Challenges to overcome: energy supply for remote consumers in the Russian Arctic

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Abstract. The paper explores challenges of power supply for remote users through the case of the Northern Sea Route (NSR) supportive infrastructure development and specially nature protected areas (NPA) of the Russian Arctic. The study is based on a comprehensive analysis of relevant data of the state of renewable energy in the Russian Arctic. The paper gives policy recommendations on how to extend the use of renewable energy power plants in the region, optimize their input and increase cost-effectiveness and safety.

1. Introduction

In recent years the interest towards the development of territories and natural resources of the Russian Arctic has increased significantly. This raises the question of how to integrate developing energy infrastructure in the Arctic region in order to provide comfortable working and living conditions, but minimize the negative environmental impact. Arctic, including economic zone and continental shelf, constitutes 30% of Russian territory, produces 12-15% of the country’s GDP and provides about a quarter of exports. On the global scale, Russia has 43% of the Arctic region of 9 million sq.km and is inhabited with more than 2.5 million people, accounting for 2% of the country population and about 40% of the population across the Arctic. It is hard to overestimate the significance of the Arctic region for Russia.

Extreme Arctic climate does not allow to develop a constantly functioning transport network. Arctic energy system is based on imported fossil fuels with irregular delivery. The complexity of this scheme results in high transportation costs and affect the high cost of energy for final consumer. In order to overcome these challenges, it is required to radically change the approach to energy supply in the region. The most promising option is the use of local renewable energy resources, such as wind, solar, hydropower and biomass [1]. A comprehensive assessment of the available renewable energy resources in the Russian Arctic has been done in the studies [2–4]. Due to heterogeneous distribution of these energy resources across the Arctic territories there is a need to analyze the possibility of efficient access. Besides, technical parameters of existing equipment require reassessment since it has to be adapted to the harsh Arctic climate [4].

2. Renewable energy resources and their use in the Russian Arctic

The main data sources for the assessment of wind and solar energy potential are the perennial actinometrical surface and meteorological measurements [5], and also reanalysis data and mathematical modeling from the global databases (e.g., NASA POWER, NASASSE [6]). NASASSE
is widely used for design purposes, because it provides the wide range of required parameters at regular spatial grid.

The high potential of solar energy exists in the Republic of Sakha (the amount of solar energy is comparable to southern parts of Russia and Germany). Other parts of the region are perspective for effective seasonal use of solar energy. Geographical and climate conditions of the Arctic require special adaptive design for solar plants (low sun declination angles, wide ranges of azimuth, low temperature, energy accumulation, etc.). Areas with lower potential of solar energy are characterized by large wind energy resource potential. High wind power potential is common for all Arctic coastal areas, which allows the efficient use of wind energy primarily to power ports and navigation systems. In addition, there is an excess of timber waste and wood pellets from low-value tree species in the Arctic region, which may be used for the local heating needs. Figure 1 shows the present distribution of renewable energy facilities on the territory of the Russian Arctic [7] and is followed by examples.

![Figure 1. Renewable energy objects in the Russian Arctic [3,7].](image)

In the North and the Far East regions there is an ongoing development of combined wind-diesel power (by OJSC "Peredvizhajnaja Jenergetika") [8], which also includes the monitoring of wind distribution for optimal hardware configurations: (1) 250 kW wind turbine in Labytnangi Yamalo-Nenets Autonomous District is built; (2) 7 wind farms with a total capacity of up to 3.4 MW in Kamchatka is on the design stage; (3) wind-diesel station in North Yakutia (Chokurdakh village) is under development. The banks of Okhotsk and the Bering Straits were equipped by more than 50 power plants (100-500 W) based on PV modules, nickel-cadmium batteries and small wind turbines (Russian Scientific Centre "Kurchatov Institute" in frames of the radioisotope generators replacement programme). Deer farms in the Republic of Sakha (Yakutia) are being supplied by mobile photovoltaic systems up to 500 W from lead-acid batteries and low power diesel generators for the household needs (illumination, battery charging, small household appliances, etc.). The cumulative installed power of the electric power plants based on renewable energy in the Arctic region is about 100 MW, which includes micro hydropower - 92 MW, wind energy - 4.9 MW, tidal energy - 1.7 MW, solar energy - 1.27 MW, geothermal energy - 0.21 MW [3, 9]. Annual output of biomass plants installed in the Russian Arctic is more than 10 million Gcal. Installed capacity of planned renewable energy facilities is projected to reach more than 380 MW (excluding the “Mezenskaja” tidal plant, 11.4 GW), from which 374 MW is wind energy, and 7 MW – solar energy. In addition at least 10 sites are under wind monitoring. To summarize, the renewable energy development is slowly ongoing, but is relatively limited.
3. Renewable energy in NSR and NPA supporting infrastructure

The special attention is required for NSR supportive infrastructure development, which consists of approximately 50 ports, port points and terminals (the largest ones are Arkhangelsk, Igarka, Dudinka, Dixon, Tiksi, Pevek, Providence, Hatanga and Sabetta), all-year and seasonal navigation and communication systems. NSR is used for the national and international transportation of petroleum products (liquefied natural gas, gas condensate and oil), natural resources, wood, consumer goods and commodities. The maritime transport can sometimes be the only way to deliver fuel and other supplies (coastal settlements of Chukotka, Taimyr, Yamalo-Nenets autonomous areas and islands), but the operation time can be strictly limited to 2-4 months depending on the climate conditions and due to the low reliability of existing security systems [10]. Table 1 shows the main ports of NSR and their characteristics including existing power supply.

Table 1. NSR ports and their characteristics [11].

| Name           | Location                  | Navigation season     | Capacity thousand tonnes/year | Power supply (power net / plant) |
|----------------|---------------------------|-----------------------|-------------------------------|----------------------------------|
| Arkhangelsk    | all year                  | 11532.9               | Arkhangelsk PP, Arkhangelsk Pulp and Paper Mill PP, Severodvinsk PP; line 220 kV (Northwest united energy grid) |
| Mezen          | June-September            | 132                   |                               |
| Onega          | May-December              | 261.5                 |                               |
| Vitino         |                           | 11000                 |                               |
| Kandalaksha    |                           | 1500                  |                               |
| Murmansk       |                           | 25000                 |                               |
| Dudinka        | all year except 20.05.-15.06. | 3500                 | centralized power supply: Norilsk PP; 2 HPP (Ust-Khantaiskaya and Kureiskaya) |
| Dixon          | June-October              | 120                   |                               |
| Hatanga        | June-September            | 95                    |                               |
| Igarka         | September - May           | 58.9                  |                               |
| Varandey       | June-December             | 12100                 |                               |
| Andermas       | July-September            | 1.0                   |                               |
| Naryan-Mar     | (until November with icebreaker) | 501                   |                               |
| Tiksi          | July-September            | 67                    |                               |
| Green Cape     |                           | n / d                 |                               |
| Anadyr         | July-September            | 900                   |                               |
| Beringovsky    | October-June              | 646                   |                               |
| Providence     | June-November             | 18.5                  | centralized power supply: Chaun PP; line 110 kV Bilibino NPP |
| Pevek          | July-October              | 330                   |                               |
| Egvekinot      | June-November             | 350                   | centralized power supply: Egvekinotskaya HPP |
| Sabetta        | Yamalo-Nenets Autonomous Okrug | all year | 572 | autonomous power supply (decentralized); portable aviation gas PP |

PP – power plant; HPP – hydropower plant; NPP – nuclear power plant
Ports of Arkhangelsk, Vitino, Kandalaksha, and Murmansk are well connected with the country's transportation system and handle over 85.4% of cargo going through the Arctic region. Some ports, like Mezen, Onega and Dixon are located in areas with no land communications. However, most of these ports serve industrial needs. Ports in Krasnoyarsk region will support the crude oil transportation infrastructure, Amderma - mining industry, and port Sabetta is primarily associated with gas liquefaction plant "Yamal LNG". These ports provide a transcontinental link from White, Barents and Kara Seas to the Pacific, access to European and North American markets, and contribute to the industrial development of the Arctic region. Besides, navigation along the NSR is provided by 37 weather stations located in the coastal zones (average consumption is between 20 to 150 kWh), hydro-monitoring systems, emergency services, life-support systems, etc. Thus, the development of NSR supporting infrastructure and its stable and continuous energy supply is one of the key challenges.

Another type of objects of decentralized energy consumption in the Russian Arctic is the supportive infrastructure of NPA, currently 14 state parks, a national park "Russian Arctic" and the federal reserve area "Franz Josef Land" (figure 2), which constitute approximately 5% of the territory of the Russian Arctic.

Figure 2. Natural protected areas in the Russian Arctic [12].

According to the previous studies, the energy supply of NPA’s can be significantly optimized, since its current condition no longer meets environmental requirements and is not economically efficient [13]. However, the analysis of the available renewable energy resources [2–4] shows that NPA can meet existing energy demand through the use of solar energy resources and thermal energy or even sell the excess of electricity if connected to the grid. This can be possible due to excess of land. Hybrid diesel-wind/solar systems have strong potential to reduce the use and therefore the cost of energy for the final consumers [13]. Apart from economic benefits the renewable energy is much more environmental friendly, than fossil fuel, thus meets nature protection goals on these territories.

4. Challenges of the renewable energy development in the Russian Arctic
Various types of renewable energy generation in the Russian Arctic are the subject for specific types of risks, where along with financial risks, operational risks (resource and technical risks) are high due to the harsh climate conditions and difficulties to provide technical support because of their isolated
character. However, the use of innovative technical solutions can minimize risks and provide environmentally safe operation in extreme climate conditions [14].

Investment risks can be mitigated through the combined use of available energy resources or stepwise transition from fossil dominating energy supply to renewable energy resources, such as the construction of small combined or hybrid power plants. According to the study [15], the payback period in the extreme cold climate can be between 5 and 12 years for wind installations with an average fuel saving around 30% annually. Resource risks associated with the intermittent nature of renewable energy sources demand reliable statistical monitoring data on seasonal and daily fluctuations actualized in relation to specific location areas. Yet the greatest threat for the development of the decentralized renewable energy in the Arctic region is the technical risks - malfunction of equipment, wrong design of process equipment, breakdowns in the production process. The main reason for those challenges is the harsh climate operation conditions, which can result in reduced energy production due to icing, increased vibration (for wind turbines), short circuit due to excessive moisture, etc. Technological risks can be reduced through the adaptation of the equipment, which includes the use of special types of foundations and construction materials, and development of corresponding protective intelligent systems against icing, wind gusts and high humidity. Power facilities can be installed more successfully when using a block-modular design with a minimum number of process steps, which also will not require the use of heavy installation equipment. These operational principles will lower the technical risks and increase economic efficiency of renewable power facilities.

5. Conclusion

Russian Arctic possess vast local resources of renewable energy, which can be widely utilized for the industrial and household needs. Still, the use of combined and renewable power plants is limited in the Arctic region both in Russian and worldwide due to the specific climate conditions and corresponding challenges. The conducted analysis of the challenges for renewable energy supply in the Russian Arctic based on the cases of NSR and NPA supportive infrastructures gives the opportunity to formulate a set of policy recommendations in order to stimulate the development of renewable energy power plants and small combined facilities.

Adapted technological solutions are required for the effective use of renewable energy facilities to ensure high system performance and resistance to ice conditions and low temperatures. Despite the technological challenges local renewable energy resources (wind, solar, hydro and biomass) have high potential to improve the reliability of the NSR infrastructure power supply, can be applicable in navigation equipment and facilities in the NPA in the Russian Arctic. Renewable energy power supply can enhance the degree of preservation of NPA and decrease the environmental impact.

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References
[1] Morgunova M O and Soloviev D A 2016 Power supply of the Russian Arctic: hydrocarbons or renewable energy? Int. Conf. The Arctic and offshore projects: perspectives, innovation and development of the regions of Russia (Russian State University of Oil and Gas (NRU)) February 18-19 Moscow 14
[2] Andreenko T I, Gabderahmanova T S, Danilova O V et al 2015 Atlas of renewable energy resources in Russia (Moscow: MUCTR. D. I. Mendeleeva) 160
[3] Popel O S, Kiseleva S V, Morgunova M O, Gabderahmanova T S and Tarasenko A B 2015 The use of renewable energy sources for power supply to consumers in the Arctic zone of the
Russian Federation *Arctic ecology and economy* 1 17 65-9

[4] Gabderahmanova T S, Kiseleva S V, Popel O S and Tarasenko A B 2016 Some aspects of renewable energy development in the Arctic zone of the Russian Federation *Alternative Energy and Ecology* 19-20 41-53

[5] *Reference Book on Russian climate (Arctic region)* (St. Petersburg: Gidrometeoizdat) 1997 4

[6] NASA *Prediction Of Worldwide Energy Resource Atmospheric science data center* 2017 available at https://eosweb.larc.nasa.gov

[7] *Renewable Energy Russia GIS* 2016 available at http://gisre.ru

[8] Popel O S 2016 On the prospects of the niches and the use of renewable energy resources in the Arctic zone of the Russian Federation *Int. Conf. The Arctic and offshore projects: perspectives, innovation and development of the regions of Russia* (Moscow: Russian State University of Oil and Gas (NRU)) February 18-19 Moscow 16

[9] Gabderahmanova T S and Tarasenko A B 2016 On the possibility of using solar energy in electric charging infrastructure *Int. Conf. Construction - the formation of living environment: proceedings of the XIX International interuniversity scientific-practical conference of students, undergraduates, graduate students and young scientists* (Moscow: NIU MSSU) April 27-29 Moscow 1025-102

[10] Voronina E P 2015 Insurance protection and promotion of maritime security along the Northern Sea Route *Analytical Bulletin* 6 559 18-24

[11] The strategy of sea port infrastructure development in Russia up to 2030 2017 (Moscow: FSUE Rosmorport) available at http://www.rosmorport.ru

[12] Stishov M S 2013 *Specially protected areas of the Russian Arctic: current state and prospects of development* (Moscow: the World Wildlife Fund) 239

[13] Boute A 2016 Off-grid renewable energy in remote Arctic areas: An analysis of the Russian Far East *Renew. Sustain. Energy Rev.* 59 1029–37

[14] Nefedova L V., Solovyev A A, Shilova L A and Solovyev D A 2016 Risk factors during construction of power plants using renewable energy sources *Vestn. MGSU* 12 79–90

[15] Tin T, Sovacool B K, Blake D, Magill P, El Naggar S, Lidstrom S, Ishizawa K and Berte J 2010 Energy efficiency and renewable energy under extreme conditions: Case studies from Antarctica *Renewable Energy* 35 8 1715-23