Transformation of the energy sector in the Arctic in the context of sustainable development of the region

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Abstract. The Arctic is the northernmost region of our planet, including the outskirts of the continents of Eurasia and North America, as well as the corresponding islands and archipelagos, the Arctic Ocean and parts of the Atlantic and Pacific oceans. Despite the still existing discrepancy in the concept of the boundaries of the Arctic region, all researchers agree in one opinion: this region is most sensitive to the climate change, and the consequences may be irreversible. As a part of the commitments on sustainable development undertaken by Russia and taking into account the importance and special status of the Arctic region, it seems necessary to consider the possibility of transforming the energy sector of the Arctic as one of the main sources of emissions of pollutants and CO₂ in the region. The combination of energy sources proposed in the article - natural gas and renewable energy sources - is the cleanest and most environmentally friendly, and a hybrid energy system based on this alliance is the most sustainable and allows to use advantages of proposed energy sources, hedging each other's limitations. Proposed hybrid system could contribute to the development of the region and the well-being of its population and the environment.

1. Introduction. The Arctic region

The concept of sustainable development involves ensuring a balanced solution to socio-economic problems and problems of preserving a favorable environment and natural resource potential in order to meet the needs of current and future generations of people. The decree on the transition to the concept of sustainable development in Russia was approved back in 1996. At the moment, one of the most important directions of the state policy of the Russian Federation is the development of the Arctic region, which has enormous economic potential, as evidenced by the approval of the decree of October 26, 2020 No. 645 of the regional development plan - "On the Strategy for the Development of the Arctic Zone of the Russian Federation and Ensuring National Security in period until 2035"[1]. Russia is faced with the tasks of further developing the set goals: the formation of energy, transport, information and telecommunications infrastructure, the solution of issues of environmental safety and social development.

The Arctic region is divided into five sectors of responsibility between the subarctic states: the USA, Canada, Denmark, Norway and the Russian Federation. The land territories of the Arctic in Russia are determined by the decree of the President of the Russian Federation of May 2, 2014 No. 296 "On land territories of the Arctic zone of the Russian Federation", which includes the Murmansk region, the Nenets, Chukotka and Yamalo-Nenets autonomous districts, some territories of the republics of Komi, Karelia and Sakha-Yakutia, Krasnoyarsk Territory and Arkhangelsk Region, including the adjacent islands and sea territory.
Currently, more than 2.5 million people live in the Russian part of the Arctic region, as well as more than 40 peoples of the Far North (approximate number - about 400 thousand people), which include Dolgans, Nganasans, Nenets, Sami, Khanty, Chukchi, Evenks, Evens, Enets, Eskimos (Yupiks) and Yukaghirs. The population is extremely unevenly distributed, with the region having the highest level of urbanization in the country. There are many industrial enterprises in the region aimed mainly at the extraction of minerals - in addition to oil and natural gas, nickel, cobalt, copper, platinum, apatite, gold, diamonds, etc. are mined here. The economic component of the region is extremely disproportionate: in the Arctic, natural resources are extracted and exported in huge quantities, while a wide range of finished goods is imported - from food and clothing to energy fuels. The Arctic region accounts for approximately 5% of Russia's GDP and 22% of total exports.

2. Energy complex & the environment

A significant part of the resources of the Russian Federation is located in the Arctic. One of the richest in natural reserves at the moment is the Yamalo-Nenets Autonomous Okrug, which, according to experts, accounts for about 43.5% of the initial total resources of the Arctic zone. In general, the reserves of the Russian Arctic zone are estimated at 7.3 billion tons, condensate - 2.7 billion tons, natural gas - about 55 trillion cubic meters, the cost of which is more than $ 20 trillion [3, 4]. The main energy companies operating in the Russian Arctic are Rosneft, Gazprom, Gazprom Neft Shelf, Arktikmorneftegazrazvedka, NOVATEK. Having such a strong resource base, the Arctic zone of Russia is of great interest both for companies and for the state, allowing to provide a large number of the population of the Russian Federation with energy resources and satisfy the external demand of importing countries, while at the same time the task of not causing environmental harm in the Arctic zone in the process of mining and transportation of minerals is not always taken into account.

The environmental issue in the Arctic region is quite acute. According to climatologists, the temperature in the Arctic region is rising 2-2.5 times faster than the global average, which will lead not only to the melting of a huge mass of ice cover and to a rise in the ocean level, but also to the extinction of rare species of animals and birds, which will jeopardize the traditional way of life of the indigenous population of the Far North [6]. At the same time, the Arctic is the region most sensitive to anthropogenic impact, as a result of which it seems necessary to limit the impact of human activity on the environment, especially in northern latitudes.

The fuel and energy complex cause great damage to the ecology of the region. The main fuel for transport and power generation is diesel fuel. Since there are no refineries in the region itself, fuel is imported from the southern regions. This process of transportation is called "Northern Delivery". Delivery is carried out in winter, when road traffic is possible, or in summer, when navigation along shallow northern rivers is possible. In addition to the fact that the use of diesel fuel for energy generation leads to emissions of carbon dioxide and other harmful substances formed during combustion, it is transported in iron barrels, which, after using diesel fuel, remain in the Arctic, rust and pollute the environment.

Today, due to the peculiarities of the Arctic zone and the methods of hydrocarbon production and usage on its territory, there are a number of environmental problems, among which the most common is pollution. One of the clearest examples of accidents of this kind in the Arctic is the disaster near Norilsk on May 29, 2020. The spill amounted to about 21,000 tons of oil products, of which 6,000 tons fell into the ground, the rest - into the Ambarnaya River and its tributary Daldykan, which flow into the large Lake Pyasino. The Pyasina River flows out of this lake and flows into the Kara Sea. According to official data, the total area of contamination was 180,000 m², and the maximum permissible concentration of pollutants in the rivers where diesel fuel has gotten exceeded tens of thousands of times. An accident of this magnitude for Norilsk Nickel immediately resulted in considerable monetary losses, as well as the initiation of criminal cases under the articles "spoilage of land", "violation of environmental protection rules during work performance" and "water pollution"[2]. Irreparable damage to nature has been caused, according to experts, diesel fuel that gets into the water cannot be completely removed from the water.
area, which will have a negative impact on fish and other aquatic organisms, and there is a possible risk of changing the life of indigenous peoples, primarily their health.

In addition, the development of hydrocarbon deposits is accompanied by emissions into the atmosphere. Greenhouse gases such as carbon dioxide and methane have a negative impact on climate change, which is one of the acute problems of our time: emissions of such gases mainly occur when burning oil or gas for energy production, as well as when burning associated gas. Non-methane volatile organic carbons (nmVOC), generated by the evaporation of crude oil during storage or handling, and nitrogen oxides (NOx), generated by the combustion of associated gas and gas in turbines, during the reaction they form ozone, the high concentration of which is harmful to animals, people, vegetation and buildings. NOx emissions also damage coastal ecosystems [5].

The possible environmental damage described above is critical for the Arctic region, which makes it necessary to minimize the consequences of the damage and search for alternatives to the energy resource used as a key fuel in the region.

The main consumers of energy in the region are housing and communal services and the mining industry. Electricity is generated mainly at TPPs of various capacities, which use imported fuel oil, coal and diesel fuel as a source of energy, as well as gas in gas-producing regions (Nenets Autonomous Okrug and Yamalo-Nenets Autonomous Okrug, Republic of Sakha-Yakutia). At the same time, there is no official statistics of the Northern Delivery and it is impossible to determine exactly what amount of polluting fuels was supplied and what damage was caused to the region.

In addition to the nuclear power plants in the Arctic (the Kola nuclear power plant, the Bilibino nuclear power plant and the Akademik Lomonosov floating nuclear power plant, which will replace the decommissioned Bilibino nuclear power plant), the region has successful experiences in the use of renewable energy sources (RES). For example, solar panels are installed at the Northern Lights ostrich farm in the Murmansk region, the largest solar power plant in Russia is installed in Yakutia, solar energy is also actively used to supply power to lighthouses along the entire coast of the Arctic Ocean. A Zapolyarnaya wind farm operates in the Vorkuta region, and a wind farm in the town of Labytnangi has been implemented in the Yamalo-Nenets Autonomous Okrug. Also, wood is used as biofuel for heat generation at boiler houses in regions rich in wood - Murmansk and Arkhangelsk regions. During the Soviet era, many small hydroelectric power plants operated in the western regions of the Arctic, but, unfortunately, almost all of them are closed today.

The use of combined energy sources such as renewable energy sources together with fossil fuels or several renewable energy sources together is considered promising for the Russian Arctic. For example, in the Murmansk region there are combined diesel-solar stations, there are opportunities for the use of wind generation connected to the grid and working "in tandem" with existing hydroelectric power plants, wind solar generators are operated in gas fields.

In the Taimyr municipal district there is the prospect of using wind-diesel complexes, and in the Chukotka district there are more than 50 thermal springs that could be used to replace coal heating [6].

Consider below the various options for the potential use of renewable energy sources in the Arctic region. Since renewable energy has a clear geographic reference, it is obvious that its use is optimal in places with one or another resource potential: high wind speed, a high number of sun hours, high hydro-potential, the presence of geothermal sources or large forests.

Wind energy. The Russian Arctic has a high potential for the use of wind energy. On the coast, the average annual wind speed reaches more than 6.5 m/s, and in some places even more than 8 m/s. The use of offshore wind parks would be promising for the region. The wind map of the Russian Federation shows that the coasts of the Murmansk Region, the Nenets Autonomous District, the Krasnodar Territory, the Republic of Sakha-Yakutia and the Chukotka Autonomous District have the greatest potential. Also, great potential is seen in the use of wind generators with a vertical axis of rotation of the blades and installations with plates operating on the piezoelectric effect [12].

Solar energy. The Arctic region cannot boast of a large number of hours of sunshine, however, on the insolation map of the region, the regions with the largest number can be distinguished - mainly
Yakutia, as well as small regions of the Krasnoyarsk Territory and the Yamalo-Nenets Autonomous District.

**Hydropower.** The only tidal power plant in Russia, the Kislogubskaya TPP, has been built on the territory of the Murmansk Region. The potential of tidal energy in the region is very high, but the problem is technical operation in the conditions of the polar night, low air temperatures and glaciation of structures.

**Geothermal energy.** From the point of view of geothermal energy, the Chukotka Autonomous Okrug has the greatest potential - there are thermal springs, whose presence indicates the best located places for the construction of geothermal energy infrastructure.

**Biofuels.** The greatest prospects for biofuels are in the Murmansk and Arkhangelsk regions, the Republic of Karelia, the Nenets and Chukotka Autonomous Okrugs. These are the regions with the largest forest area.

### 3. Proposed hybrid energy system

Considering the above, there is an obvious need to transform the energy system in the Arctic region, which is a rather difficult and ambitious task. Without setting the aforementioned tasks on a full scale, this study attempts to consider a possible change in the energy system of the region, taking into account its features and tasks identified in the framework of regulatory documents and sustainable development of the Arctic zone.

The particular qualities of the region include:

- High ecological sensitivity of the region.
- Low population density and, as a result, the inability to build a centralized energy system.
- Dependence on imports of diesel fuel, which contradicts the task of ensuring the energy security of the region.
- Large volume of associated gas flaring during oil production.

The tasks identified in the regulatory documents include:

- Environmental protection in the Arctic.
- Development of liquefied natural gas production.
- Development of the power supply system, modernization of local generation facilities, expansion of the use of renewable energy sources, liquefied natural gas and local fuel.
- Reducing the share of local electricity generation based on the use of economically ineffective and environmentally unsafe diesel fuel.

In the hybrid energy system proposed in this article, natural gas was chosen as the basic energy source to replace diesel fuel. Natural gas reserves are very significant in the region; therefore, it is possible to abandon the procedure for the northern delivery and import of diesel fuel, fuel oil or coal from the southern regions. Natural gas is the cleanest type of fossil fuel, which will minimize the harm caused to the environment from CO₂ emissions during combustion, and if CCS/CCUS technologies are introduced, it will level them to a minimum.

The main problem of using natural gas in a decentralized energy supply for a long time was the lack of the necessary infrastructure for its transportation - the construction of gas pipelines over long distances with low final demand turned out to be absolutely unprofitable. This problem can be solved by liquefying natural gas and building small-scale infrastructure for its liquefaction, transportation and regasification. Small-scale LNG (SSLNG)¹ is currently a fast-growing segment in the LNG industry due to its significant commercial potential, greater flexibility and lower investment costs.

SSLNG is widely used to meet off-grid gas demand and to supply distant markets where demand is too low for traditional suppliers. SSLNG can be supplied for power generation, and can also be positioned as a fuel for transport in the maritime, rail, automobile and aviation sectors. SSLPG can serve

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¹ The International Gas Union (IGU) defines small-scale LNG production as follows: all gas liquefaction plants and regasification plants with a capacity of less than 1 million tons per year belong to small-scale production (in the case of ships, the capacity should be less than 18,000 cubic meters).
industrial end users with small regasification units or provide natural gas to rural areas. Such operations are already taking place in areas where gas infrastructure is less well developed, or in regions with high gas production, where SSLPG can provide power to settlements remote from gas fields and pipelines.

The cryogenic containers of the International Organization for Standardization (ISO) have facilitated the development of small-scale LNG supplies. Specially designed tanks contain LNG in a liquid state and can be placed on trains, ships or heavy trucks for transportation to their final destination. Transporting fuel by rail or in cryo-tanks can help projects in remote fields where gas can be liquefied at production sites and monetized in the future, rather than being flared.

Studies show that the Arctic region, due to its low temperatures, is ideal for the construction of infrastructure for the liquefaction of natural gas, because if the ambient temperature drops, the load on the refrigeration cycles is reduced, resulting in large volumes of LNG production at lower costs.

In addition to suitable temperature conditions, the construction of LNG infrastructure in the Arctic region is growing every year. In addition to the existing PJSC Novatek Yamal LNG plant (Table 1), the region is also considering the construction of the following large-scale projects:
- Pechora LNG (Ruskhim Gas).
- Vostok Oil (Rosneft).
- Arctic LNG 1, Arctic LNG 2, Arctic LNG 3 and Ob LNG (Novatek).
- Kara LNG (Rosneft).

Small and medium-sized projects also include Yakutsk LNG (A-Property (YATEK)) and Northern Dvina-LNG of the state corporation Rostec, as well as the Novatek transshipment terminal in Murmansk [10]. Given the upcoming boom in the construction of LNG plants, there will be no shortage of a source of liquefied natural gas in the region, which can be transported to end users by small tankers from both small and large-scale plants.

In addition to transporting gas directly from the plant, it is possible to place small-scale liquefaction units at gas distribution station (GDS) in regions with existing gas pipelines (Republic of Karelia, Arkhangelsk Oblast, Komi Republic, Yamalo-Nenets Autonomous Okrug), following the example of installation at GDS-4 in the Sverdlovsk Oblast.

LNG can be transported both by low-tonnage tankers along sea and river routes (especially taking into account the lower draft compared to ships carrying oil products - low-pass, shallow northern rivers will now be available for transportation), as well as by road cryo-tanks. As the experience of foreign countries shows, the optimal zone for LNG delivery by road is a circle with a radius of about 500 km from the LNG storage facility, but in China, LNG is delivered for a length of about 4,000 km.

For all its obvious advantages, natural gas is, albeit a reliable, but still a fossil fuel, and therefore greenhouse gas emissions will be present during its usage. To reduce the harm done to the environment, it is proposed to combine the advantages of gas as a fuel source with the advantages of renewable energy sources (RES). Natural gas and renewable energy sources are often viewed as competing with each other (for example, in the power generation sector). Taking into account the need to reduce greenhouse gas emissions as soon as possible and insufficient technical progress in the field of energy storage and the issue of intermittent generation of electricity from renewable energy sources, as well as taking into account the environmental characteristics of the region and its potential in terms of renewable energy sources, the proposed model was made with appropriate adjustments to create synergies from combining the advantages of LNG and RES. In this model, the above energy sources complement each other, allowing their advantages to neutralize their disadvantages. Within the framework of the model, the most successful combinations of natural gas and renewable energy sources were determined depending on the sector of the energy system, taking regional characteristics into account [7,8].
Table 1. List of existing and planned LNG plants in the Arctic region.

| Name of LNG plant | Owner | Location | Capacity/year | Investment | Status |
|-------------------|-------|----------|---------------|------------|--------|
| Yamal LNG         | NOVATEK (50,1%), Total (20%), CNPC (20%) and SRF (9,9%) | Yamalo-Nenets Autonomous Region | 17,4 million tons | RUB 2 trillion | There are 3 large-scale lines operating (5.5 million tons / year each), in May 2021, a 4 line was launched, operating on Novatek's technology – “Arctic cascade” |
| Kara LNG          | Rosneft | Archipelago Novaya Zemlya | Up to 30 million tons | from $ 27 billion to $ 45 billion | The preliminary start of work is 2030-2035. Construction is not in progress. |
| North Dvina LNG   | State Corporation Rostec | Arkhangelsk | 120 thousand tons | RUB 14 billion | A business plan and a financial model of the plant were developed. No construction is in progress. |
| Pechora LNG       | Ruskhim Gas | Nenets Autonomous Region | Up to 4,3-5 million tons | RUB 200 billion | It is planned to build an export-oriented methanol production facility on the resource base of the fields. No construction is in progress. |
| Arctic LNG-1      | NOVATEK | Yamalo-Nenets Autonomous Region | 19,8 million tons | - | No construction is in progress. |
| Arctic LNG-2      | NOVATEK | Yamalo-Nenets Autonomous Region | 20 million tons | $ 6 billion | The plant is under construction. At the end of 2020, the readiness of the project was estimated at 32%, the readiness of the first line - at 46% |
| Arctic LNG-3      | NOVATEK | Yamalo-Nenets Autonomous Region | - | - | No construction is in progress. The launch of the project is possible at the end of this or the beginning of the next decade. |
| Ob LNG            | NOVATEK | Yamalo-Nenets Autonomous Region | 5-6 million tons | - | Novatek changed the Ob LNG project to the Ob Gas Chemical Complex, which will produce clean fuels such as ammonia, hydrogen and methanol. No construction is in progress. |
| Taimyr LNG (Vostok Oil) | Rosneft, Trafiguра (10%), Vitol and Mercantile & Maritime (5%) | Krasnoyarsk Region | 30-50 million tons | from $ 27 billion to $ 74 billion | No construction is in progress. Implementation is planned until 2035. |
| Norilsk LNG       | Norilskgasprom | Krasnoyarsk Region | 2 million tons | - | The project is planned to be implemented from January 2022 to March 2023. No construction is in progress. |
| Yakutsk LNG       | "A-Property" (YATEK) | Saha Republic | 17,7 million tons | $ 30-35 billion | Pre-FEED of the project was completed. No construction is in progress. |

Many combinations of gas and renewable energy sources can be efficient through co-location. These include:

- Synthetic gas produced artificially from excess electricity from renewable energy sources can be stored/transported thanks to the existing gas infrastructure.
- Depleted gas fields can be converted into thermal or compressed air energy storage.
- Wastewater treatment plants that use waste heat from natural gas power plants can create clean fuels such as biogas or hydrogen for fuel cells.

Hybrid power plants are designed to improve efficiency and flexibility, manage fluctuations in renewable energy sources, and reduce the risk of fuel price changes. For example, GE's 530-megawatt power plant under construction in Karaman, Turkey will use gas, solar and wind power to increase its
efficiency. Concentrating Solar Power Plants (CSPs) from Solar Energy Generating Systems in California burn natural gas when solar power decreases, allowing the operator to ensure the supply of electricity regardless of weather conditions [9].

*Electricity generation sector.* In the power generation sector, it is optimal to use hybrid installations, where natural gas will be used as the base fuel, and in case of the onset of optimal natural conditions, renewable energy sources will be also implemented - solar or wind energy. The main problem of such hybrid installations is the harsh climate of the region - strong winds and low temperatures. However, there is already experience in using such systems, where petroleum products are used as the main fuel, which can be used in the future to switch to hybrid gas installations. In the Yamalo-Nenets Autonomous Okrug, small autonomous complexes with a capacity of 40 kW are already being used, where diesel generators are combined with wind and solar installations, while the main energy sources are renewable energy sources, and diesel is automatically turned on only when there is not enough solar and wind energy.

*Industry sector.* In the industrial sector, it is proposed to move away from the use of diesel fuel for the needs of production and replace equipment with gas installations of a combined cycle, and use not only gas, but also biogas as an energy source. It’s possible to increase income by providing electricity to the grid during periods of peak consumption. By using biogas as an energy source, the plant owner can also participate in the green certification trade, contributing to corporate sustainability goals and reducing net carbon emissions.

*Housing and communal services.* For residential buildings in the region, it is proposed to introduce smart hybrid energy systems. Such systems can use multiple fuel sources, smart energy infrastructure and local generation. Such house or several houses can use energy from solar panels (or a local solar station), small wind turbines and thermal power plants using natural gas. Smart energy infrastructure will allow a household to sell electricity to the grid in case of its surplus and become not only a consumer, but also an energy producer (prosumer).

In the commercial sector, some of the synergies can be illustrated by an example of a shopping mall that generates, consumes, stores and sells energy and energy services. The complex can have a combination of local photovoltaic panels, TPP with flexible fuel, obtain biogas from waste and store energy in storage. For a TPP, an enterprise can purchase waste from the local municipality and, in combination with waste generated on site, use it to fuel the flexible fuel TPP turbine, which can also consume natural gas. As heating needs and electricity market conditions change, energy from the cogeneration system can be dynamically redirected to generate more electricity or to the air conditioning system to provide cooling [9].

*Transport sector.* Taking into account the peculiarities of the region and its low temperatures, the synergy of gas and renewable energy in the transport sector seems to be difficult to implement due to the inability of electric motors to operate at constant low temperatures. However, as technology advances, any gas station can also be equipped with a combination of solar panels and wind turbines and energy storage. In general, it is proposed to convert vehicles to LNG as fuel. Given the gas reserves in the region, there will be no shortage of fuel sources and import dependence will decrease. As a fuel for heavy trucks and public transport, LNG has successfully established itself in China and the United States, bringing not only environmental, but also economic benefits. As a fuel for railway transport, LNG provides an opportunity not to install power lines, and prototypes of Russian-made gas turbine locomotives that run on LNG demonstrate economic and traction efficiency. In the air transport sector, the switch to LNG could boost the development of small aircraft in the region and reduce CO2 emissions from aviation fuels.

In the marine and river transport sector, LNG may remain the only promising fuel, given the restrictions imposed by the International Maritime Organization (IMO). The regulation came into force worldwide on January 1, 2020 to protect the environment and human health by reducing the content of sulfur oxides in the air. The IMO 2020 regulation limits the sulfur content in marine fuel oil to a maximum of 0.5%. However, in designated Emission Control Areas (ECA), the maximum limit for sulfur in fuel oil is 0.1%. At the moment there are only four ECA zones: the Baltic Sea zone; the North
Sea area; the North American zone (covering certain coastal areas off the coast of the United States and Canada); and the United States Caribbean region (around Puerto Rico and the United States Virgin Islands)). With these limits on sulfur emissions in fuels, LNG is becoming the preferred choice for ship-owners operating in the above regions. In June this year, at a joint meeting of the UN and IMO, it was decided to ban the use of heavy marine fuels in the Arctic region from July 1, 2024, and, therefore, the demand for LNG for bunkering will only grow.

As a result of climatic changes, the importance of the Northern Sea Route as a transport corridor will only increase. Expansion of the possibilities of navigation along the White Sea-Baltic Canal, the basins of the rivers Onega, Northern Dvina, Pechora, Ob, Yenisei, Lena, Kolyma, etc. will lead to an increase in the use of marine fuel in the region [11]. It seems necessary in the light of climate change to provide the development of bunkering infrastructure for the most environmentally acceptable fuel - in this case, liquefied natural gas.

![Figure 1. Prospective development map of the LNG and perspective zones for RES](image)

Obviously, such a transformation is impossible in a short time frame and without government support. Investments and political will are needed to move the energy complex of the Arctic region into the channel of sustainable development. Mechanisms of tax incentives and public-private partnerships, fines for CO2 emissions and associated gas flaring, green certificates, state subsidies for the cost (full or partial) of the technical transition to gas/renewable energy sources, the obligation of state-owned companies to acquire/use energy only from clean sources can be used as incentives to transfer the energy sector to environmentally friendly fuel sources.

4. Socio-economic impact of the proposed hybrid system

The transfer of the region’s energy system to clean sources will help to reduce harmful emissions from the combustion of low-quality oil products and reduce carbon dioxide emissions. In order to calculate the reduction in the carbon footprint in connection with the introduction of a new energy system in the Russian Arctic, calculations were carried out. The following energy sources were considered: fuel oil, diesel fuel (winter type) and coal. Since natural gas is measured in cubic meters and other fuels in tons, the natural gas equivalent for each of the replaced fuels was calculated using the specific heat of combustion. Next, the volume of carbon dioxide emitted by the equivalent was calculated. The final stage of the calculations was the calculation of the delta of emissions of carbon dioxide equivalent (natural gas) and one of the types of fuel. The calculation results are shown in Table 2.
Table 2. Carbon dioxide reduction calculations.

| Name of the replaceable energy source | Specific heat of combustion (kcal) | Carbon dioxide emissions | Carbon dioxide difference |
|--------------------------------------|-----------------------------------|-------------------------|--------------------------|
| Fuel oil                             | 9 700                             | 3.1 t CO$_2$ / t        | 600 kg CO$_2$ / t        |
| Diesel fuel (winter type)            | 10 300                            | 3.15 t CO$_2$ / t       | 450 kg CO$_2$ / t        |
| Coal                                 | 6 450                             | 2.8 t CO$_2$ / t        | 1400 kg CO$_2$ / t       |
| Natural gas                          | 8 000                             | 1.85 t CO$_2$ / t       | -                        |

Based on Table 2, it can be concluded that in all cases of replacing petroleum products with natural gas, it becomes possible to reduce carbon dioxide emissions and reduce the carbon footprint. The maximum effect is observed in the replacement of coal with natural gas: each replaced ton of coal reduces carbon dioxide emissions by 1400 kg.

As an example, we can consider a coal mini-thermal power plant located in Dixon. The station operates on coal from the Kayerkansky coal deposit in the city of Norilsk; coal consumption is up to 8500 tons per year. In addition, there are several diesel generators in the port on the island and in the mainland urban settlement of Dikson, and they use 2,500 tons of winter type diesel fuel per year. [6] By replacing coal and winter diesel fuel with natural gas, we get a decrease in CO$_2$ emissions from coal - by 11,900 kg per year, from diesel - by 1125 kg per year.

Also, the socio-economic effects from the implementation of the proposed hybrid energy model include:

- Creating new jobs in the region.
- Reducing pollution and greenhouse gas emissions.
- Attracting investment to the region.
- Increasing the energy security of the region.
- Preservation of the unique ecological system of the region.
- Providing the population in hard-to-reach regions with clean and sustainable energy.
- Limitation of associated gas flaring.
- Growth of domestic scientific research in the field of liquefied natural gas and renewable energy sources and their usage in harsh climatic conditions.
- Reduction in the cost of energy services for the population due to the absence of a premium for transportation.

5. Conclusion

Within the framework of the hybrid model for reducing harm to the environment and the population, ensuring energy security and sustainable development of the region is proposed:

- To replace oil products in the region with natural gas.
- To develop small-scale LNG industry to improve access to natural gas.
- To introduce appropriate renewable energy sources in areas with favorable climatic and geographical conditions.
- To provide this transformation with maximum public, legal, tax and investment support.

According to the hybrid energy system, it is proposed to use natural gas instead of petroleum products. To solve the problem of the emergence of free unrealizable volumes of petroleum fuel, let us consider how the delivery of liquid fuel to the Arctic zone is carried out. Delivery goes from Yaroslavl, Omsk, Achinsk, Komsomolsk, Khabarovsk refineries and Angarsk petrochemical complex.

All of the above refineries produce a wide range of products, the equipment is in the process of modernization or has already been updated. Due to a decrease in domestic demand for diesel fuel, the freed-up volumes can be exported to consumers, to border states, or the volume of production can be redistributed by directing the plant's capacity to products with higher added value, such as lubricants.
It should also be noted that high quality oil produced in the Arctic region, is exported to other states, when the Arctic region itself is supplied with oil of lower quality, produced in the southern and central parts of Russia. This option for providing the region with fuel is fraught with environmental damage due to harmful emissions accompanying the transportation and further use of low quality diesel fuel in the region. It is possible to avoid such damage to the environment by building small refineries (oil refinery) located in close proximity to oil production sites in the Arctic region. Thus, the region will be provided with high-quality petroleum products that are significantly less harmful to the environment due to reduced emissions during combustion and the absence of a long transport shoulder.

The Arctic is a special region, the climatic changes of which have consequences for the whole world. For a more responsible approach to this problem and wide publicity, it is proposed to create a special site for monitoring the environmental situation in the Russian Arctic, where in real time every person from anywhere in the world can look at the ecology in this region. The content of the site offers the following: monitoring of temperature, concentration of carbon dioxide, carbon monoxide, ozone, sea level and salinity, melting Arctic ice. Also, it’s possible to add the change in these indicators over the years, information about the subjects of the Russian Arctic, their history, population, etc. A similar initiative is already being implemented in Russia; residents can track air pollution in cities.

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