Renewable energy in the Russian Arctic: Environmental challenges, opportunities and risks

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Abstract. The Arctic is a specific geographical region with extreme climate conditions, vulnerable environment, but rather intensive ongoing industrialization. The Arctic requires alternative solutions to provide energy supply to the energy consumers due to the growing energy demand and small-scale decentralized character of energy supply. At the moment, the largest part of energy consumption in the region is covered by hydrocarbon energy resources delivered from the mainland. Renewable energy technologies may be efficiently implemented to cover the needs of small scale decentralized energy consumers in the Russian Arctic, but at the moment they are applied on a very modest scale. The current study analyses and discusses the main challenges and risks related to renewable energy resources use in the Russian Arctic. Further, the study elaborates on the issues related to the environmental challenges and climate change-related threats, their relationship and influence on the technological choices of the future energy supply in the region, addressing the perspectives of sustainable development of the Russian Arctic.

1. Introduction

The Arctic region has received another wave of attention primarily due to substantial natural resources potential, including oil and natural gas [1], and also because of geopolitical interplay related to territorial, sovereignty and resource issues [2]. The Arctic region in general possesses huge reserves of minerals and other raw materials, many of which are already involved in the economic circulation of the Arctic countries. In the Russian Arctic, the production of raw materials constitutes about 80% of natural gas, more than 90% of nickel and cobalt, 60% of copper, 96% of platinoids, and 100% of barite. The estimates of initial recoverable resources of oil and natural gas in the offshore areas of the Russian Arctic reach 100 billion tonnes of oil equivalent (toe) [3].

The Russian Arctic also possesses the vast industrial and transportation infrastructure, including oil and gas production facilities, long-distance pipelines, power plants (including the northernmost operating Bilibino nuclear power plant), mines, railroads, aviation infrastructure, sea and river ports, which are predominantly constructed to support extractive industries. However, the availability of
energy resources in the Russian Arctic and existing infrastructure do not help to solve the issues of energy supply in the region. Most of the oil and natural gas reserves in Russia are situated in remote areas with restricted transportation conditions [4], with some production sites located in the shore and offshore areas.

As local energy resources are not available for the consumers in the required volumes, energy resources (fuels and coal) are supplied from the mainland. Transportation costs considerably influence the end prices, sometimes 2-3 times exceeding the price on the world market [5]. Aside from resource availability and electricity cost issues, the sustainability of energy supply in the Russian Arctic is also challenged by a high level of risks related to the current exploitation of hydrocarbon energy resources of the region [6]. Those risks are related to environmental challenges and climate change-related threats [7]. The before mentioned challenges are also present in many Arctic communities in Canada [8] and Alaska [9], but also in other remote locations worldwide-Africa [10] and Antarctica [11].

One of the solutions to reduce the environmental and climate impacts and contribute to the sustainable development of the energy infrastructure in the Arctic region is a broader deployment of renewable energy technologies. Such solutions are especially relevant for remote energy consumers with no access to centralized energy supply infrastructure, as renewable energy provides a higher degree of energy independence for a lower price. There are many cases internationally, where renewable energy is successfully used for remote small energy consumers, also in harsh climate conditions [12]. For example, a larger part of energy in the Arctic territories of Norway, Sweden, and Finland is produced from renewables [13]. The feasibility study in Canada in the communities of Nunavut shows the possibility of 35% renewable energy penetration with lower initial costs followed by the significant reduction of CO₂ emissions [14], where combined renewable-diesel installations can give significant savings on fuel costs for mining in the Arctic [15]. The Russian Arctic, possessing high wind and solar energy potential [16–18], can significantly benefit from adopting renewable energy technologies on a larger scale.

2. Energy supply and demand in the Russian Arctic
There are many industrial energy consumers in the Russian Arctic, including transportation and transit infrastructure, the Northern Sea Route (NSR) [19] and pipeline-related facilities (e.g., pumping stations) [18]. Industry and transportation have the highest shares in the energy consumption, but also energy losses. The population and the service sector have a rather modest share in the total energy consumption. However, the structure of the energy consumption, specifically for electricity, differs. The analysis of the structure of electricity consumption ranges in the Russian Arctic by selected consumers is shown in table 1. Based on the maximum loads the largest consumers are population (big cities) and transportation (transport hubs and industrial infrastructure), which influences the character of energy supply.

Table 1. Electricity consumption ranges in the Russian Arctic by selected consumers based on [18,20].

| Type of consumer                          | min, kW | max, kW |
|------------------------------------------|---------|---------|
| **Industry**                             |         |         |
| small scale manufacturing and processing plants | 10      | 100     |
| medium and large scale plants            | 1 000   | 100 000 |
| pumping stations (oil & gas industry)    | 1 500   | 100 000 |
| **Population**                           |         |         |
| private households                       | 0.1     | 1       |
| settlements up to 150 people             | 10      | 50      |
| up to 300 people                         | 50      | 500     |
| more than 300 people                     | 500     | 100 000 |
| **Transport and navigation**             |         |         |
| navigation and communication             | 0.1     | 10      |
| transport hubs                           | 50      | 500     |
| NSR ports                                | 1 000   | 100 000 |
| **Other**                                |         |         |
Due to the uneven development of the energy and transport infrastructure in the Russian Arctic, there are considerable challenges in providing stable and affordable power supply. The western parts of the Russian Arctic have more developed energy and transport infrastructure, even though some areas have limited access to electricity.

The most dramatic challenges but also considerable potential in the development of distributed power systems were identified in the eastern part of the Russian Arctic. A centralized power supply network is available there only in four power units in Norilsk in the north of Krasnoyarsk Krai, Chaun-Bilibinsky, Anadyr and Egeviknotsky in Chukotka Autonomous Okrug. The northern part of the Sakha Republic (Yakutia) is covered by the decentralized power supply. In Taimyr and Turukhansky districts of Krasnoyarsk Krai 88% of power capacity is represented by the power plants of the Norilsk power unit, where in Chukotka Autonomous Okrug 64% of power capacity is the power plant Chaun-Bilibinsky, Anadyr and Egeviknotsky power units. In the eastern part of the Russian Arctic large power stations are located mainly in Krasnoyarsk Krai (total power about 2.6 GW), providing electricity supply for mining industries, including JSC Norilsk-Taymyrskaya energy company of five thermal power plants of total 2276 MW. In the Sakha (Yakutia) Republic, all the power plants in 13 areas of the total 156 MW can be classified as autonomous. In total, in the eastern part of the Russian Arctic, there are 260 MW of autonomous municipal power plants. There are also independent municipal power plants, primarily gas-turbine installations of LLC RN-Vankor (total power about 250 MW) on the Tagulsky field in Krasnoyarsk Krai. [21,22]

Nevertheless, in the remote locations with poor transport communication the fuel expenses in the Russian Arctic are continually increasing. Due to the remoteness and rather small consumption volumes, it is not economically efficient to connect such small-scale consumers to the centralized electricity networks. The considerable number of remote consumers (certain settlements and villages, meteorological stations, frontier posts, objects of the northern fleet) use independent diesel power plants (DPP). DPP vary from 8-16 to 300-500 kW. For many isolated power supply systems, other than DPP are efficiently applied for electricity generation but on an extremely modest scale.

It is possible to decrease the dependence on inefficient diesel-based power systems through more intensive use of renewable energy resources (RES). However, such solutions will require the construction of power grids and generating capacities to reach decentralized settlements. Such infrastructure is of considerable cost. The connection to the centralized electrical networks with a power less than 250 kW is limited to a maximum of 10 km, and construction of more high-voltage power lines (for example, 35 kV) at the small connected loadings is not efficient [23]. Many settlements with isolated power systems are situated more than 100 km from large cities. The cost-efficient transmission distance lies in range of 25-75 km (associated loading of 1-5 MW) even with rather high costs of 15-20 cents/kWh (9-12 rub/kWh) [24]. The higher tariffs will allow bigger coverage, but in general, the distances to the nearest large power clusters in the Russian Arctic are much longer than 100 km. Therefore, the connection to the centralized systems of power supply in many cases is currently impossible.

At the same time, large energy consumers, such as industry and transportation, will increase energy consumption in the future. The NSR infrastructure is rapidly developing due to increasing cargo transportation from Europe and Russia to the countries of the Pacific region [25]. Thus, it requires the corresponding port infrastructure to meet operational and safety requirements including energy supply [19]. Some of the key growing transport hubs are Murmansk, the port of Sabetta in the Yamal-Nenets Autonomous Area, and also the ports of Arkhangelsk, Indigo, Tiksi, and Pevek.

Another exponentially growing sector is liquefied natural gas production (LNG). The LNG production plants at the Yamal and Gydan peninsula can reach production volumes of 37 million tons of LNG annually [26], significantly affecting the LNG shipment volumes.
3. Decentralized power generation in the Russian Arctic: opportunities and risks

Decentralized power generation technologies (including electric power accumulation and control inventory) become more available and affordable in different parts of the globe, where the considerable part of electricity generation comes from RES. RES include predominantly solar and wind energy. Due to harsh climate conditions, which require more advanced technologies and construction materials for the RES installations, as well as the issues related to the intermittent character of power supply, the use of RES is challenging. The analysis of positive and negative factors of the use of RES (SWOT analysis) in the Russian Arctic is presented in table 2.

Table 2. SWOT analysis of the broader deployment of RES in the Russian Arctic.

| Strengths: | Weaknesses: |
| --- | --- |
| • high potential of wind resources | • intermittent character of renewable power supply |
| • significant potential of solar resources during the summer period | • considerable periods of equipment downtime |
| • availability of wind monitoring data in prospective sites | • low capacity factor of solar installations |
| • the technical possibility to construct modular power systems of small and medium scale | • lack of domestic renewable energy technologies adapted for the Arctic climate conditions |
| • experience in operating wind and solar power plants in the Arctic region | • difficulties in logistics and high cost of equipment delivery |

| Opportunities: | Threats: |
| --- | --- |
| • electricity generation in the required volumes in remote areas of decentralized power supply | • harsh climate conditions: gale-force winds, blizzards and drifts, cryogenic destruction of underground designs |
| • reducing greenhouse gas emissions and impact on the Arctic nature | • technical obstacles: difficulties of construction in permafrost, lack of transport infrastructure |
| • governmental support | • weak policy framework (lack of stimulating mechanisms for RES and small-scale power installations) |
| • international cooperation | • competition from other types of energy sources |
| • vast unused land available for installations | • poorly defined electricity pricing mechanisms |

PJSC RusHydro is one of the companies with experience of RES generation in the extreme Arctic conditions in Russia. The company operates a wind power plant of 900 kW in Tiksi (the Sakha (Yakutia) Republic). The wind turbines were designed for extremely low temperatures down to -50 °C and to sustain a wind speed of up to 70 m/s, where they were already tested during the winter seasons of 2018 - 2019 (down to -42 °C with wind speeds of up to 30 m/s). [27] The total power of a wind-diesel power plant with an automated control system will be 3.9 MW. A solar power installation of 1 MW operates in Batagai, Yakutia since 2015. There are other wind and solar projects to follow [28], also in such locations as national parks in the Arctic [29].

The remote power systems with higher RES share have advantages in the areas with price and cost restrictions on the expansion of centralized power supply. With decreasing RES generation cost, more households may be interested in having their own generation installations. In the Russian Arctic, it is expected that the shares of RES in decentralized power systems will grow due to the hybridization of the existing power supply systems through the broader application of solar energy combined with fossil fuels based generation. Such installations are seen as more efficient solutions in the Arctic conditions. Wind installations are applicable in the areas with the average wind speed profitability threshold of 5 m/s, which primarily occurs along the coast of the Barents Sea (up to 8 m/s) [30]. Such systems may also be supplemented by biomass and small hydroelectric power stations. Moreover, the use of RES in combination with other advanced accumulation technologies will allow a higher level of power generation independency for the consumers.
4. Climate change, environmental issues and the future of energy supply in the Russian Arctic

Within the considerable number of risks related to the development of the decentralized energy supply in the Russian Arctic, the most uncertain and also dramatic are threats related to climate change and environmental impact.

Anthropogenic influence in the Russian Arctic is significant and it increases due to the accelerating economic growth and industrial activities. In some regions it already exceeds the established norms [12]. The adverse ecological situation in the Russian Arctic is caused by the structural deformations of the national economy, which led to a dominance of mining industries with resource-intensive and power-intensive technologies. Some of the current problems and environmental threats in the Russian Arctic are pollution and degradation of all components of the environment; ongoing accumulation of industrial waste and pollutants; violation of the ecological balance of marine and geological environments in mining areas and along the transportation routes, and others. The highest environmental and technological risks are due to mining and smelting plants, pulp and paper mills, oil and gas facilities in the Nenets and Yamal-Nenets autonomous areas, nuclear facilities of the Russian northern fleet and also dumps of the crude sewage from production facilities, as well as household waste.

The Russian Arctic also faces the strongest effect from global climate change. An average temperature increase constitutes 0.5 °C p.a. since the beginning of the 1980s [31]. The global warming leads to a significant change in temperature, reduction of the winter heating period and decrease in required power of combined heat and power plant [5]. The calculations based on the INM CM4 model (within the scenario RCP8.5) [32,33] for the Kola Peninsula showed that by the middle of the XXI century the visible shift in spring and autumn seasons would occur, resulting in the higher range of positive temperatures by the end of the century. The significant changes are also predicted for space-time variability of wind speed [34], resulting in different operation modes and higher risks for wind power generation. Degradation of permafrost, especially in coastal areas, will require a higher focus on its impact on existing infrastructure objects. So far, the number of observed damages due to climate change issues is growing (based on the example of the city of Norilsk) [35]. Another threat related to climate change is the higher possibility of natural disasters, extreme sea conditions as wave heights and increasing ice drift.

Climate change is expected to influence the power consumption in the Arctic region. In case of sharp temperature declines and the occurrence of dangerous hydrometeorological phenomena, the existing and future power systems should be reliable enough to carry out the related pressures. Besides, it may affect the heating period by reducing it to 5-10% by the middle of the XXI century. In the northern areas of the Russian Arctic the potential effect may be much higher, also resulting in decreasing fuel consumption [5].

Thus, there is a necessity to consider climate and environmental issues during planning and implementation of energy and infrastructural projects, as their successful implementation will to a significant extent depend on the reliability of long-term forecasts of the climatic processes [36]. For the Russian Arctic, these issues are of particular urgency, as the infrastructure development plans are vast and include energy, transportation, and production facilities, such as ports, terminals, offshore platforms, pipelines, and other. The energy supply solutions should be adapted to the current pace of occurring climate change.

5. Conclusion

The Russian Arctic is the special geographical region with accelerating socio-economic development and industrial growth. It shows the growing trends in energy consumption, but there are numerous challenges related to the supply of remote energy consumers, climate change and environmental issues.

The use of distributed energy in the Arctic shows more advances than centralized energy supply. The use of local energy resources, in particular, renewables, is one of the main directions of creating
new energy capacities, as well as ensuring an environmentally friendly and cost-effective generation of electricity.

The existing experience in the use of RES in the Arctic at a small and medium scale shows its viability and efficiency. The next stage should be a broader implementation of RES for the needs of decentralized remote energy consumers. The carried-out SWOT analysis of the broader deployment of RES in the Russian Arctic shows a considerable number of weaknesses and threats related to that. Those negative factors have to be considered during the planning and implementation of any projects related to the RES power generation in the Russian Arctic.

Climate change and environmental issues are those critical factors to consider in relation to the development plans of the power supply in the Arctic region. Climate change creates new opportunities, in particular, increasing wind power potential, shorter heating season, but also creates threats. There is the need to secure existing energy facilities, plan the future ones accordingly, and take into account the potential volatility in the future electricity demand.

Implementation of new renewable energy generation technologies and their integration into the existing power systems will contribute to the challenges of increasing energy supply, access to electricity for remote consumers, decreasing power generation costs and will also reduce greenhouse gas emissions.

Acknowledgments
The study was carried out within State Assign (AAAA-A16-116051810068-1; 0149-2020-0003) and with the financial support of the Russian Foundation for Basic Research in the framework of the research project No. 19-08-00945\19.

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