Study of feasibility of local renewable resources for substitution of fossil fuels in the Far North of Russia

Z B Namsaraev¹, A M Konovalov² and G V Baturova²

¹ NRC Kurchatov Institute, Moscow, 123182, Russia
² Moscow Technological University (MIREA), Moscow, 119454, Russia

e-mail: zorigto@gmail.com

Abstract. The problem of replacing fossil fuels is extremely important for the sustainable development of the Far North of Russia. At present, the power supply of this region is solved by delivering fossil fuel by water and road transport ("Northern delivery" or "Severniy zavoz" in Russian), which significantly increases its cost. The goal of this paper is to estimate the volume of fossil fuel delivery to the Far North and compare it with potential technical bioenergy resources for a transition of the local power systems to the local renewable resources. The analysis of the Northern delivery volume in 2015 showed that fuel constitutes 95.1% of the total volume of the Northern Delivery. The estimated energy content of the different types of fuels is equal to 112.7 PJ (diesel 81.5 PJ, gasoline 9.6 PJ, coal 21.6 PJ). The total technical potential of forest waste in the northern Federal Districts is 355.9 PJ. Thus, the bioenergy potential of forest residues of these Federal Districts is more than 3 times higher than the energy content of fuels delivered to Far North. This makes the partial transition of the Far North to renewable energy sources theoretically possible, which will also help to solve a number of environmental problems related to the accumulation of waste from a forest industry. The use of the existing infrastructure of the Northern Delivery will allow creating a new local market for the forest residues and increasing the efficiency of the bioenergy industry. The possibility of transition to renewable energy resources should be taken into account during the modernization of the energy infrastructure in the Far North, including the possibility of using renewable resources for heating. The process of replacement of fossil fuels by renewable biofuels has already begun in a number of regions of the Far North, such as the Arkhangelsk region, which is one of the largest producers of wood pellets in Russia.

1. Introduction

The problem of replacing fossil fuels is extremely important for the "areas of the Far North and equated localities with limited delivery periods" of Russia (further in the text "Far North"). Such areas include completely or in part the territories of 25 regions of the Russian Federation. The area of regions completely or partially belonging to the territory of the Far North is 11.25 million square km that is equal to 65.7% of the total territory of the Russian Federation (figure 1). The number of permanent residents living in the territories of the Far North is 9.9 mln people or 6.8% of the total population of the Russian Federation [1]. The Russian economy essentially depends on the resources obtained in the territories of the Far North. 76% of Russian oil, 93% of natural gas, 95% of coal, 95% of gold, 100% of diamonds, 100% of salmon, and many other useful resources are produced on these territories [2]. A presence of large cities in the regions of the Far North is characteristic for Russia. For example, in the territory to the north of the Arctic Circle, there are 5 large cities with a
population of more than 50 thousand people: Murmansk (298 thousand people), Norilsk (178 thousand), Vorkuta (58 thousand), Apatity (56 thousand), Severomorsk (51 thousand). Murmansk is the largest city in the world beyond the Arctic Circle, and Norilsk is the most northern city with a population of more than 100 thousand people [3]. To the south of the Arctic Circle, it is necessary to note Yakutsk with a population of 311 thousand people, which is the largest city in the Far North of Russia [1].

The energy supply of the Far North is a very difficult task. 33 % of territory of Russia, mainly on the Far East and Siberia, are not connected to the Unified Energy System of Russia and located on the Far North Territories [4]. At present, this problem is solved by delivering fuel by water and road transport ("Northern delivery" further in the text ND, "Severniy zavoz" in Russian), which significantly increases its cost. In remote settlements with extremely expensive power supply from local power plants operating on fossil fuels, the energy costs for end-users are up to 50 % of local GRP. The energy supply is possible only because of the huge state subsidies (more than 50 billion rubles per year) [2]. Currently, a correct calculation of the total volume of the ND is complicated due to change in the accounting system that occurred in 2014 and the methodology of calculation requires development. This complicates the assessment of the volume of renewable resources that could replace fossil fuels in the ND.

Given the high cost of electricity and heat in the Far North, the use of local renewable energy resources is an important way to increase the energy efficiency and diversify energy sources. This is reflected in the major documents in the field of energy in Russia: "The Energy Strategy of Russia for the period up to 2030" and "The State Program on Energy Efficiency and Energy Development" [5, 6]. Russia leads the world in the forest area that is located mainly in the Far North territories (809 million hectares as of 2010, 20 % of the world's forest area) [7]. Given a huge amount of biomass in Russia, the bioenergy industry could play an important role in the power supply of the Far North territories. A number of regions of Russia located in the Far North have large bioenergy resources. Nevertheless, the role of bioenergy in Russia is now surprisingly low [8]. The goal of this paper is to estimate the volume of fossil fuel delivery to the Far North and compare it with potential technical bioenergy resources for a transition of the local power systems to the local renewable resources.

2. Materials and methods
The estimation of the ND composition as well as volume of the main categories of industrial goods and products represents a methodological problem. Until 2014, the Federal plan for statistical works included a separate section for statistical survey in areas of the Far North and equated localities with limited delivery periods. It was formed in accordance with the list of areas adopted by the Government of the Russian Federation [9] and published in the official statistical yearbook of the Federal State Statistics Service (Rosstat) [10]. According to mentioned list the data were aggregated by the form No. 1-SB sever (urgent) "Data on incoming delivery of consumer goods and industrial products to areas of the FN and equated localities with limited delivery periods for supply of the population, the enterprises and the organizations of the social sphere, housing and utilities infrastructure".

Currently these data collected only by the Federal Agency for Maritime and River Transport (Rosmorrechflot) and published in the aggregated form in the statistical yearbook "Transport and communication in Russia". Data on the volumes for some industrial goods and products are published in statistical yearbook "Regions of Russia. Socio-economic indicators" as well. In this regard the authors developed a method for ND volume estimation in 2015. The method is based on the following principles.

Firstly, for the regions of the Russian Federation that are completely or partially located on the territory of the Far North, we used the information from a statistical yearbook of Rosstat (data on volumes for the main categories of industrial goods and products in the context of subjects of the Russian Federation [11]). Secondly, for each region of the Russian Federation that is located in the FN, we calculated the weighted-average coefficients for 2005–2014. These coefficients were defined as the ratio of volumes of the major categories of industrial goods and products delivered to the Far
North to the total volume of industrial goods and products delivered to the region. These coefficients for each region were extrapolated for 2015. According to these coefficients, we determined ND volume in 2015 based on data of statistical yearbooks of Rosstat [11, 12]. For verification of the method we compared the official statistical data for the period between 2010 and 2014 [10] with ND volumes calculated by our method for the same period. It showed the minimum deviation and reliability of elaborated method. For analysis of the composition of water transport to the Far North we used the official data of Rosstat for the relevant time periods [11, 12]. For the assessment of budget expenditures for purchase and delivery of fuel and food products to the areas of the Far North we used the information from the published budgets of Russian regions for the corresponding years taking into account the regional funds allocated for these purposes and subsidies from the budget of the Russian Federation. Federal budget expenditures were determined using the data on the "equalisation transfer" from federal to regional budget in accordance with article 131 of the Budget code of the Russian Federation. The data on the Mezen district were obtained from the report prepared by the Government of the Arkhangelsk region on the results of the Northern delivery in 2015 and the data obtained by Alsufiev & Shnayder [13].

The primary energy content of different fuels was calculated using the following lower heating values: gasoline – 43.6 MJ/kg, winter and arctic diesel fuel – 43.6 MJ/kg, summer diesel fuel – 43.4 MJ/kg, coal – 27 MJ/kg [14]. The technical bioenergy potential of Federal Districts of Russia data was obtained from the paper published by Namsaraev and coauthors [8]. The technical biomass potential considers all biomass theoretically available in the Russian Federation that can be technically supplied during one year.

**Figure 1.** The map of the areas of the Far North.

Bold lines show the borders of the Federal Districts of Russia: 1 – Central, 2 – North Western, 3 – Southern, 4 – Volga, 5 – Ural, 6 – Siberian, 7 – Far Eastern. The boundaries of the Federal Districts are shown as of 19 January 2010, before the North Caucasian Federal District was separated from the territory of the Southern Federal District. Blue area – regions of the Russian Federation referred in the list of the areas of the FN. A – Arkhangelsk region. Dark blue area on the territory of Arkhangelsk region – municipal districts belonging to Far North. Shaded area – the area technologically isolated from the Unified Energy System of Russia [8, 9].
3. The analysis of the ND volume

The analysis of the ND volume in 2015 showed that the major categories of goods delivered to the Far North are goods for the technical and industrial purposes (3048.3 thousand tons), including fuel, and food (69.3 thousand tons). The total volume of various types of fuel is 2897.2 thousand tons or 95.1% of the total volume of the ND. The major type of fuel is a diesel fuel, which makes up to 61.6% of the ND. It includes summer (34.8%), winter (9.8%) and Arctic diesel fuel (17%). Coal is the second most important type of energy source and accounts for 26.3% of the ND. Motor gasoline is in the third place (7.2%) (figure 2). The estimated energy content of the different types of fuels is equal to 112.7 PJ (diesel 81.5 PJ, gasoline 9.6 PJ, coal 21.6 PJ).

![Figure 2. The composition of the ND of industrial goods by major categories in 2015 in thousands tons](image)

The major type of transport used for ND is a water transport. In 2015 by the water transport 20383.6 thousand tons were delivered to the Far North that is 5% less than in 2014 and 27% less than in 2008. The volume of deliveries by water transport considerably exceeds the volume of ND because it also includes goods that are not considered as ND (building materials, consumer goods, etc.). Most of the cargo (84%) was delivered using the inland waterway transport. The dry cargo dominated in the ND and accounted for a little less than 80%, the share of the liquid bulk cargo was 12% and the rest was delivered in rafts (figure 3). In recent years, the dynamics of the volume of delivered products has a downward trends.

Also, it is necessary to note the heterogeneity of the regions of the Far North in terms of existing transport infrastructure and type of cargo delivery. In most regions of the Far North, the transport system does not provide year-round accessibility of settlements by a land transport, and the delivery of goods is carried out mainly during the navigation period by a water transport.
4. Comparison of the volume of fuel delivery and bioenergy resources of the Far North Federal districts

The territories of the Far North are located in the northern parts of the four Federal districts (FD) including Northwest FD, Ural FD, Siberian FD, and Far East FD. The dominant types of bioenergy resources in these districts are forest residues, which are also the most convenient for transportation among other types of biomass resources [8]. Therefore, only forest residues data will be used for analysis in this article. In the Northwest FD, the technical potential of forest waste is 133.5 PJ, Ural FD 50.2 PJ, Siberian FD 130.9 PJ, and Far East FD 41.3 PJ. The total technical potential of forest waste in these districts is 355.9 PJ. Thus, the bioenergy potential of forest residues of these FD is more than 3 times higher than the energy content of fuels delivered to Far North (112.7 PJ).

Substitution of fossil fuel supplies by the renewable resources has a number of positive aspects. Firstly, it will solve a number of environmental problems associated with the accumulation of waste in areas with a developed forest industry. Secondly, the use of the existing infrastructure of the ND will create a new domestic market for forest residues, which can stimulate a further development of the bioenergy industry. The possibility of transition to renewable energy resources should be taken into account during the modernization of the energy infrastructure in the Far North, including the possibility of using renewable resources for heating. This process has already begun in several regions of Russia, in which the number of boiler stations using forest residues (wood pellets) is gradually increasing.

5. Arkhangelsk region as an example of the transition to renewable energy sources

The most active process of the transition to the renewable energy resources takes place in regions with a well-developed wood pellet industry, such as the Arkhangelsk region [15]. The northeastern part of the Arkhangelsk region which includes Mezensky, Pinezhsky, and Leshukonsky municipal districts is classified as the territory that belongs to the Far North and Mezensky region also belongs to Arctic zone of the Russian Federation [9]. The transition to the local renewable energy sources in these areas
will increase the local market for pellets and support the local bioenergy industry since the opportunities to increase export of pellets from Russia are currently limited. Proskurina and coauthors analyzed the pellet-export potential of the Northwestern FD [16]. This FD has the highest level of the pellet production; it is close to seaports and major export markets (Denmark and Sweden). However, when considering an increase, the pellet exports from this region face lots of problems throughout the supply chain.

Local energy resources in the Arkhangelsk region are mainly represented by low-grade wood, wood processing waste (chips, sawdust), pulp and paper industry waste, wood pellets. In 2013, they accounted for 36% of energy resources used in municipal energy generation. In 2013, 320 boiler stations (out of 750) used them as the main fuel, and 72 more as additional. However, in the northernmost Mezensky district, coal-fired boiler stations generate 96% of the thermal energy and wood-burning boiler stations – only 4%. In 11 municipal districts and cities of the region, the share of firewood, pellets, chips and wood waste exceeds 40% of the energy balance of the boiler stations, and by 2030 the Arkhangelsk region plans to completely abandon the use of fossil fuel in the municipal boiler stations by maximizing the use of forest residues [17, 2]

6. Conclusion
Optimization of the economic mechanisms of the ND through the use of renewable local energy resources, modernization of outdated power plants, and the increase of energy efficiency are one of the major priorities of the "Strategy for the development of the Arctic zone of the Russian Federation and ensuring national security for the period until 2020" [18]. However, on the regional level the major measures to support the ND are focused on creating favorable conditions for the delivery of fuel. Only in rare cases it is planned to develop the local production of biofuels and promote the use of renewable energy resources. Our analysis showed that the bioenergy potential of the FD that includes the territories of the Far North is 3 times higher than the volume of the ND of fuel. This makes the partial transition of the Far North to renewable energy sources theoretically possible, which will also help to solve a number of environmental problems related to the accumulation of waste from a forest industry. The use of the existing infrastructure of the ND will allow creating a new local market for the forest residues and increasing the efficiency of the bioenergy industry. The possibility of transition to renewable energy resources should be taken into account during the modernization of the energy infrastructure in the Far North, including the possibility of using renewable resources for heating. The process of replacement of fossil fuels by renewable biofuels has already begun in a number of regions of the Far North, such as the Arkhangelsk region, which is one of the largest producers of wood pellets in Russia.

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