underway for more than 80 years and makes a great contribution to the development of Russian energy. In the 1980s, deep exploration drilling began in the western part of the Russian Arctic (the Barents and Kara Seas). Interest in the Arctic shelf especially increased during the period of high oil prices: geological exploration became active, a unique project for oil production was implemented at the Prirazlomnoye field, and a complex Yamal-LNG project for the extraction and liquefaction of gas was launched.

According to the head of Rosnedra Evgeny Kiselev [72], "there are 657 active licenses on the land and shelf of the Arctic for hydrocarbon raw materials production, 240 of them combine the purposes of geological studying, exploration and production, 193 licenses were issued for the purpose of geological exploration, 224 licenses—for exploration and extraction. Over the past three years, the companies have discovered 13 hydrocarbon deposits in the Arctic". In the coming years, the Russian sector of the Arctic will continue to play a leading role in gas production, and its role in oil production will increase.

The Russian government has formed a plan for the large-scale development of the Arctic region, expecting about 5 trillion rubles to be invested in the Arctic by 2050 for the implementation of about 150 projects.

Thus, according to [73], the environmentally friendly development of offshore fields, which, as shown in Appendix A, are at an early stage of exploitation, will require investments, as shown in Table 2.

Table 2. Required investments for the perspective offshore field development [73].

Deposit Name	Investments, Billion Rubles
Severo-Gulyayevskoye	55
Prirazlomnoye	65
Medynskoye more	63
Dolginskoye	85
Ledovoye	128
Murmanskoye	63
Shtokmanovskoye	65
Ludlovskoye	92
Rusanovskoye	250
Leningradskoye	255
Kamennomyskoye	102
Severo-Kamennomysskoye	58

Intensive and efficient development of the Arctic, especially the shelf zone of the Barents, Kara, Pechora Seas, and the Yamal Peninsula, which have the greatest hydrocarbon potential, will multiply the Russia's resource potential and increase the competitiveness of the Russian economy at the global level.

3.3. Implementation of Oil and Gas Projects: Challenges for the Sustainable Development of the Arctic Ecosystem

The development of hydrocarbons in the Arctic is accompanied by a number of problems (Table 3), including the key problems, as follows: low level of exploration of the region; high cost of geological exploration, especially drilling of exploration wells; high capital and operating costs; lack of necessary technologies, due to the introduction of international sanctions; underdeveloped infrastructure; high vulnerability; the likelihood of causing harm to the Arctic ecosystem.

Table 3. Problems of development of hydrocarbon deposits in the Arctic (created by the authors, based on [24,27,74–78]).

Type of Problems	Problems
Organizational	- Insufficient level of development of industry capable of ensuring large-scale development of the Arctic. - Underdeveloped infrastructure. - Introduction of sectoral sanctions. - Limited access to offshore work for both Russian and foreign companies.
Geological, climatic	- Low degree of exploration of the Eastern Arctic. - Depth of occurrence. - Difficult ice conditions during the development of offshore fields. - Constantly low air temperature.
Technological	- Dependence on imports of many types of equipment and technologies. - Low rates of technology development. - Complex mechanism of technology commercialization.
Economic	- Volatility of hydrocarbon prices. - High cost of production and transportation of hydrocarbons. - High capital expenditures for exploration, field development, creation of the necessary industrial and transport infrastructure, and maintenance of production. - High cost and impossibility of using traditional energy sources in some cases.
Social	- Low population density in almost the entire region. - Migration outflow of population, even from some central territories of the Arctic. - Lack of qualified personnel. - Insufficient development of the personnel training system.
Environmental	- Vulnerability and high probability of damage to the Arctic ecosystem. - Water pollution. - Reduction in biodiversity. - Global warming.

For the Arctic, the environmental problems of the development, transportation, and production of hydrocarbons are more vital than for other regions due to the need to conduct large volumes of exploration and production drilling, and the need to perform a great number of cargo loading, unloading, and bunkering operations. Oil and gas production in the Arctic is also associated with complex geological and harsh climatic conditions.

During the implementation of oil and gas projects, water resources, the earth's surface, and the atmosphere experience an intense technogenic load, while the level of negative impact is determined by the duration and scale of field exploitation. Changes in the state of the environment have a negative impact on the Arctic ecosystem, which is a biodiversity of flora and fauna living and developing in a unique ecological environment. It is characterized by certain climatic conditions associated with a lack of heat, widespread permafrost, the presence of fast ice and floating ice in the sea, and terrestrial glaciation, as well as, on the one hand, the uniqueness of species diversity—including more than 20 thousand species of microorganisms, fungi, plants, and animals—and on the other hand, species poverty, which is extremely sensitive to anthropogenic impact. Currently, the Arctic ecosystem is experiencing a serious anthropogenic impact associated with the transport of pollutants, ice melting, global warming, and habitat disruption.

Due to short food chains and the vulnerability of the Arctic natural environment, further active oil and gas activities in the Arctic can become destructive and disrupt the sustainable development of the Arctic ecosystem, which means its ability to maintain its structure and functioning will be disrupted under external stimulation. At the same time, due to its fragility and uniqueness, the Arctic ecosystem has a low potential for sustainability.

To minimize, prevent, and eliminate the negative impact of oil and gas production on the Arctic ecosystem, the authors identified the sources, consequences, and scale of such impact, defining their roles and developing recommendations for the state and business.

The authors proposed an approach assuming that the impact of oil and gas projects on the Arctic ecosystem should be considered in two aspects: the processes accompanying the implementation of oil and gas projects are highlighted (Table 4) and the environmental risks associated with the implementation of oil and gas projects are identified (Table 5). The risks and processes are analyzed in terms of "stage of oil and gas field development—source—impact on the ecosystem".

In most of the literature, these concepts are mixed and not considered systematically. In this study we attempt to identify all processes accompanying the implementation of oil and gas projects and all possible environmental risks. The authors define environmental risk as a possible event that has adverse consequences for the environment, arising in the course of economic activity.

Extraction, transportation, refining of oil, flaring of associated petroleum gas, own sources of energy supply, and various types of equipment lead to emissions of greenhouse gases into the atmosphere, and storage and transshipment of oil lead to nmVOC emissions (non-methane volatile organic carbons). When implementing oil and gas projects, wastewater is discharged into water bodies. Despite the fact that most wastewaters are classified as normatively clean, these waters contain pollutants, which negatively affect the state of the environment. Oil industry enterprises annually disturb large volumes of land resources, use water resources for household and industrial needs, and accumulate production waste, some of which is not processed in due time and become an additional source of environmental pollution. Additionally, oil and gas activities are characterized by noise pollution of the environment, accumulation, and leakage of toxic chemicals used in enhanced oil recovery methods.

Together with the above-mentioned processes accompanying the implementation of oil and gas projects, the activities of oil and gas companies are associated with significant environmental risks.

Table 4. Register of processes accompanying the implementation of oil and gas projects in the Arctic (created by the authors, based on [11,12,18,25,27,35,38–55,74–78]).

<table>
<tr><th>Processes Accompanying the Implementation of Oil and Gas Projects</th><th>Source</th><th>Influence on the Arctic Ecosystem</th></tr>
<tr><td>1. Emissions of greenhouse gases</td><td>Exploration and production drilling, application of enhanced oil recovery methods flaring of associated petroleum gas, use of hydrocarbons for company’s own needs, operation of internal combustion engines or diesel engines at the field and during logistical support, losses and leaks of hydrocarbons.</td><td>Arctic marine life has difficulty breathing, death of flora due to the formation of unstable thin films on the surface of the seas as a result of the deposition of greenhouse gases.
Difficulty in the life of polar bears, walruses, seals, white seagulls, and others due to the gradual warming of the water temperature.
Reduction in biodiversity, disease, migration, and shortening of the life span of animals and birds (golden eagles, reindeer, and others) due to an increase in temperature and melting of permafrost.</td></tr>
<tr><td>2. nmVOC emissions (non-methane volatile organic carbons)</td><td>Oil storage, oil transshipment.</td><td>Oppression of living Arctic creatures, eye and cardiovascular diseases, difficulty breathing in Arctic animals.</td></tr>
<tr><td>3. Noise pollution</td><td>Marine seismic exploration, well drilling, offshore transportation.</td><td>Loss of the ability of organisms to identify different sounds, disruption of communication with each other, difficulty in finding food. This is especially relevant for whales.</td></tr>
<tr><td>4. Water hammer effect</td><td>Seismic wave generation, hydraulic fracturing.</td><td>Death and damage of organs and tissues of adult fish and fry; violation of the migration routes of Arctic fish (Arctic char, trout), change of habitats, death of Arctic animals.</td></tr>
<tr><td>5. Accumulation, leakage of toxic chemicals</td><td>Hydraulic fracturing, application of other methods of enhanced oil recovery.</td><td>Toxic effects, unfavorable regime for the development of flora and fauna due to pollution of drinking water sources, violation of the oxygen regime of reservoirs.</td></tr>
<tr><td>6. Ingress of reservoir waters into the environment</td><td>Oil production by drilling wells, violation of the production process, wear of equipment, incorrect choice of cleaning technologies.</td><td>Unfavorable regime for the development of flora and fauna due to changes in mineral composition, pH, water-air regime, carbon-nitrogen balance of groundwater, reduced soil formation and fertility, and formation of an oil film on the water surface and sedimentation of heavy fractions of oil products.</td></tr>
<tr><td>7. Utilization and storage of technological drilling waste</td><td>Exploration and production drilling.</td><td rowspan="3">Withdrawal of a significant area of land from circulation, oppression, and suppression of normal organic life, changing in the composition of biocenoses.
A decrease in the life expectancy and death of individuals, the complete disappearance of some species, the appearance of pathological signs and histological disorders in the body of fish and invertebrates, the accumulation of petroleum hydrocarbons, and wastes in the organs and tissues of plants and animals, the deterioration of the condition and survival of fish, fish killed, and the death of spawning grounds. Changes in living microorganisms inhabiting the soil. Reduction in biological activity and soil fertility.</td></tr>
<tr><td>8. Accumulation of production waste</td><td rowspan="2">Geological exploration, exploitation of a hydrocarbon fields, construction of refineries and LNG plants.</td></tr>
<tr><td>9. Discharge of normatively clean water</td></tr>
<tr><td>10. Violation of the integrity of the Earth’s surface, withdrawal of a significant area of land from circulation</td><td>Geological exploration, exploitation of a hydrocarbon fields, construction of refineries and LNG plants, laying of pipelines.</td><td>Landslides, formation of deep depressions, flooding of low habitats of fauna, death of representatives of fauna, changes in flora and fauna violation of the migration processes of animals and birds.</td></tr>
</table>

Table 5. Environmental risks register (created by authors, based on [11,12,18,25,27,35,38–55,74–78]).

<table>
<tr><th>Risk</th><th>Stage of Oil and Gas Production</th><th>Source of Risk</th><th>Influence on the Arctic Ecosystems</th></tr>
<tr><td rowspan="4">1. Spills of oil and petroleum products</td><td>1.1 Offshore hydrocarbons’ production</td><td>1.1 Explosion, fire, failure of equipment on an oil platform, tanker hitting the platform.</td><td rowspan="11">Disease and death, reduction in the life span of living creatures (fish eggs, bottom living organisms, shellfish, fish, dolphins, birds, sea turtles, polar bear, seal and others) due to a decrease in oxygen in the water.
Skin irritation, loss of the ability to swim, death of marine mammals (sea otters, polar bears, seals, newborn seals, walruses and others).
Toxic effects of residual oil on crabs and fish, problems with the arrangement of crab burrows.
Reduced water-repellent ability of plumage, hypothermia, loss of buoyancy and ability of seabirds to fly.
Chronic stress in seabirds, which causes various diseases and negatively affects the ability to reproduce.
Poisoning and death of commercial fish when hydrocarbons get into rivers.
Violation of root nutrition of plants due to a sharp change in the ratio between carbon and nitrogen in the soil, deterioration of the nitrogen regime of soils.
Displacement of oxygen from the soil, loss of soil productivity, long-term restoration of the fertile layer.
Degradation of soil cover, deformation of the structure of biocenoses.
Intoxication by vapors of oil, petroleum products of soil bacteria, microorganisms, animals (caribou, musk ox, arctic fox) and birds (ducks, geese, waders and others), poisoning of animals when hydrocarbons get into rivers
Violation of bird nesting.</td></tr>
<tr><td>1.2. Offshore hydrocarbons’ transportation</td><td>1.2 Explosion, fire, failure of equipment on ships carrying oil, oil products; accidents involving such ships, stranding.</td></tr>
<tr><td>1.3 Onshore hydrocarbons’ transportation</td><td>1.3 Depressurization of pipelines, explosion, pipe rupture, accidents caused by construction defects, factory defects, corrosion.</td></tr>
<tr><td>1.4 Oil processing</td><td>1.4 Explosion, fire at an oil refinery, depressurization of tanks for storing oil, oil products.</td></tr>
<tr><td rowspan="2">2. Spills of liquefied natural gas (LNG)</td><td>2.1. Offshore hydrocarbons’ transportation</td><td>2.1 Explosion, fire, equipment failure on ships carrying LNG, accidents involving such ships, stranding, loading and unloading operations on ships and terminals.</td></tr>
<tr><td>2.2 LNG production</td><td>2.2 Depressurization of LNG storage tanks, explosion, fire at an LNG plant.</td></tr>
<tr><td>3. Fuel spills</td><td>3.1 Material and technical support of the offshore fields</td><td>3.1 Explosion, fire, equipment failure on ships carrying cargo, accidents involving such ships, stranding.</td></tr>
<tr><td rowspan="4">4. Oil and gas emissions (uncontrolled fountaining)</td><td>4.1 Offshore geological exploration</td><td rowspan="4">4.1, 4.2, 4.3, 4.4
Failure of wellhead blowout equipment, failure to comply with safety requirements when drilling a well, untimely, poor-quality wellhead sealing.</td></tr>
<tr><td>4.2 Onshore geological exploration</td></tr>
<tr><td>4.3 Offshore hydrocarbons’ production</td></tr>
<tr><td>4.4 Onshore hydrocarbons’ production</td></tr>
</table>

Table 5. *Cont.*

Risk	Stage of Oil and Gas Production	Source of Risk	Influence on the Arctic Ecosystems
5. Hydrocarbons leaks	5.1 Offshore geological exploration	5.1 Drilling exploration wells.	
	5.2 Onshore geological exploration	5.2 Drilling exploration wells.	
	5.3 Offshore hydrocarbons' production	5.3 Shipment of hydrocarbons from the platform, drilling operating wells.	
	5.4 Offshore hydrocarbons' transportation	5.4 Bunkering of vessels carrying cargo, oil, oil products, LNG, minor violations of the integrity of such vessels, loading and unloading operations on sea vessels and terminals.	
	5.5 Onshore hydrocarbons' transportation	5.5 Poor-quality butt joints, mechanical damage, assembly defects of pipes.	
	5.6 Onshore hydrocarbons' production	5.6 Depressurization at the well, infield transportation.	
	5.7 Oil and gas processing	5.7 Shipment to the receiving point of an oil refinery, structural integrity failure, the presence of corrosion in tanks for storing oil, oil products.	
	5.8 LNG production	5.8 Structural integrity failure, corrosion in LNG storage tanks, LNG shipment from the plant.	
6. Discharge and leakage of drilling and production waste	6.1 Offshore geological exploration	6.1, 6.2 Accidents on drilling platforms, leakiness of the collection and transportation systems.	Toxic effect of waste on plankton and benthic organisms of the Arctic seas Structural and functional changes in the population level of arctic fish. Disruption of the vital functions of juvenile fish, planktonic and benthic filter-feeding organisms due to increased water turbidity. Physical impact on benthic organisms. Chronic disorders of the functions of living organisms, which leads to mutation and disappearance of various species.
	6.2 Offshore hydrocarbons' production		
	6.3 Onshore geological exploration	6.3, 6.4 Accidents on oil and gas fields, violation of the closed circulation cycle at the drilling stage, violation of the structure of sludge pits.	
	6.4 Onshore hydrocarbons' production		
7. Collapse of the upper layers of rock	7.1 Onshore hydrocarbon production	7.1 Drilling wells, long field operation.	Death of living beings. Destruction of arctic animal habitats.

The authors highlighted oil and petroleum products, LNG, fuel spills, oil and gas emissions, hydrocarbons leaks, discharge and leakage of drilling and mining waste, and collapse of the upper layers of rocks as the main environmental risks. These risks pose the greatest threat to the Arctic ecosystem. Thus, the oil spill in the Gulf of Mexico in April 2010 became a huge ecological disaster, the consequences of which will be experienced by the ecosystem for many years to come.

3.4. Qualitative Analysis of Environmental Risks of the Implementation of Oil and Gas Projects in the Arctic

In Table 4, the authors presented an analysis of the processes accompanying the implementation of the oil and gas projects by creating a register that specifies the sources of such processes and their impact on the Arctic ecosystem.

In Table 5, the authors presented an analysis of the environmental risks of the implementation of oil and gas projects by creating a risk register which associates risks with the stage of oil and gas production, identifying specific sources of risks and their impact on the Arctic ecosystem.

The authors argue that risks arising at different stages of oil and gas production should be considered separately, due to the different likelihoods of their occurrence and different scale of consequences. For example, oil spills during onshore transportation are more likely to occur than at sea, but due to the large volume of oil transported by water, the consequences of an offshore oil spill are much more harmful.

To conduct a qualitative analysis of the environmental risks of the implementation of the oil and gas projects in the Arctic, and identify the most important ones, a risk map was developed (Figure 4). It ranks risks by such indicators as the probability of occurrence (unlikely, probable, and highly probable) and the scale of negative consequences for the sustainable development of the ecosystem (insignificant, acceptable, and significant). To assess the probability of occurrence and the scale of consequences, the expert method was used.

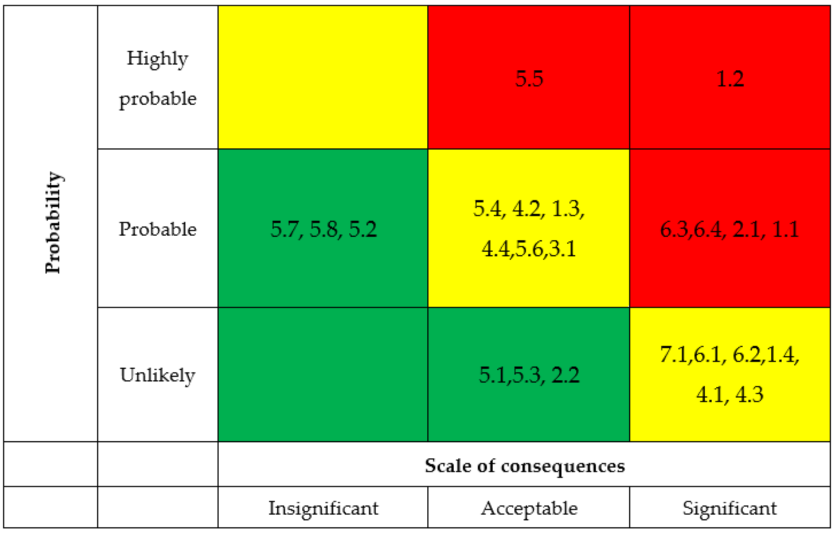

Figure 4. Environmental risk map.

The authors collected individual opinions of ten experts by questionnaire and processed them. The experts were selected based on their industrial or scientific experience, areas of interest, ability to quickly communicate in an online format, and specific knowledge in the research field.

At the first stage, the authors asked the experts to compile a list of environmental risks and processes that negatively affect the ecosystem (Appendix B), which they associate with oil and gas production. Thus, the experts helped the authors create a list of 24 environmental risks and 10 processes that negatively affect the ecosystem.

At the second stage, experts were asked to assess the risks in terms of the scale of negative consequences for the sustainable development of the ecosystem and the probability of their occurrence (Appendix D). At the third stage, experts were asked to rank risks within one range of consequences and one range of probability. The results were processed using the pairwise comparison matrix method.

As can be seen from Figure 4, the most important environmental risk is the risk of oil and petroleum product spills during offshore transportation of hydrocarbons. Particular attention should be paid to the risks in the red and yellow zone. However, due to the fragility of the Arctic ecosystem, the green zone cannot be ignored either.

3.5. General Principals and Recommendations for the State and Business in Providing Sustainable Development for the Arctic Ecosystem

The 17 Sustainable Development Goals adopted by the UN General Assembly in 2015 include the goal of combating climate change, the conservation and sustainable use of marine resources, and the protection and sustainable use of terrestrial ecosystems [79]. In order to achieve the Sustainable Development Goals, and due to the negative impact of oil and gas activities on the Arctic ecosystem, the authors have developed the following fundamental operating principles for oil and gas companies and the state (Figure 5):

To implement the formulated principles of the sustainable development of the Arctic ecosystem, the authors have also developed recommendations for the state and business ensuring the ecologically balanced development of the Arctic. In particular, the authors consider the exceptional vulnerability of the harsh Arctic nature and address the problems of maximum preservation of the biodiversity of flora and fauna and their natural habitats (Table 6). The table is organized as follows: the first column shows recommendations for businesses, while the second one provides the risk/processes whose probability and consequences could be reduced by considering the recommendations.

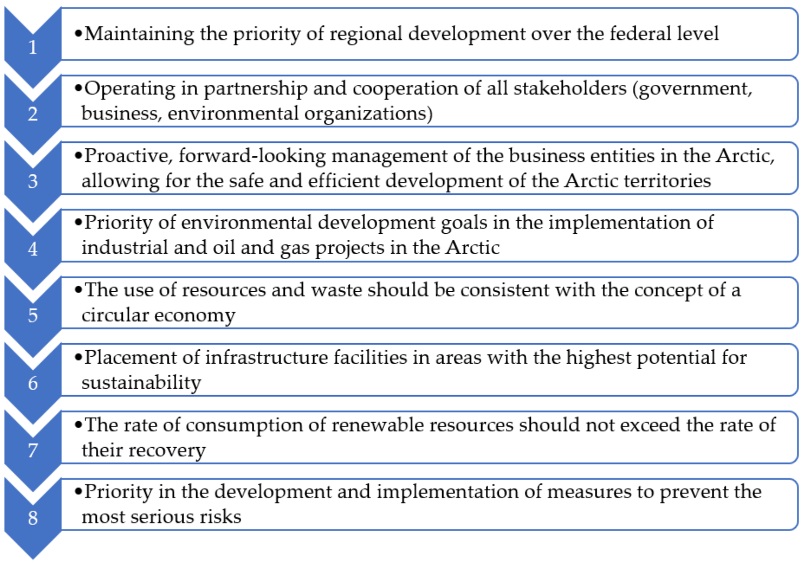

Figure 5. The principles of implementing oil and gas projects for the preservation of ecosystems.

Due to the uniformity of recommendations for companies in some cases, we classify them by risk groups and processes; for the state, the authors present general recommendations.

General recommendations for the state, to increase the environmental responsibility of companies, are as follows:

1. Encouraging companies to take environmental measures by:

- provision of tax incentives, for example, a CO_2 tax and toughening of environmental legislation (increasing fines for emissions of greenhouse gases and other pollutants, violations of environmental standards, improper waste handling, and an increase in the cost of payments for the use of water and land resources);
- implementation of constant supervision over the use of natural resources and environmental pollution;
- subsidizing and providing benefits for the implementation of waste management programs, with the introduction of environmentally friendly, safe, and innovative technologies for the production and processing of hydrocarbons (the best available technologies), cleaning up places where significant amounts of hydrocarbons accumulate;
- installation of environmentally friendly equipment, the use of eco-materials;
- carrying out activities to preserve the biodiversity of the Arctic region, and others.

2. Organization of environmental monitoring.

3. Regular inspections of vessels carrying hydrocarbons—as well as vessels engaged in logistics—regular inspections of platforms, pipelines, and equipment used for the extraction, storage, and processing of hydrocarbons.

4. Organization of joint environmental measures to improve the level of environmental education and training among employees.

5. Facilitating the establishment of strong and long-term relationships between companies and venture capital funds.

Environmental problems in the Arctic and the intensification of economic activity in the Arctic make it necessary to strengthen the environmental focus of the implementation of Arctic projects. Currently, despite the already existing environmental initiatives, this process is just beginning to develop.

To ensure the maximum large-scale effect from the rational use of the environment in the Arctic region of the Russian Federation, the following measures are necessary:

(1) integration of environmental safety policy into all areas of regional economic development;
(2) the formation of environmental standards that clearly regulate acceptable and unacceptable actions in the Arctic;
(3) active cooperation between the state and companies in the field of environmental protection in the Arctic;
(4) strengthening international cooperation in the field of environmental safety.

3.6. Measures to Provide the Sustainable Development of the Arctic Ecosystem: The Case of Prirazlomnoye Field

To prevent the negative impact on the ecosystem of Russian companies, a number of measures are being carried out, as follows: environmental evaluation of projects, introduction of environmental protection measures, production control, and monitoring. State environmental supervision is carried out by the State. The largest Russian oil and gas company, Gazprom, whose main share of gas production falls on the Arctic region, annually spends huge funds on environmental protection and rational use of natural resources (Figure 6).

Currently, the Prirazlomnoye field of Gazprom Group is the only project on the Russian Arctic shelf where commercial oil production is maintained. To prevent a negative impact on the Arctic ecosystem, the following is envisaged: the cerange protection and control system is installed, wells are equipped with an automated security system and a set of anti-imaging equipment, 30 parameters are constantly monitored during transportation, the flight altitude is determined taking into account the characteristics of the ecosystem, and marine life is monitored. The key environmental solution of the project is the zero-waste method (drilling waste is pumped into a special well) and protection of ichthyofauna (four fishing devices operate) [64].

Table 6. Recommendations for businesses on ensuring the sustainable development of the Arctic ecosystem.

Recommendations for Businesses	Impact on Risk/Process
Maintaining a safe distance of vessels from each other and from the coastline. Providing ships with improved navigation. Training of personnel to prevent misuse of equipment.Continuous monitoring and control over the technical condition of the equipment.	Reducing the likelihood of equipment failures, fires, and ship collisions Risk number 1.1, 1.2, 2.1, 2.2, 3.1, 6.1, 6.2, 6.3, 6.4.
Preparation of hydrocarbon storage tanks for seasonal changes. Regular inspections of the integrity and condition of hydrocarbon storage tanks.	Reducing the likelihood of failure of hydrocarbon storage tanks. Risk number 1.4, 2.2.
Implementation of a real-time operating center well drilling monitoring system. Equipping wells with plugs and special mechanisms. Compliance with safety requirements when drilling wells.	Reducing the likelihood of failure of drilling equipment, and rapid response to possible well blowouts. Risk number 4.1, 4.2, 4.3, 4.4, 5.1, 5.2, 5.3, 5.6.
The use of biotechnology for remediation of hydrocarbon-contaminated soil.	Reducing the consequences of spills, hydrocarbon leaks, and well blowouts. Risk number 1.3, 1.4, 4.2, 4.4, 5.2, 5.5, 5.6, 5.7.
Conducting inspections of pipeline transport on an ongoing basis. Timely repair and replacement of worn-out pipes.	Improving the reliability of pipeline systems, reducing the likelihood of spills and leaks during transportation by land. Risk number 1.3, 5.5.
Application of technologies for recovery of hydrocarbon components based on low-temperature condensation and rectification (processing of associated gas). Application of technologies for capturing and disposal (utilization) of carbon dioxide. Reconstruction and complex repair of equipment to reduce technological gas losses, the use of modern and innovative gas-saving technologies during repair. The use of alternative energy sources for own needs, replacing coal with gas. The use of equipment with reduced power consumption.	Reducing greenhouse gas emissions. Process number 1.
Implementation of a distributed fiber-optic strain gauge system in a seismic streamer.Impulse distortion filtering. Rational, from the acoustic point of view, arrangement of facilities, machinery, and equipment. The use of sound attenuators, improvement of their design, application of sound insulating enclosures. The use of sound-absorbing drilling rig envelopes with the required sound insulation.	Reducing the noise impact and the water hammer effect on the environment. Process number 3, 4.
The use of low-toxic solutions in the application of enhanced oil recovery methods.The use of polymer-specific enzyme breakers (degraders). The use of polymer-free liquids.	Reducing the negative effects of enhanced oil recovery methods. Process number 5.

Table 6. *Cont.*

Recommendations for Businesses	Impact on Risk/Process
Application of systems for cleaning and drying drilling waste, allowing maximum return of previously used drilling sludge and process water to the production process. Application of the "tubeless drilling" technology, which proposes the use of drilling sludge to obtain an inert material. Thermal neutralization of drilling waste without separation of liquid and solid phases. Use of low-toxic drilling sludge. Quality control of waste disposal operations.	Better use of drilling waste, reduction in production waste and water consumption. Process number 7, 8, 9.
Biological water purification, installation of water treatment facilities at all operating facilities. Introduction of innovative methods of formation waters purification with the use of sorption-filtering units with a large sorbent capacity.	Reducing the volume of water consumed, reducing the volume and improving the quality of produced water discharged into the environment. Process number 6.8.
Application of "green seismic" technology, which proposes the use of compact mobile equipment and rational placement of equipment in the field.	Withdrawal of less land from circulation and preservation of forests. Process number 10.

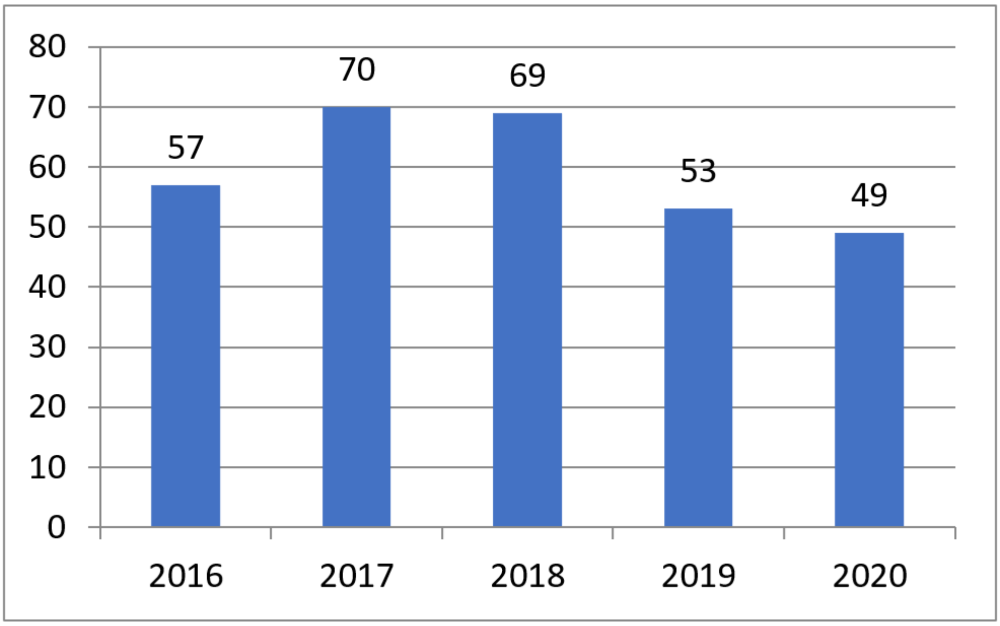

Figure 6. Gazprom Group expenses on environmental protection and rational use of natural resources, in billion rubles [80].

4. Discussion and Conclusions

The Arctic is a region rich in mineral resources. For years, many oil and gas projects have been successfully implemented in the Arctic, and recently, special attention has been paid from the government and businesses to the development of offshore fields and the implementation of natural gas liquefaction projects.

At the same time, the implementation of oil and gas projects is accompanied by negative consequences for the environment, and the activities of oil and gas companies are associated with high environmental risks, as well as negative processes accompanying the implementation of oil and gas projects, which lead to degradation of ecosystems and a decrease in their sustainability. To reduce the negative impact of oil and gas activities on the ecosystem, an environmentally friendly approach is needed.

In accordance with this background and the purpose of the research, the following results were obtained:

- the analysis of the most large-scale projects being implemented and planned in the Russian Arctic was presented;
- the key problems of the implementation of oil and gas projects were identified;
- environmental risks and processes that have an adverse effect on the environment during geophysical exploration, well drilling, equipment operation, tanker transportation, transportation through pipeline systems, LNG and oil products production—which are expressed in potential spills and leaks of hydrocarbons—generated noise, rock collapses, emissions of harmful substances into the atmosphere, wastewater discharge, accumulation of production and drilling waste, and land and water withdrawal were determined and systematized;
- a qualitative analysis of the processes and environmental risks arising during the implementation of Arctic oil and gas projects was carried out, which made it possible to form a common vision of the problem under study;
- the basic principles of sustainable development have been developed for oil and gas companies and the state, as well as general recommendations for reducing the negative impact and maximizing the conservation of the Arctic ecosystem.

The results obtained in the research regarding the presented list of risks of oil and gas activities and the processes associated with the production of hydrocarbons that negatively affect the environment do not contradict previous studies [48,49,51–56,69], but they unite and clarify them. The mentioned studies consider individual risks and processes that are not systematized and analyzed in the source–risk–consequence system. This study proposes an approach that highlights both the environmental risks of oil and gas activities and the processes associated with the production of hydrocarbons that negatively affect the environment; a complete list of such risks and processes was drawn up and their qualitative analysis was carried out. The authors assumed that such a result is obtained for the first time, since in previous works, one can find a description and study of individual risks or processes accompanying the implementation of oil and gas projects, which are often associated with risks. The authors' approach made it possible to form a common vision of the problem under study.

As for practical implementation, the principles and general recommendations, based on a qualitative analysis of risks and processes, can be used to update the state policy in the field of environmental protection in the Arctic, and to elaborate sustainable development strategies by companies.

The main assumptions of the research are the following:

- risk assessment in terms of the level of negative consequences and the likelihood of their occurrence is approximate and subjective; with the implementation of a larger number of projects in the Arctic the likelihood of risks and consequences will increase;
- the authors studied various tools and methods and compiled a list of recommendations for preventing the negative impacts on the ecosystem but did not investigate which methods and tools are more effective in Arctic conditions.

As for future research directions, the authors will focus on a specific project case study to work out a qualitative analysis and try to carry out a quantitative analysis of risks. The authors will also try to study, more thoroughly, foreign experience in environmental protection in oil and gas projects in harsh climatic conditions to identify best practices and specify recommendations.

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Appendix A

Table A1. Significant oil and gas projects implemented in the Russian Arctic (created by the authors, based on [64–71]).

Project Type	Deposit/Project Name (Resource Base)	Location	Year of Discovery	Type of Deposit	Status	Characteristic
Developing onshore hydrocarbon fields	Chibuskoye	Purovsky district, Yamalo-Nenets Autonomous District	1930	Oil	Operation completed	The first oil field in the Arctic. For the first time in Russia, industrial oil was extracted from Devonian fields.
	Yregegian	Ukhta district, Komi Republic	1932	Oil	In operation (production)	One of the largest fields of high-viscosity oil and one of the first fields of hard-to-recover oil to be developed. Production was carried out by LLC LUKOIL-Komi. For the first time, the mine method (1939) and then the thermal mine (1972) method of production were tested at the field. At the moment, production is carried out by underground thermal mining and surface methods, using the technology of thermogravitational drainage of the formation.
	Urengoyskoye	Yamal Peninsula, Yamalo-Nenets Autonomous District	1966	Oil and gas condensate	In operation (production)	The largest in the world at the time of opening. Production is carried out by LLC Gazprom Mining Urengoy. The state of the production well stock is more than 1300 wells. At the deposit, creation of horizontal wells is practiced. The field contains hard-to-reach Achimov sediments, which are currently a promising area of development.
	Bovanenkovsky	Yamal Peninsula, Yamalo-Nenets Autonomous District	1971	Gas Oil and gas condensate	In operation (production)	The largest field on the Yamal Peninsula in terms of proven gas reserves. Production is carried out by LLC Gazprom Mining Nadym. Many technologies were developed specifically for Yamal by leading Russian scientific institutions and domestic enterprises. For the first time in Russia, a unified production infrastructure is used for gas production from different types of deposits (Senomanian and APT-Albian).
	Novoportovskoyee	Yamal Peninsula, Yamalo-Nenets Autonomous District	1964	Oil and gas condensate	In operation (production)	The largest oil and gas condensate field under development on the Yamal Peninsula. Production is carried out by LLC Gazpromneft-Yamal. It is characterized by complex, from a technological point of view development conditions. Construction of horizontal and multi-bored wells and multi-stage hydraulic fracturing are practiced at the field.

Table A1. *Cont.*

Project Type	Deposit/Project Name (Resource Base)	Location	Year of Discovery	Type of Deposit	Status	Characteristic
	Yamburg	Tazovsky district, Yamalo-Nenets Autonomous District	1969	Oil and gas condensate	In operation (production)	Super giant deposit. Production is carried out by LLC Gazprom Mining Yamburg. For the first time, a centralized development system was used at the field, where one complex gas treatment unit was used instead of three. For oil production from the Achimov formation, a long-term risk operator contract with PJSC Gazprom Neft was signed.
	Group of Messoyakh deposits (East Messoyakh and West Messoyakh deposits)	Tazovsky district, Yamalo-Nenets Autonomous District	1990 1983	Oil and gas condensate Gas and oil	In operation (production)	The most northern Russian oil deposits being developed on the continent. Production is carried out by Messoyakhneftegaz JSC which is a joint venture of PJSC Gazpromneft and PJSC NK Rosneft. The deposit was the first in Russia to test the Fish Bone drilling technology. Horizontal drilling made it possible to reach complex layers of mineral deposits, without significant costs.
	Vancorskoye	Krasnoyarsk Territory, Siberian Autonomous District	1988	Oil and gas	In operation (production)	Large deposit of oil and gas. The first project in the framework of the integrated development of fuel deposits in the North of the Krasnoyarsk Territory. Production is carried out by LLC RN-Vankore. Modern technical solutions are used. The oil produced is of high quality.
	Harasweanian	Yamal Peninsula, partly—the water area of the Kara Sea	1974	Oil and gas condensate	In operation (production)	The deposit is unique in terms of reserves. The field development license is held by PJSC Gazprom and its subsidiary LLC Gazprom Mining Nadym. Wells for the development of the offshore part of the field will be drilled from the shore. The construction of industrial facilities is complicated by the large thickness of the permafrost layer and high soil salinity.
LNG projects	Yamal LNG (South Tambian deposit)	Yamal Peninsula, Yamalo-Nenets Autonomous District	1974	Gas condensate	In operation (production)	Integrated project for the extraction, liquefaction and sale of gas based on the South Tambian deposit beyond the Arctic Circle. The operator of the project is PJSC Yamal LNG—a joint venture of PJSC NOVATEK (50.1%), the Total Concern (20%), China National Oil and Gas Corporation (20%), and the Silk Road Fund (9.9%). The project is characterized by a significant resource base, low development and production costs, high efficiency of the liquefaction process, and access to many sales markets.

Table A1. *Cont.*

Project Type	Deposit/Project Name (Resource Base)	Location	Year of Discovery	Type of Deposit	Status	Characteristic
	Arctic LNG 2 (Morning Deposit)	Gydan Peninsula, Yamalo-Nenets Autonomous District	1980	Oil and gas condensate	Adopted investment decision	Integrated project for the production, storage, and shipment of liquefied natural gas and stable gas condensate, based on the Morning oil and gas condensate deposit. The project includes the construction of three technological lines for the production of liquefied natural gas and stable gas condensate. The operator of the project is LLC Arctic LNG 2—a joint venture of PJSC NOVATEK (60%), TotalEnergies Concern (10%), Chinese Corporations CNPC (10%) and CNOOC (10%), and Japan Arctic LNG (Consortium of Japanese companies Mitsui and Jogmec) (10%).
	Obski LNG (Verkhnetiuteyskoye and West-Seyakhinsky field)	Yamalo-Nenets Autonomous District	1982 1984	Gas Gas condensate	It is planned to implement in 2024–2025	The project included the production of liquefied gas on two lines with a capacity of up to 5 million tons on the basis of the Verkhnetiuteyskoye and West-Seyakhinsky deposits. The initiator of the project is PJSC NOVATEK. The launch of the project was scheduled for the end of 2022; however, a change in the project was decided—revise the gas liquefaction technology or convert the plant for the production of ammonia and methanol.
	Pechora LNG (Korovinskoye and Kumzhinskoye deposits)	Northeast from Naryan-Mar, Nenets Autonomous District	1985 1980	Gas Gas condensate	It is planned to implement in 2025, the decision is not accepted	According to the project, it was planned to create a natural gas liquefaction plant with a capacity of up to 4.3 million tons per year, but at the moment the possibility of producing methanol and exporting it on the basis of discovered fields is being discussed.
Developing offshore hydrocarbon fields	Severo-Gulyayevskoye	Pechora sea	1986	Oil and gas condensate	Prepared for the development	In terms of hydrocarbon reserves, it belongs to medium-sized fields. The operator of the deposit is PJSC NK Rosneft. One well was drilled at the deposit, in the cut of it two deposits were revealed: oil and gas condensate. The sea depth in the field area is 10–30 m. The ice-free period is 4 months.
	Prirazlomnoye		1989	Oil	In operation (production)	The only project operating in Russia for the production of hydrocarbons on the Arctic shelf. In terms of hydrocarbon reserves, it belongs to large fields. The operator of the field is PJSC Gazpromneft. The ice cover persists for 7 months, the height of the hummocks reaches 2 m. Oil reserves exceed 70 million tons, which makes it possible to achieve an annual production level of about 5.5 million tons.

Table A1. *Cont.*

Project Type	Deposit/Project Name (Resource Base)	Location	Year of Discovery	Type of Deposit	Status	Characteristic
	Medynskoye more	Barencevo sea	1997	Oil	Prepared for the development	In terms of hydrocarbon reserves, it belongs to large fields. Four wells are drilled at the field. The operator of the deposit is PJSC Gazprom.
	Dolginskoye		1999	Oil	Exploration drilling	In terms of hydrocarbon reserves, it belongs to large fields. The operator of the field is PJSC Gazpromneft. At the field, seismic surveys and seismic studies were carried out, and the drilling of three exploration wells was completed.
	Ledovoye		1982	Gas condensate	Prepared for the development	In terms of hydrocarbon reserves, it belongs to unique fields. The deposit operator is PJSC Gazprom. Two exploratory wells have been drilled.
	Murmanskoye		1983	Gas	Exploration drilling	It is the first deposit discovered in the offshore part of the Western Arctic shelf. In terms of hydrocarbon reserves, it belongs to large fields. Nine wells have been drilled at the field. The field has a complex multi-layer structure.
	Shtokmanovskoye		1988	Gas condensate	In conservation	One of the largest gas condensate deposits in the world. License for the search, geological study and production of gas and gas condensate is held by PJSC Gazprom. The development is terminated due to the current market situation.
	Ludlovskoye		1990	Gas	Exploration drilling	In terms of hydrocarbon reserves, it belongs to large fields. The operator of the deposit is PJSC Gazprom. Three wells have been drilled at the field. One gas reservoir discovered.
	Rusanovskoye	Kara Sea	1989	Gas condensate	Exploration drilling	In terms of hydrocarbon reserves, it belongs to unique fields. The operator of the deposit is PJSC Gazprom. Currently, two wells have been drilled and seven gas condensate deposits have been revealed.
	Leningradskoye		1990	Gas condensate	Exploration drilling	In terms of hydrocarbon reserves, it belongs to unique fields. The operator of the deposit is PJSC Gazprom. Eleven gas deposits have been revealed within the field. It is proposed to develop a test site for subsea production complexes created in Russia and test them in Arctic conditions.

Table A1. *Cont.*

Project Type	Deposit/Project Name (Resource Base)	Location	Year of Discovery	Type of Deposit	Status	Characteristic
	Kamennomyskoye		2000	Gas	Exploration drilling	In terms of hydrocarbon reserves, it belongs to large fields. The operator of the deposit is PJSC Gazprom. Seven wells have been drilled at the field. The development of the field is comparable in importance to the development of the Prirazlomnoye field.
	Severo-Kamennomysskoye		2000	Gas	Exploration drilling	In terms of hydrocarbon reserves, it belongs to large fields. The operator of the deposit is PJSC Gazprom. The number of wells drilled in the field is eight. It is proposed to start the development of the field next after the commissioning of the Kamennomysskoye More field.

Appendix B

Full name: ________________________________

Age: ________________________________

Position: ________________________________

Place of work: ________________________________

Dear colleague, please identify the environmental risks and processes accompanying the implementation of oil and gas projects.

Table A2. List of risks.

№	Risk
1.	
2.	
…	

Table A3. List of processes.

№	Processes
1.	
2.	
…	

Appendix C

Full name: Berezikov Sergei Aleksandrovich

Age: 41

Position: Head of the Research Sector (Laboratory)

Place of work: The Institute of Economic Problems G.P. Luzin, the Kola Scientific Center of the Russian Academy of Sciences

Table A4. List of risks.

№	Risk
1.	Spills of oil and petroleum product
2.	Fuel spills
3.	Hydrocarbons leaks
4.	Discharge and leak-age of drilling and production waste
5.	Collapse of the upper layers of rock

Table A5. List of processes.

№	Processes
1.	Emissions of greenhouse gases
2.	Accumulation, leakage of toxic chemicals
3	Noise pollution
4	Utilization and storage of technological drilling waste
5.	Discharge of normatively clean water

Appendix D

Dear colleague, please assess the risks in terms of the level of negative consequences for the sustainable development of the ecosystem and the likelihood (probability) of their occurrence.

If you think that the risk is unlikely—put 1, if the risk is likely—put 2, if the risk is highly probable put 3.

If you think that the scale of negative consequences for the sustainable development of the ecosystem is insignificant—put 1, acceptable—put 2, significant—put 3.

Full name: ______________________
Age: ___________________________
Position: ________________________
Place of work: ____________________

Table A6. List of risks.

Risk	Probability	Consequences
1.1 Spills of oil and petroleum products during offshore production of hydrocarbons		
1.2 Spills of oil and petroleum products during offshore transportation of hydrocarbons		
. . . .		
7.1 Collapse of the upper layers of rocks during onshore production of hydrocarbons		

Appendix E

Dear colleague, please assess the risks in terms of the level of negative consequences for the sustainable development of the ecosystem and the likelihood (probability) of their occurrence.

If you think that the risk is unlikely—put 1, if the risk is likely—put 2, if the risk is highly probable put 3.

If you think that the scale of negative consequences for the sustainable development of the ecosystem is insignificant—put 1, acceptable—put 2, significant—put 3.

Full name: Berezikov Sergei Aleksandrovich

Age: 41

Position: Head of the Research Sector (Laboratory)

Place of work: The Institute of Economic Problems G.P. Luzin, the Kola Scientific Center of the Russian Academy of Sciences

Table A7. List of risks.

№	Risk	Probability	Consequences
1.1	Spills of oil and petroleum products during offshore production of hydrocarbons	3	3
1.2	Spills of oil and petroleum products during offshore production of hydrocarbons offshore hydrocarbons' transportation	3	3
1.3	Spills of oil and petroleum products during onshore hydrocarbons' transportation	2	2
1.4	Spills of oil and petroleum products during oil processing		
2.1	Spills of liquefied natural gas (LNG) during offshore hydrocarbons' transportation	2	3
2.2	Spills of liquefied natural gas (LNG) during LNG production	2	2
3.1	Fuel spills during material and technical support of the offshore fields	2	1
4.1	Oil and gas emissions (uncontrolled fountaining) during offshore geological exploration	2	2
4.2	Oil and gas emissions (uncontrolled fountaining) during onshore geological exploration	1	3
4.3	Oil and gas emissions (uncontrolled fountaining) during offshore hydrocarbons' production	2	3
4.4	Oil and gas emissions (uncontrolled fountaining) during onshore hydrocarbons' production	2	2
5.1	Hydrocarbons leaks during offshore geological exploration	2	1
5.2	Hydrocarbons leaks during onshore geological exploration	2	1

Table A7. *Cont.*

№	Risk	Probability	Consequences
5.3	Hydrocarbons leaks during offshore hydrocarbons' production	1	2
5.4	Hydrocarbons leaks during offshore hydrocarbons' transportation	2	2
5.5	Hydrocarbons leaks during onshore hydrocarbons' transportation	3	3
5.6	Hydrocarbons leaks during onshore hydrocarbons' production	2	2
5.7	Hydrocarbons leaks during oil and gas processing	3	1
5.8	Hydrocarbons leaks during LNG production	2	1
6.1	Discharge and leakage of drilling and production waste during offshore geological exploration	1	3
6.2	Discharge and leakage of drilling and production waste during offshore hydrocarbons' production	1	3
6.3	Discharge and leakage of drilling and production waste during onshore geological exploration	2	3
6.4	Discharge and leakage of drilling and production waste during onshore hydrocarbon production	2	3
7.1	Collapse of the upper layers of rock during onshore hydrocarbon production	3	2

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