Valery Minin

ECONOMIC ASPECTS OF SMALL-SCALE RENEWABLE ENERGY DEVELOPMENT IN REMOTE SETTLEMENTS OF THE KOLA PENINSULA

BELLONA REPORT 2012

BELLONA
Murmansk

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2012

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Foreword

Recent years have seen researchers worldwide concentrate their efforts on finding, and introducing into the fuel and energy production cycle, non-conventional renewable energy sources such as solar and wind power, small-scale hydropower, tidal energy, and other resources. The application potential of these energy sources is vast, and their ecological advantages are likewise undisputed.

The great benefits offered by renewable energy have not been completely disregarded in Russia, and certain steps have been undertaken to put them to economic use.[1] Russia's Energy Strategy for the Period up to 2030,[2] which sets priorities for the country's energy development in the long term, provides for an increased scale of application of renewable energy sources. Similarly, the "Principal aims of state policy in the field of enhancing energy efficiency of electric power production based on the use of renewable energy sources for the period until 2020" – a document approved by Decree No. 1-r, of January 8, 2009, of the Government of the Russian Federation – also envisions engaging renewable energy sources for economic purposes, as a means to promote energy conservation, reduce consumption of carbon-based fuels, and curb environmental pollution.

Murmansk Region, a large administrative area on the Kola Peninsula in Russia's European North, has a broad range of non-conventional renewable energy sources at its disposal – the sun and wind, small rivers, tides and ocean waves, etc. Each of these resources has its own distinct seasonal characteristics. For instance, the supply of solar energy and hydroenergy is at its peak during summer periods, while consumer demand is traditionally highest during the winter. Conversely, energy derived from the wind and ocean waves reaches its maximum availability in the winter, with the onset of seasonal cyclone activity. Finally, tidal energy is not contingent on a particular season, and its mean monthly values remain unchanged throughout the year or across multi-year spans. These peculiarities determine the specific areas and scope of practical application of renewable energy sources on the peninsula.

Energy production and power supply in Murmansk Region depend to a considerable degree on fuel shipped from other regions. A special category among the region's energy consumers is formed by remote decentralized consumers based in outlying, coastal, and border areas of the Kola Peninsula. Fuel deliveries to such consumers are fraught with significant logistical difficulties. Furthermore, because of the rising fuel expenses incurred by the sea, road, and other transport – including, at times, aviation – whose services are used for such deliveries, the prime cost of electric power and heat produced at local diesel-fired power stations and boiler houses ends up being several times as high as that of electricity and heat provided to consumers served by the grid. This is why the issue of utilizing local energy sources – renewable energy sources among them – is one deserving of the greatest attention with respect to decentralized consumers specifically. In particular, a more vigorous use of renewables in local energy production could become a main avenue for advancing the goals of energy conservation and enhancing the economic efficiency of decentralized energy supply systems.

These considerations prompted what was deemed both an important and timely effort to take a closer look at renewable energy's prospects and resources available to the energy industry of the Kola Peninsula, and to attempt an outline of the basis for – as well as the possible scale and areas of – application of renewable energy sources in off-grid energy supply. The results of this study are offered to the reader in the present report.

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[1] Bezrukikh P.P., Borisov G.A., Vissarionov V.I. et al. Energy resources and the efficiency of using renewable energy sources in Russia. – St. Petersburg: Nauka, 2002. – 314 pages. (Ресурсы и эффективность использования возобновляемых источников энергии в России / Безруких П.П., Борисов Г.А., Виссарионов В.И. и др. – С.-Пб.: Наука, 2002. – 314с.).

[2] Energy Strategy of Russia for the Period up to 2030. – Moscow: Institute of Energy Strategy, 2010. – 180 pages. (Энергетическая стратегия России на период до 2030 года. – М.: ГУ Институт энергетической стратегии, 2010. – 180с.). See also the English version of this document at http://www.energystrategy.ru/projects/docs/ES-2030_%28Eng%29.pdf.

1. Murmansk Region: A brief survey

1.1 Geography, climate, and infrastructure

Spanning a total area of 145,000 square kilometers, Murmansk Region stretches across the northwesternmost tip of European Russia, covering the Kola Peninsula and the adjacent territories of the mainland in the west and southwest. Statistics available as of January 1, 2010, put total population at 865,000 inhabitants, with 8.8 percent residing in rural communities.

Climate. Over 90 percent of Murmansk Region lies north of the Polar Circle, and the area mostly owes its climate and weather conditions to this peculiarity of its geographical location. The warm Atlantic ocean current Gulf Stream also plays a significant role in shaping the local climate. Taken together, these factors account for the region's relatively soft, yet protracted winters – up to seven or eight months in duration – and short, cool summers. Average monthly air temperature values range between -8° and -14° C in the winter, and between 7° and 14° C in the summer.[3] Annual mean temperatures hover around 0° C. Snow cover usually appears strong in November and remains stable for 180 to 200 days. The Kola Peninsula is also characterized by a distinctive wind regime; robust winds with speeds of over 10 to 15 meters per second are a common feature, especially during the winter period.

The polar day and night are another characteristic phenomenon of Murmansk Region. At 69° north latitude – which crosses the area around the region's administrative center, the city of Murmansk – the polar day lasts from May 31 to July 11, and the polar night from December 2 to January 11.

The predominantly cold climate of the Kola Peninsula is what determines the high demand for electric power and, especially, heat supply among all categories of the region's energy consumers. The heating season spans approximately 250 to 300 days, or even longer in certain populated areas along the coast of the Barents Sea, where it continues almost all year round, for up to 350 days.

Roads and other transport networks. Murmansk Region is served by a diverse transport system operating railroad, water (sea-based), air, and road routes (see Pic. 1.1).

The railroad network is represented, first and foremost, by the major line connecting Murmansk and Russia's second largest city of St. Petersburg, in the country's northwest, with local links branching out toward Alakurtti, Kovdor, Kirovsk, and Nikel. A system of departmental railroads is also used to deliver cargoes to mining enterprises and non-ferrous metal smelters and refiners, as well as sites of the energy production industry.

Over-the-road transport is particularly common in the region. An extensive road network now covers most of the region's cities and towns, only lacking in sufficient development in the outlying areas to the east, where small settlements are both quite removed – to distances of up to between 150 and 300 kilometers – from the major roads and broadly dispersed geographically. These are, for instance, the villages of Krasnoshchelye and Kanevka in the central part of the Kola Peninsula, and all of the coastal localities of Tersky, Lovozersky, and Severomorsky Districts.

Sea-based transport accounts for a considerable share of the region's shipping traffic. Murmansk is a major warm-water sea port, and remains in operation throughout the year. This is the point of origin for local cargo traffic bound for coastal communities of the Kola Peninsula. The region's other large sea port is Kandalaksha, which handles hefty volumes of freight moved along the shipping routes of the White Sea.

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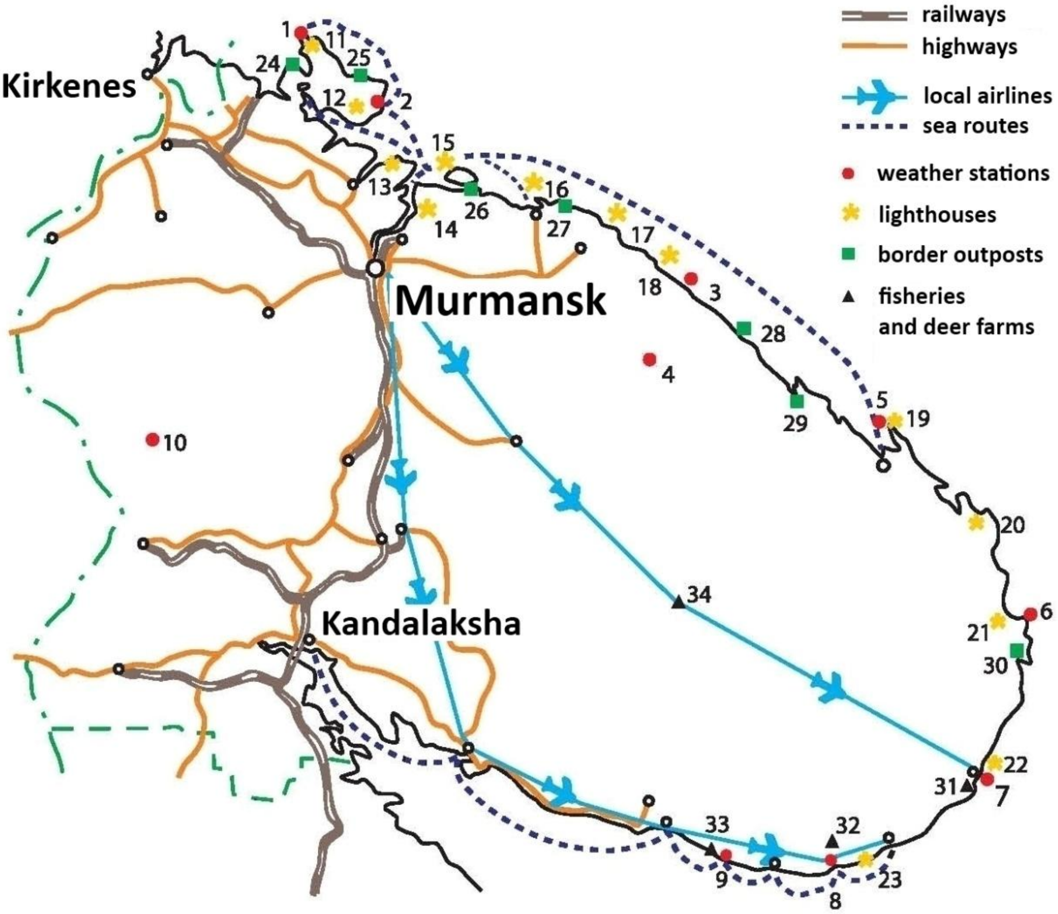
[3] USSR Climate Reference Book. Vol. 1, Part 2. Air and soil temperatures. – Leningrad: Gidrometeoizdat, 1965. – 359 pages. (Справочник по климату СССР. Вып. 1, ч. 2. Температура воздуха и почвы. – Л.: Гидрометеоиздат, 1965. – 359с.).

Air traffic is mostly routed through the two principal airports of Murmansk and Kirovsk. Local air routes, serviced by the airports Lovozero and Umba, also connect the region's central areas with remote localities, where aviation remains all but the single accessible means of transport during the winter period.



Pic. 1.1. Traffic networks of Murmansk Region: Off-grid energy consumers.

Weather stations: 1 – Vayda-Guba; 2 – Tsyp-Navolok; 3 – Kharlov Island; 4 – Kolmyavr; 5 – Svyatoy Nos; 6 – Tersko-Orlovsky; 7 - Sosnovets Island; 8 – Pyalitsa; 9 – Chavanga; 10 – Nivankyul.

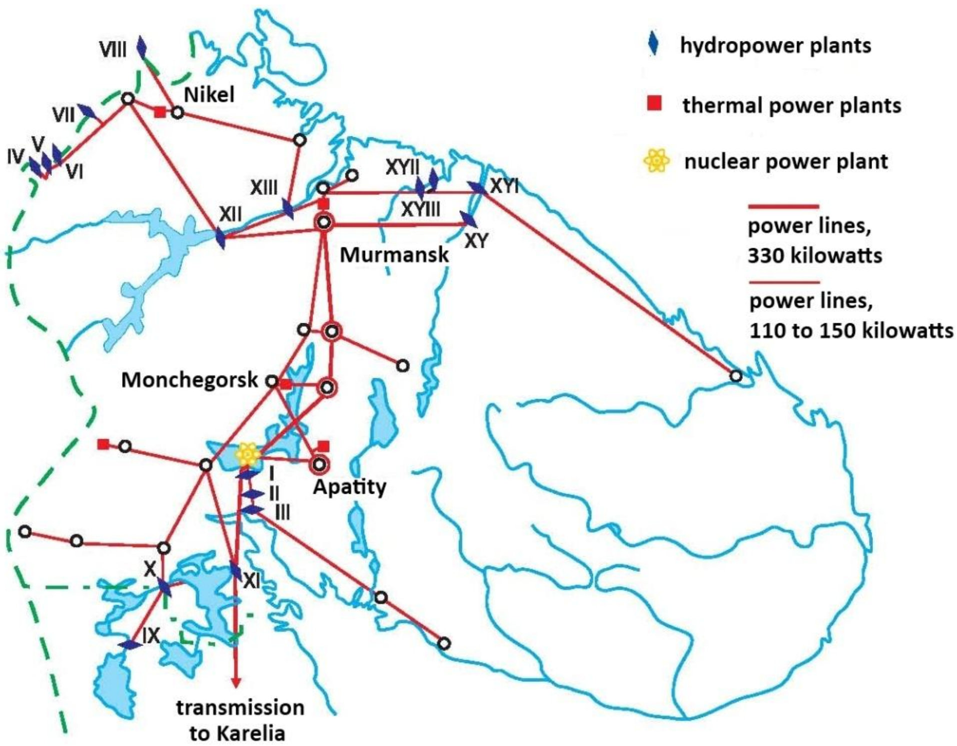
Lighthouses: 11 – Vaydagubsky; 12 – Tsyp-Navolok; 13 – Set-Navolok; 14 – Tyuvagubsky; 15 – Kildinsky Severny (North Kildinsky); 16 – Teribersky; 17 – Russkiy; 18 – Kharlovsky; 19 – Svyatonossky; 20 – Gorodetsky; 21 – Tersko-Orlovsky; 22 – Sosnovetsky; 23 – Nikodimsky.

Border outposts: 24 – Pummanki; 25 – Tsyp-Navolok; 26 – Kildin; 27 – Gavrilovo; 28 – Vostochnaya (East) Litsa; 29 – Drozdovka; 30 – Ponoi.

Fisheries and deer farms: 31 – Sosnovka; 32 – Chapoma; 33 – Chavanga; 34 – Krasnoshchelye.

<u>*Power networks.*</u> The majority of Murmansk Region's urban and rural energy consumers receive their power from the Kola Power Grid. The grid's total installed capacity exceeds 3,700 megawatts and is unique in composition: It derives electricity from 17 hydropower stations; five thermal power plants; Kola Nuclear Power Plant; and a tidal power plant, the only one in operation in Russia. All these sources supply power to a unified high-voltage transmission network (see Pic. 1.2) for distribution managed via central dispatch.

The Kola grid is connected by 330-kilovolt overhead transmission lines with the Republic of Karelia, to the southwest of the Kola Peninsula, and, via Karelia, with the unified power grid of Northwest Russia. High-voltage power lines also link the Kola power system with those of Norway and Finland.



Pic. 1.2. Electric power networks of the Kola Power Grid.
Hydropower plant cascades: I-III: Nivsky (Niva) Cascade; IV-VIII: Pazsky (Paz) Cascade; IX-XI: Kovdinsky (Kovda) Cascade; XII-XIII: Tulomsky (Tuloma) Cascade; XV-XVI: Serebryansky (Serebryanka) Cascade; XVII-XVIII: Teribersky (Teriberka) Cascade.

Centralized power supply is available on roughly one half of the territory of Murmansk Region, or to over 99 percent of total population. At the same time, several dozen settlements (see Pic. 2.1 through 2.3 below), due to their locations at considerable distances from the grid and low levels of power consumption, do not have access to centralized electricity supply and instead receive their power from small diesel-fired stations running at capacities of between 8 and 500 kilowatts.

1.2. Fuel and energy resources and their development

The territory of Murmansk Region has no fossil fuel deposits available for development. However, intensive geological exploration of the last fifteen to twenty years has led to the discovery of several oil and gas fields in the Barents Sea, on the shelf adjacent to the northeastern coast of the Kola Peninsula. The combined extractable resources of two of the natural gas fields closest to the peninsula – Murmanskoye (Murmansk) and Severokildinskoye (North Kildin) deposits – total no less than 300 to 500 billion cubic meters, while the reserves of the Shtokman field are estimated at 3,700 billion cubic meters.

At the same time, the practical development of the discovered gas reserves is in its initial stages at the moment. For the time being, all types of fuel that Murmansk Region employs for various uses – gasoline, fuel oil varieties, gas, coal, diesel, and nuclear fuel – are shipped from other Russian regions. Gasoline and fuel oil are used to power road and sea transport; boiler houses and cogeneration heat and power plants run on coal and fuel oil; liquefied gas is used in households for domestic purposes; and nuclear fuel is burned in the four reactors of Kola Nuclear Power Plant. Off-grid consumers in small settlements commonly have demand for gasoline and diesel fuel, which they use as car fuel and at local diesel power stations. Heat generation plants often run on firewood, either locally produced or shipped from elsewhere, and, less frequently, on coal.

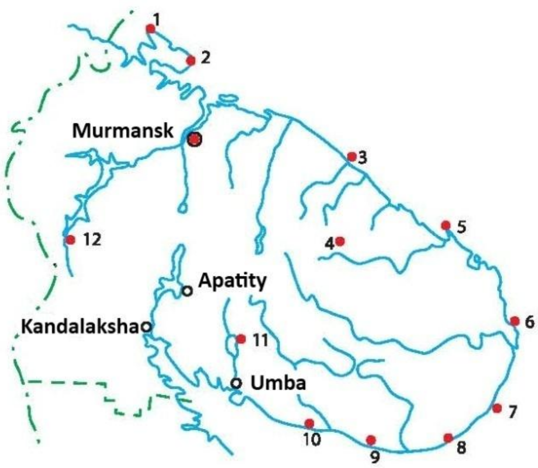
2. Off-grid energy supply in Murmansk Region: Current situation

2.1. Types and brief descriptions of off-grid consumers of Murmansk Region

Depending on their location, the specific activities they are engaged in, and levels of demand for energy and power supply, off-grid consumers in Murmansk Region fall into the following distinct groups:

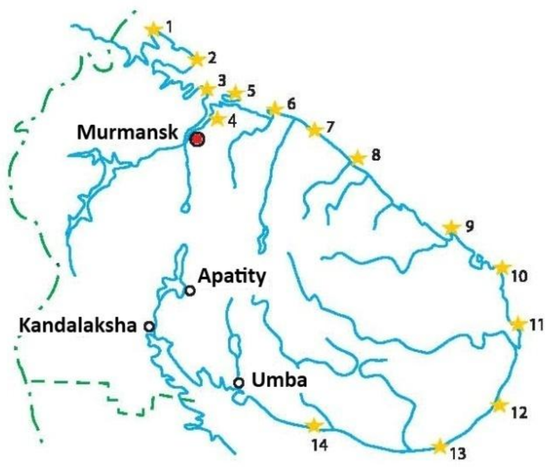
a) Weather stations and lighthouses (see Pic. 2.1 and 2.2).

The electricity these consumers receive is used to power the special equipment and devices operated at these sites, to provide lighting in the buildings and on the surrounding premises, and to run various domestic appliances. A significant amount of total energy consumed – as much as 60 to 80 percent – is used to heat both the work areas and living quarters. At present, electricity supplied to these consumers is provided by gasoline- and diesel-driven power generators of capacities ranging between 8 and 20 kilowatts; heat is supplied by means of boilers running at capacities of up to 20,000 kilocalories per hour or simple fire stoves. The total power and heating load per each consumer in this group varies between 20 and 50 kilowatts.



Pic. 2.1. Remote weather stations operating in Murmansk Region.

1 – Vayda-Guba; 2 – Tsyp-Navolok; 3 – Kharlov Island; 4 – Kolmyavr; 5 – Svyatoy Nos; 6 – Tersko-Orlovsky; 7 - Sosnovets Island; 8 – Pyalitsa; 9 – Chavanga; 10 – Kashkarantsy; 11 – Kanozero; 12 – Nivankyul.

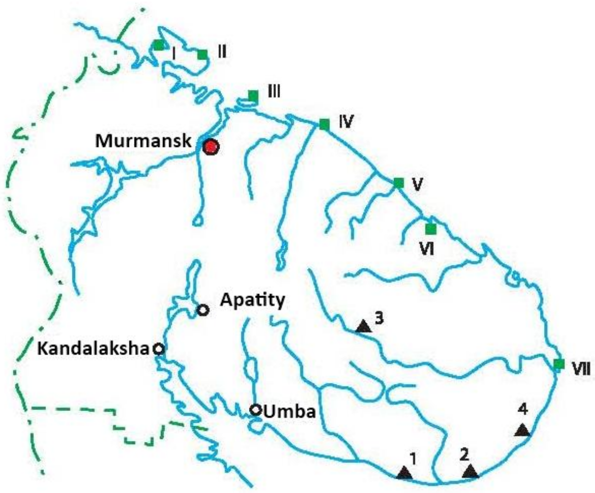


Pic. 2.2. Lighthouses run by the Hydrographic Service on the coast of the Kola Peninsula.

1 – Vaydagubsky; 2 – Tsyp-Navolok; 3 – Set-Navolok; 4 – Tyuvagubsky; 5 – Kildinsky Severny (North Kildinsky); 6 – Teribersky; 7 – Russkiy; 8 – Kharlovsky; 9 – Svyatonossky; 10 – Gorodetsky; 11 – Tersko-Orlovsky; 12 – Sosnovetsky; 13 – Nikodimsky; 14 – Kashkarantsy.

b) Coastal border outposts (see Pic. 2.3).

Electricity is supplied to these sites by small diesel-fired power stations with installed capacities of up to 60 kilowatts (running two or three diesel-generators of between 15 and 20 kilowatts each). Coal- or liquid-fuel-based boiler systems with capacities of 0.1 to 0.2 gigacalories per hour are used to provide heat to work and residential areas. Common wood- or coal-burning stoves are also in widespread use. The combined electricity and heating load for each consumer in this group is between 100 and 150 kilowatts.



Pic. 2.3. Locations of border outposts (I through VII), fisheries, and deer farms on the Kola Peninsula.

Border outposts: I – Pummanki; II – Tsyp-Navolok; III – Kildin; IV – Gavrilovo; V – Vostochnaya (East) Litsa; VI – Drozdovka; VII – Ponoi.

Remote settlements: 1 – Chavanga (Belomorsky Rybak fishing cooperative); 2 – Chapoma (Chapoma fishing cooperative); 3 – Krasnoshchelye (Tundra deer farm); 4 – Sosnovka.

c) Shore-based naval sites of the Russian Northern Fleet.

These operate to provide support to the Navy's various services and differ in their specific activities and the volumes of energy consumed. Some of these sites receive electric power from 100- to 150-kilowatt diesel power stations running two or three diesel generators with capacities of between 30 and 50 kilowatts each. The heating load at such sites reaches between 0.3 and 0.5 gigacalories per hour and is provided by boiler plants fired by either coal or liquid fuel.

d) Fishing enterprises, large deer farms, and other isolated remote settlements (see Pic. 2.3).

These include the fishing collective farms (or *kolkhozy*) Belomorsky Rybak and Chapoma, in Chavanga and Chapoma, respectively – both in Tersky District – as well as the deer-breeding farm (or state farm, *sovkhoz*) Tundra, in Krasnoshchelye, and the settlement of Sosnovka, these two in Lovozersky District.

Electricity supply to these consumers is provided by local diesel power stations with capacities ranging between 200 and 500 kilowatts. For heating purposes, boiler systems running on fossil fuel with capacities of 2 to 3 gigacalories per hour could be used in the future.

2.2. Fuel deliveries to decentralized consumers

A wide variety of methods are used to deliver fuel to small off-grid consumers residing in outlying areas of Murmansk Region. The logistics at hand depend on the consumer's specific needs and activities, the settlement's location relative to the nearest source of fuel supply, and the current condition of the traffic network. Coastal communities on the White and Barents seas receive their fuel via shipments by sea. Deliveries of full annual fuel supplies are made during the summer navigation period. Tankers, proceeding along the shore, offload fuel supplies to each of the settlements in turn. Where a particular settlement lacks berthing facilities, fuel unloading is done while the ship is at anchorage, and either smaller vessels or a pipeline are then used to deliver the fuel to shore. Further delivery to remote communities on the mainland is done by road transport or track-type vehicles, as well as cat trains and, sometimes, by air.

Information collected on the costs of fuel shipping and deliveries by various transport means in Murmansk Region indicates that higher costs involved in local logistics cause fuel prices to rise significantly for the end consumer. Analysis shows that as shipments are taken over for local deliveries, prices increase by 1.2 to 1.5 times if delivered by road transport, 1.3 to 1.8 times if transported by boats, 1.5 to 2.5 times if off-road vehicles are used, and by three times or more if delivered by air, compared to the original selling price when initially disbursed at the fuel supply distribution point.

With wholesale prices for diesel hovering in 2011 at between RUR 26,000 and RUR 27,000 per ton, its price after delivery to the end consumer can reach between RUR 30,000 and RUR 50,000 (EUR 750 to EUR 1,250*) per ton. Calculated in standard fuel values**, this corresponds to EUR 550 to EUR 900 per ton of fuel equivalent, respectively (the heating value of standard fuel is 7,000 kilocalories per kilogram; for diesel fuel, this value is 10,000 kilocalories per kilogram).

The high fuel prices affect the efficiency and economic performance of the region's energy-producing sites. This is why one of the crucial issues faced by remote communities with no access to centralized power and energy supply is one of mindful and frugal use of delivered fuel and finding ways and methods to enhance energy efficiency and reduce fuel consumption.

2.3. Off-grid power supply

Because of the geographical locations of the areas where most off-grid consumers reside – and the low levels of power and energy consumption – bringing a grid connection to these highly scattered and isolated remote communities is an economically unviable option. Accordingly, local – mostly, diesel-based – power plants will likely continue to serve as primary electricity sources for these consumers both today and in the near future.

Large diesel power plants operate five to six diesel generators, while smaller sites are usually equipped with just two or three generating sets. Lower-capacity sets are commonly used during the low-load summer months or provide additional electricity along with the primary generators during peak-load periods.

Table 1 lists the operating and economic characteristics of some of the diesel power plants currently in use in a number of rural localities of Murmansk Region. As shown in the table, the number of hours the installed capacity of sites is used over the year varies widely. At best, this value reaches slightly over 3,300 hours. But in those communities that are experiencing financial difficulties, and where the goal of extending the service life of the diesel engines is, by necessity, a priority, the common practice is to use the generators as sparingly as possible – which amounts to no more than between 800 and 1,000 hours of operation a year. In these localities, power stations do not, as a rule, work during night hours, and in the summer, due to the prolonged length of day and the decreased demand for lighting, the stations' operating time is limited to between five and eight hours a day (in the morning and late afternoon only).

The capacity of a particular site and the time it remains in operation throughout the day have a direct effect on the number of personnel working at the plant. During the summer months, a single employee is sufficient to run a 30- to 100-kilowatt station. In the winter, two or three employees usually remain on site. Larger power plants require a significantly higher number of operating staff.

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* Here and elsewhere in the report (unless otherwise indicated), prices and euro equivalents for amounts in Russian roubles are rendered as given in the Russian original, written in 2011. Present exchange rates may differ. – Translator.

** Standard fuel (or fuel equivalent) is a concept used in the USSR and Russia to measure comparative efficiencies of various types of fuel, with one unit corresponding to one kilogram of fuel with a heat combustion of 7,000 kilocalories per kilogram. A common international unit of energy is the ton of oil equivalent, or the amount of energy released by burning one ton of crude oil. The International Energy Agency (IEA) determines one ton of oil equivalent to be equal to 41.868 gigajoules. – Translator.

The specific fuel consumption rate of natural diesel fuel at diesel power plants is quite high – at 320 to 400 grams per kilowatt-hour. Calculated in standard fuel units, this corresponds to 460 to 570 grams of fuel equivalent per kilowatt-hour***. The prime cost of power produced at diesel-fired stations is likewise quite considerable, ranging between RUR 13 and RUR 17 (EUR 0.34 and EUR 0.44, respectively****) per kilowatt-hour. A comparison with the prime cost of energy that is supplied to grid-connected consumers gives a difference marked enough to put diesel-produced electricity in a separate pricing range.

Table 1. Operating and economic characteristics of diesel power plants in coastal communities of Murmansk Region's Tersky District.

Locality, name	Indicator											
	Installed capacity, in kilowatts	Number of power-generating sets	Annual output, in thousand kilowatt-hours	Use of installed capacity, in hours	Number of operating personnel	Yearly fuel consumption rate, in tons	Actual specific fuel consumption rate, in grams per kilowatt-hours	Operating costs				
								Including, in percent				Total, in thousand roubles
								Fuel costs	Salaries/wages	Depreciation	Other	
Varzuga, Kuzomen, Kashkarantsy	535	6	1,801	3,366	19	716	398	87	9	1.9	2.1	11,588
Chavanga, Tetrino	310	4	297	958	6	101	341	71.1	15.3	4.1	9.5	1,844
Chapoma	540	6	440	815	4	141	320	90	9.1	-	0.9	1,868

Operating expenses involved in running a diesel power plant and how they are distributed across the cost structure (see Table 1 above) depends to a significant degree on local factors such as the logistics of fuel delivery and delivery costs. In those localities that lack well-established and convenient transport links, fuel expenses are what primarily determines the prime cost of power produced. The share of these expenses in the overall structure of operating costs may reach 70 to 80 percent (of which 25 to 35 percent will account for delivery costs).

Fuel expenses, further, are composed of fixed and variable costs, the former representing the cost of fuel loading and unloading upon delivery, and the latter contingent on the length of haul. An in-depth look at these expenses reveals that the fixed costs involved in liquid fuel delivery are four or five times greater than the variable costs. An increase in the distance of haul from 200 to 600 kilometers only results in a 10- to 15-percent increase in the shipping expenses. This, furthermore, is true for

*** See also Footnote ** for background on this and other references to "standard fuel" or "fuel equivalent" in this report. – Translator.

**** This rouble-to-euro conversion is accurate as per the rate current as of March 21, 2012. – Translator.

destinations that have well-developed berthing infrastructure to facilitate fuel unloading from the tanker upon delivery. In practical reality, however, not all of the remote coastal communities that depend on fuel deliveries for electricity and heating offer suitable and reliable conditions for ships to approach the shore or the necessary facilities available for mooring. Where this is the case, fuel is unloaded from the tanker while at anchorage with the help of small vessels – the only option of choice that leads to longer unloading times and further increases the fixed costs of fuel delivery, and, by extension, fuel expenses overall. In the end result, fuel expenses are influenced more by how fast and efficiently fuel is unloaded upon delivery than by the distance it has traveled before arriving at its destination.

Depreciation expenses at old diesel-based power plants in operation in Murmansk Region remain within the range of 5 to 7 percent of total operating costs – a characteristic accounted for, apparently, by the high degree of wear and tear sustained by the plants' buildings and equipment.

Standard calculation of the prime cost of electric power produced at diesel-based power plants

Total annual operating costs at a diesel power plant include fuel expenses, wages and salaries, depreciation costs, maintenance, and other expenses. The prime cost of power produced at a diesel plant will be calculated as the ratio of the total sum of operating costs to the plant's annual output.

Other values used in the calculation – specific fuel consumption rate, number of operating staff, depreciation rate, and capital investment per unit of production – are provided in Table 2 below. The results of the calculation are shown in Pic. 2.4.

Table 2. Operating characteristics of diesel power plants.[4]

Number of residents in locality	Diesel plant capacity, in kilowatts	Specific consumption rate, in grams of fuel equivalent per kilowatt-hour	Number of personnel	Depreciation rate, in percent	Capital investment per unit of production, in thousand roubles per kilowatt
20	20	460	2	20	23
50	50	428	3	17	17
100	100	410	5	15	13
200	200	395	7	13	10
500	500	383	14	10	7.5

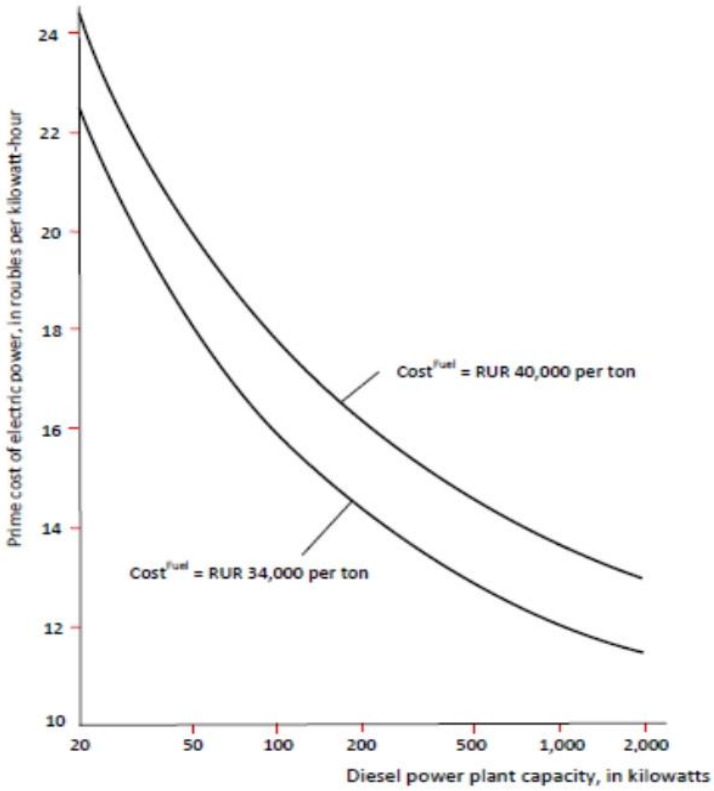
As illustrated in Pic. 2.4 below, at a plant capacity of 100 to 300 kilowatts, the prime cost of power generated by the diesel power plant will be RUR 14 to RUR 18 per kilowatt-hour. Because of the high fuel prices, fuel expenses will remain the predominant component of this, accounting for between 50 and 80 percent of the prime cost of diesel electricity. Employee compensation is the second largest expense item, corresponding to 15 to 30 percent of the prime cost.

[4] Vissarionov V.I., Belkina S.V., Deryugina G.V., Kuznetsova V.A., Malinin N.K. Energy-producing equipment for the application of unconventional and renewable energy sources. – Moscow: OOO Firma VIEN, 2004. – 448 pages. (Энергетическое оборудование для использования нетрадиционных и возобновляемых источников энергии / Виссарионов В.И., Белкина С.В., Дерюгина Г.В., Кузнецова В.А., Малинин Н.К. – М.: ООО фирма "ВИЭН", 2004. – 448с.).

The number of hours the installed capacity of a diesel power plant is in use has been taken as equal to 3,000, a value considered suitable to ensure both the optimal conditions for the operation of the plant's equipment and a sufficiently comfortable level of power supply for the residents of a remote community.

Diesel fuel expenses have been assumed to be within a range of between RUR 34,000 and RUR 40,000 per ton (or RUR 24,000 and RUR 28,000 per ton of fuel equivalent, respectively), with costs of delivery by local distribution transport taken into account.

The main strategy to reduce the prime cost of electricity generated at diesel power plants could be focused on fuel-saving measures, including by utilizing the potential of local renewable energy sources – such as wind and solar energy, small-scale hydropower, bioenergy resources, and similar.



Pic. 2.4. Prime cost of diesel electricity and its correlation with diesel power plant capacity and fuel costs.

2.4. Off-grid heating

The common types of fuel that consumers in small rural localities of Murmansk Region use for heating are coal, oil products, firewood, and timber waste. In boiler systems with capacities of no less than 2 gigacalories per hour, the specific fuel consumption rate reaches between 240 and 208 kilograms of fuel equivalent per gigacalorie. Coal-fired boilers have an efficiency factor of 50 to 60 percent; for those that burn liquid fuel, that value is within the range of 60 to 70 percent.

Small boiler systems do not allow for a high level of mechanization or automation in their operation, which implies a greater number of staff needed to run the plant. Boiler plants with a capacity of 2 gigacalories per hour have a staffing ratio of 5 to 7 employees per one gigacalorie per hour. This value increases to as many as 25 to 30, or even higher, to 35 to 40 employees per gigacalorie per hour, when servicing 0.2-gigacalorie-per-hour units running on either liquid fuel or coal, or firewood, respectively.

The number of hours the installed capacity of a boiler house remains in use in a year depends on the expected functions of the particular site and the prevailing weather conditions in the locality it serves. As the material compiled for this report shows, this number for heating plants ranges between 3,000 and 3,500 hours.

Standard calculation of the prime cost of heat energy produced at boiler plants

The heating load of small rural communities with populations under 500 residents does not exceed 2.5 gigacalories per hour. This is why, in this report, the following boiler capacity parameters have been used as examples when examining heating options for such consumers: 0.05, 0.10, 0.25, 0.5, 1.0, and 2.5 gigacalories per hour.

Annual operating costs of boiler plants consist of fuel expenses, salaries and wages, depreciation, maintenance, and other expenses. The prime cost of the heat energy produced will be defined as the ratio of total operating costs to annual energy output.

Source data used to calculate annual operating costs and the prime cost of energy produced have been applied with the following factors taken into account:

- delivered fuel costs, contingent on the geographical location of the end consumers and the condition of road and other transport links in the area;
- distance to the nearest fuel distribution point – either Murmansk in the north or Kandalaksha in the south of the Kola Peninsula (see also Table 3 below).

As of 2011, diesel fuel prices were at the level of RUR 26,000 to RUR 27,000 per ton; fuel oil prices were within the range of between RUR 12,000 and RUR 14,000 per ton; and coal prices hovered between RUR 1,800 and RUR 2,100 per ton. With payments for delivery by local distribution transport added to the fuel purchase expenses, overall fuel costs rose significantly.

Table 3. Distances between remote coastal communities of Murmansk Region and fuel supply distribution points in Murmansk and Kandalaksha.

Locality, name	Distance to Murmansk, in kilometers	Locality	Distance to Kandalaksha, in kilometers
Pummanki	180	Sosnovka	420
Vayda-Guba	160	Pyalitsa	350
Tsyp-Navolok	100	Mayak Nikodimsky	330
Kildin	70	Chapoma	320
Gavrilovo	110	Tetrino	290
Russkiy Island	135	Chavanga	270
Kharlov Island	185		
Vostochnaya (East) Litsa	210		
Svyatoy Nos	310		
Mayak Gorodetsky	380		
Mayak Tersko-Orlovsky	440		
Ponoi	470		

As mentioned above, the number of hours the installed capacity of a boiler plant is used over a given year depends on the purposes it serves and weather conditions commonly expected in the area. If the boiler plant is used to provide heating, ventilation, and hot water supply, this parameter can be taken as equal to 3,000 hours.

Table 4 below lists data specifying boiler efficiency ratio, number of operating personnel, and capital investment per unit of energy produced at the plant. With heating systems running on coal and wood, the value for the latter parameter increases by 1.3 and 1.8 times, respectively, when compared to those burning liquid fuel.

The yearly salary of one employee working at a wood- or coal-fired boiler plant has been taken – with Murmansk Region's benefits and special compensation paid for work in the conditions of the Russian Far North factored in – as equal to RUR 180,000 (RUR 15,000 a month); for employees working at liquid-fuel-based plants, that value has been taken as equal to RUR 240,000 (RUR 20,000 per month). The depreciation rate at small boiler plants ranges between 7 and 13 percent. In our standard calculations, based on averaged values, this value has been assumed as equal to 10 percent.

Table 4. Boiler plant characteristics depending on the type of fuel used.[5]

Boiler plant capacity, in gigacalories per hour	Efficiency factor, in percent, if fuelled by			Number of staff servicing boiler plant, depending on fuel type			Capital investment per unit of production based on liquid fuel, in million roubles per gigacalorie per hour
	Liquid fuel	Coal	Firewood	Liquid fuel	Coal	Firewood	
0.05	0.60	0.50	0.40	4	4	5	2.50
0.10	0.60	0.50	0.45	4	5	7	2.35
0.25	0.60	0.50	0.45	5	6	8	2.20
0.50	0.65	0.55	0.50	6	7	9	2.10
1.00	0.65	0.55	0.50	7	8	10	2.05
2.50	0.70	0.60	0.55	8	9	12	1.65

The main factors that determine the operating parameters and economic performance of a heating plant are its installed capacity and the price of the fuel used. A series of calculations using different sets of source data have been done in order to assess the influence these factors have on a plant's operation.

Table 5 lists the results of calculating the overall operating costs and the prime cost of one unit of heat energy produced at boiler plants running on liquid fuel. A graphic representation of the calculated prime cost is shown in Pic. 2.5 below (Curve 1). Analogous calculations have been done with respect to boiler plants based on other fuel types (fuel oil, coal, and wood). The results are likewise represented graphically in Pic. 2.5 (Curves 2, 3, and 4).

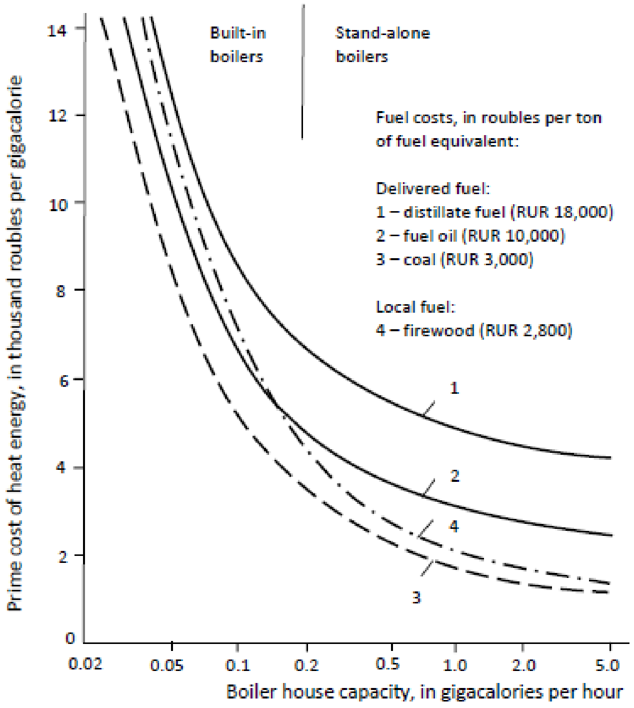
Analysis shows that if a heating plant is located close to a railroad link, and thus no additional outlay occurs as a result of paying for fuel delivery by local distribution transport, those boiler plants that run on coal prove to be the most efficient: They provide the cheapest energy compared to other plants within the examined capacity range (0.05 to 2.5 gigacalories per hour).

Table 5. Prime cost of heat energy produced by liquid-fuel-based heating plants located close to fuel supply distribution points (no additional expenses on local fuel delivery).

Number of residents	Boiler plant characteristics			Operating costs, in thousand roubles					Prime cost, in thousand roubles per gigacalorie
	Capacity, in gigacalories per hour	Efficiency factor, in percent	Number of operating staff	Fuel expenses	Salaries/wages	Depreciation	Other	Total	
10	0.05	0.60	4	677	960	13	195	1,845	12.3
20	0.10	0.60	4	1,355	960	24	197	2,536	8.4
50	0.25	0.60	5	3,387	1,200	55	251	4,893	6.5
100	0.50	0.65	6	6,252	1,440	105	309	8,106	5.4
200	1.00	0.65	7	12,505	1,680	205	377	14,764	4.9
500	2.50	0.70	8	29,029	1,920	413	467	31,829	4.2

[5] Barabaner Kh.Z. Heating in rural communities. – Tallinn: Valgus, 1976. – 196 pages. (Барабанер Х.З. Теплоснабжение сельских населенных пунктов. – Таллинн: Валгус, 1976. – 196с.).

It should be specified that the curves in Pic. 2.5 illustrate calculation results based on just such conditions where no expenditures are incurred on additional fuel delivery costs (boiler plants are located close to the railroad). The price of distillate fuel – diesel, kerosene, and similar – is in such cases determined by the wholesale price alone – at around RUR 26,000 per ton (or RUR 18,000 per ton of fuel equivalent). The same is true for the price of fuel oil, at RUR 12,000 to RUR 14,000 per ton (or RUR 9,000 to RUR 10,000 per ton of fuel equivalent).



Pic. 2.5. Expected prime cost of heat energy produced by boiler plants located close to railroad links (no local delivery costs) and its correlation with boiler capacity and fuel type.

With regard to other types of fuel, coal prices may differ depending on the source. Coal from two sources – the Pechora basin, in the Komi Republic in Russia's northwest, and the Kuznetsk basin (Kuzbass), in Kemerovo Region in southwestern Siberia – is in use in Murmansk Region. According to information provided by Apatitskaya Thermal Power Plant, in Murmansk Region's town of Apatity – this station uses coal from both sources – the price of Pechora coal is about RUR 1,800 per ton, and Kuzbass coal comes at a price of around RUR 2,100 per ton, transportation costs included in each case.

Calculated in fuel equivalent values – taking the heating value of coal from each source into account, at 4,000 kilocalories per kilogram and 5,600 kilocalories per kilogram, respectively – the average price of coal supplied to Murmansk Region should be within the range of between RUR 2,700 and RUR 3,100 per ton of fuel equivalent. In our calculations, a value of RUR 3,000 per ton of fuel equivalent has been used for this parameter.

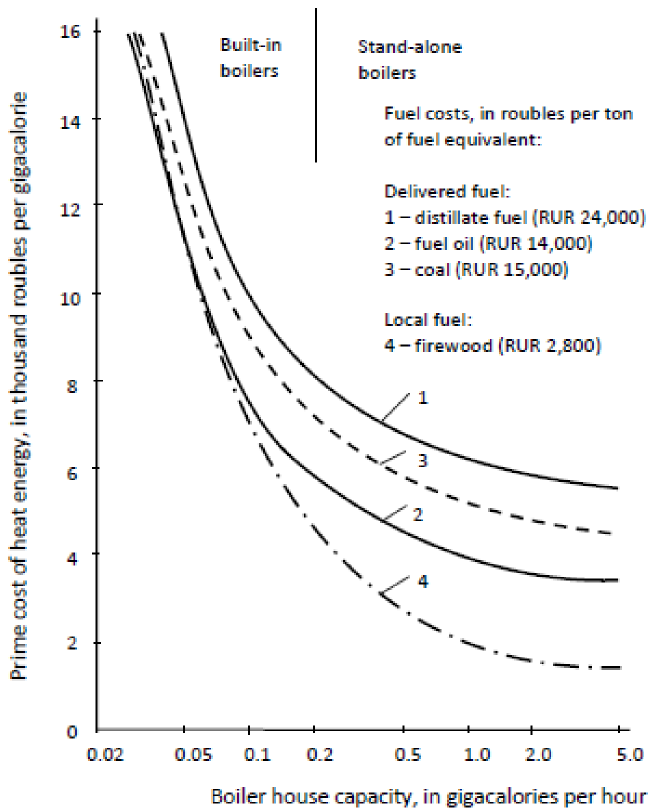
Wood supply costs in Murmansk Region fluctuate widely and depend on a number of factors. According to data from the forestry management, logging, and sawmill company Tersky Leskhoz and the lumber producer Belomorlesprom (both in the locality of Umba), the average price of firewood stands at around RUR 700 per cubic meter. Taking wood density to be equal to 700 kilograms per cubic meter, and heating value at 2,500 kilocalories per kilogram, the price of wood as calculated using standard fuel units will be around RUR 2,800 per ton of fuel equivalent. This, accordingly, is the price that has been used in our calculations.

In Murmansk Region, only a limited number out of all small-capacity heating plants in operation are located near the railroad. As a rule, the distance between a heating plant and the nearest railroad link spans between 200 and 300 kilometers, or more, and one of the additional local options – such as road, off-road, sea, or air transport – is required to deliver the fuel to the end consumer.

A significant number of remote communities in Murmansk Region are those scattered along the coasts of the White and Barents seas. Tankers are used to transport diesel fuel and gasoline to these consumers. Experience shows that the costs incurred when paying for both loading and unloading works and the shipping per se drive the price of the delivered fuel up by one third – or RUR 8,000 per ton – compared to the initial price. For instance, distillate fuel delivered to a destination located close to the railroad costs RUR 26,000 per ton, but this price will increase to RUR 34,000 per ton if the destination is one of the outlying localities on the coast. The price of fuel oil, likewise, will rise from RUR 12,000 to RUR 20,000 per ton depending on the location of the end consumer. Calculated in standard fuel values, the price of distillate fuel and fuel oil will be RUR 24,000 and RUR 14,000 per ton of fuel equivalent, respectively.

As noted above, coal remains the cheapest of the fuel types shipped to Murmansk Region's consumers from elsewhere. Its price after delivery by rail and unloading does not exceed RUR 2,000 per ton. The idea of using it to power heating plants to provide district heating in coastal localities seems quite attractive. However, one needs to take into account that the heating value of Kuzbass coal, though it has greater calorific properties than Pechora coal, is still less than that of liquid fuel – at 5,600 kilocalories per kilogram compared to liquid fuel's 10,000 kilocalories per kilogram. In other words, the calorific value of distillate fuel and fuel oil is 1.7 to 1.8 times greater than that of coal.

Besides, with loose goods such as coal, transportation is fraught with sizable losses: Around 20 percent of this commodity is lost while shipping, transshipping, and storage – compared to liquid fuel, where spillage during transportation only constitutes 5 percent. This means that in order for a heating plant to maintain efficient operation based on coal as the fuel of choice rather than liquid fuel, the amount of coal it needs to burn to produce the same amount of energy must be multiplied by 1.75 times to account for the difference in calorific properties, and further by 1.2 times to offset anticipated spillage during delivery – or by a total factor of 2.1. If shipping one ton of fuel to a remote coastal community – irrespective of whether liquid fuel or coal is the cargo being delivered – costs RUR 8,000, then the resulting price of coal after it is delivered to the end consumer will, accordingly, include both the initial price of RUR 2,000 and the RUR 8,000 in shipping charges, with the latter multiplied by 1.2 to compensate for the coal lost during transportation. The total will come to RUR 11,600 per ton of coal or, in standard fuel values, to around RUR 15,000 per ton of fuel equivalent.



Pic. 2.6. Expected prime cost of heat energy produced by boiler plants located in remote communities (local delivery costs taken into account) and its correlation with boiler capacity and fuel type.

Pic. 2.6 shows the results of calculating the prime cost of heat energy produced by boiler plants in remote coastal communities. The factors mentioned above – those particular to different fuel types, as well as the increases in fuel costs caused by additional payments for local delivery and how they affect the end prices – are all reflected in these results. A noteworthy conclusion is that even though coal remains the cheapest of all the types of fuel shipped to the Kola Peninsula from other Russian regions, still, the prime cost of heat energy generated by coal-based heating plants ends up higher than that found with boiler plants running on fuel oil, and commensurate with that of boiler plants burning distillate fuel. The reason is the higher level of capital investments per unit of production and the greater number of operating personnel required by coal-fired boiler plants. If, furthermore, coal of Pechora origin – which has a lesser calorific value (4,000 kilocalories per kilogram) compared to Kuzbass coal (5,600 kilocalories per kilogram) – is used at the plant, this serves as an additional factor of influence, making the difference in prime cost values all the more appreciable.

The conclusion to make from this analysis is that even though coal remains a cost-effective solution for boiler plants located close to the railroad, its use in outlying rural communities proves economically unsound, compared to liquid fuel. As for alternatives to liquid fuel, locally collected firewood presents a better option if sufficient quantities of this resource are in place to ensure reliable supply to the consumer. This may be possible on the southern coast of the Kola Peninsula, where forests available for harvesting are found in close vicinity. But the same cannot be said about the woodless expanses of the open tundra stretching inland from the northern shore.

What particular costs are involved in the generation of heat energy at boiler plants can be seen in Table 5 above. It shows that of all expense items, fuel costs remain the predominant one, accounting for between 40 and 90 percent of all operating costs. Again, vigorous development and use of local renewable energy sources could greatly facilitate efforts to reduce reliance on liquid fuel supplies and to save on associated delivery costs.

2.5. Expected energy consumption levels in small rural communities of Murmansk Region

The overall scope of energy consumption and specific consumption patterns vary from one rural community to another depending on a number of factors: Local climate and weather conditions, the kinds of economic activities that are performed in a given locality, the design, planning, and layout of existing buildings and infrastructure, the condition of housing and communal services, etc. Forecasting future demand for energy for such a diversified group of consumers is a challenge, since the parameters needed to determine expected consumption rates are quite variegated as well, and their impact is difficult to predict in advance.

Because in small localities energy consumption rates are, for the most part, determined by the patterns of heat use in domestic and communal services sectors and depend on the number of residents, assessing the amount of energy that is commonly used in a community can be done by examining an abstract range of localities with the following population sizes: 10, 20, 50, 100, 200, and 500 residents.

In rural communities, the share of heat energy in the overall amount of energy consumed is quite significant, reaching between 60 and 80 percent. Before going further with this analysis, the specific purposes for which heat energy is used by consumers – the components that make up the heat energy consumption mix – need to be distinguished here, which are: Cooking, hot water supply, space heating, and ventilation. Specific heat consumption rates associated with cooking and hot water supply depend little on weather conditions and, combined, constitute a total of 1.4 to 1.6 gigacalories per person-year. The amounts of heat that are used for space heating and ventilation, on the other hand, do depend considerably on the seasonal factor – the duration of the heating period – as well as the thermal characteristics of buildings and the residents' living conditions (residential floor space per person). Calculations show that with the thermal characteristic of one- and two-storey wood and brick buildings at 0.6 kilocalories per cubic meter-hour-degree Celsius, living space quota at 15 square meters per person (residential volume quota at 45 cubic meters per person), and rated outdoor and indoor temperatures at –30 and +20 degrees Celsius, respectively, the maximum hourly rate of heat use for space heating and ventilation will total 1,350 kilocalories per person; with heat use in public buildings taken into account (20 to 30 percent), this value will reach 1,750 kilocalories per person. With the number of hours of maximum heating load taken as equal to 3,500 a year, the annual per capita rate of heat use for space heating and ventilation purposes will total 6.5 gigacalories per person-year.

Using the parameters above and assuming the fuel utilization factor as equal to 50 percent, we can estimate (see Table 6) the required boiler plant capacities for the examined typical localities to be within the range of 0.05 to 2.3 gigacalories per hour.

Table 6. Calculated boiler plant capacities required to meet heating needs in remote communities of Murmansk Region.

Number of residents in locality	Specific heat energy consumption rate, in gigacalories per person-year			Annual heat energy demand in locality, in gigacalories per year	Use of boiler plant maximum load, in hours	Fuel use efficiency factor, in percent	Required boiler plant capacity, in gigacalories per hour
	Cooking and hot water supply	Space heating and ventilation	Total				
10	1.5	6.5	8.0	80	3,500	50	0.046
20	1.5	6.5	8.0	160	3,500	50	0.092
50	1.5	6.5	8.0	400	3,500	50	0.228
100	1.5	6.5	8.0	800	3,500	50	0.456
200	1.5	6.5	8.0	1,600	3,500	50	0.914
500	1.5	6.5	8.0	4,000	3,500	50	2.286

As for power plant capacities, with the average required capacity per person ranging between 0.75 and 1.00 kilowatt per person[6], the electric power capacities of power stations serving communities with populations of between 10 and 500 residents will need to be within the range of 8 and 500 kilowatts.

3. Murmansk Region's renewable energy sources and prospects of their application

3.1. Wind power

Wind as a source of energy is described as a total of its aerological and energy properties unified into a concept of wind power cadastre[7,8]. These cadastral characteristics include such parameters as average annual and monthly wind speeds, annual wind cycle, and recurrence rate of wind speeds.

Data on average annual wind speeds serve as the basic parameter used to estimate the overall wind intensity level, allowing, as a first approximation, for an assessment of the prospects available for the application of wind energy converters in a particular area.

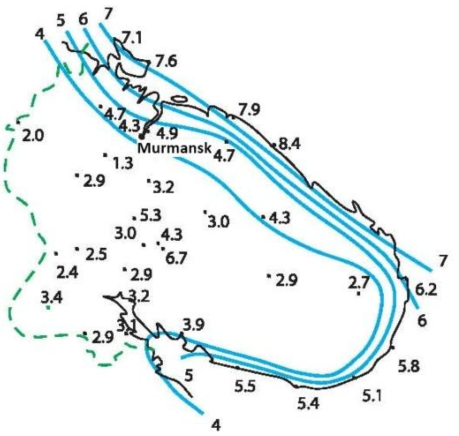
[6] Stepanov I.R. Issues of energy production and supply in the north. – Leningrad: Nauka, 1976. – 129 pages. (Степанов И.Р. Проблемы энергетики Севера. – Л.: Наука, 1976. – 129с.).

[7] Minin V.A., Stepanov I.R. Wind energy cadastre of the European North of the USSR. – News of the USSR Academy of Sciences. Energy and Transport, No. 1, 1983. – Pp. 106-114. (Минин В.А., Степанов И.Р. Ветроэнергетический кадастр европейского Севера СССР. // Изв. АН СССР. Энергетика и транспорт, №1, 1983. – С.106-114.).

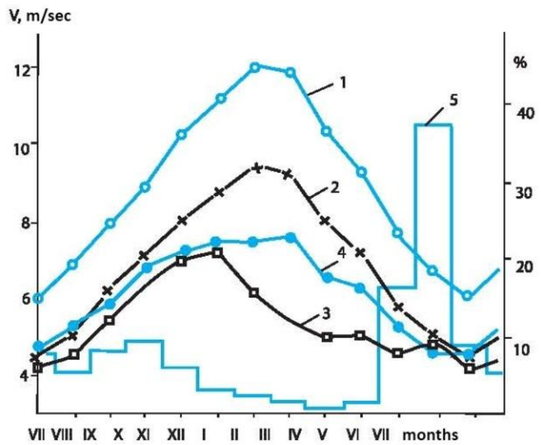
[8] Zubarev V.V., Minin V.A., Stepanov I.R. Application of wind energy in the Arctic. – Leningrad: Nauka, 1989. – 208 pages. (Зубарев В.В., Минин В.А. Степанов И.Р. Использование энергии ветра в районах Севера. - Л.: Наука, 1989. – 208с.).

Results of analyzing data compiled from a series of wind speed observations carried out at the Kola Peninsula's 37 weather survey stations[9] over a period of 20 years are summarized in Pic. 3.1. Because wind speeds depend on the area's land relief, the wind's elevation above the ground, and other factors – conditions that vary considerably from one survey station to another – survey data have been analyzed with these parameters processed accordingly for a comparison under commensurable conditions, namely, flat open surface and a set wind elevation. The map shown in Pic. 3.1 demonstrates that the highest wind speeds can be observed in the coastal areas of the Barents Sea. Here, on the northern coast of the Kola Peninsula, and at an elevation equaling 10 meters above the ground, wind speeds reach 7 to 9 meters per second. It is worth noting that the farther inland from the shoreline, the more noticeable is the decrease in wind speeds. But the higher the elevation, the greater are the values of average multi-year wind speeds. Incremental changes in elevation from 10 meters to 20, 50, and 70 meters result in average multi-year wind speed increases of 0.6, 1.7, and 2.1 meters per second, respectively.

The annual wind cycle, represented in Pic. 3.2, reflects seasonal changes in average wind speeds. On the Kola Peninsula, these changes are manifest most prominently on the northern coast, where the difference between the winter wind speed maximum and the summer wind speed minimum reaches 5 to 6 meters per second. The curves in Pic 3.2 show that in all areas surveyed, rather favorable conditions exist for efficient application of wind energy in the region. Maximum wind speeds are observed during colder seasons of the year and coincide with the seasonal period of peak electric power and heat consumption.



Pic. 3.1. Average multi-year wind speeds (in meters per second) at a 10-meter mark above the ground in a flat open-surface area.



Pic. 3.2. Annual cycle of average monthly wind speeds (V, in meters per second) on the islands (1) and coast (2) of the Barents Sea, on the coast of the White Sea (3), in the Khybiny mountains (4), and a river hydrograph (5).

Summarizing the analysis of wind energy potential of Murmansk Region, one can make the following conclusion: Wind energy resources are not evenly spread throughout the region. Wind intensity is noticeably above the average level in the coastal and mountainous parts of the peninsula. On the coasts of the Barents and White seas, in fact, wind conditions are nothing short of unique, with annual average wind speeds reaching 6 to 8 meters per second at an elevation mark of 10 meters. This,

[9] Minin V.A., Dmitriyev G.S. Wind energy: A promising renewable energy resource in Murmansk Region / Minin V.A., Dmitriyev G.S., Ivanova Ye.A. et al. / Preprint. – Apatity: Kola Science Center of the Russian Academy of Sciences, 2006. – 73 pages. (Энергия ветра – перспективный возобновляемый энергоресурс Мурманской области / Минин В.А., Дмитриев Г.С., Иванова Е.А. и др. / Препринт. – Апатиты: Изд. КНЦ РАН, 2006. – 73с.).

simply put, is one of the windiest areas in all of Russia’s European North. Such favorable factors as wind speed recurrence rate, the presence of stable prevalent winds, and the winter wind intensity maximum – all of these create unquestionably propitious conditions for a successful use of wind energy converters in the area.

3.2. Small hydropower

For a long time, the development of the energy production industry of Murmansk Region pivoted on a steadily expanding use of high-efficiency hydropower resources. By now, a considerable portion of the potential offered by the region’s major rivers has been put to use; seventeen hydropower stations have been built in Murmansk Region. The large and medium-sized hydropower plants are plugged into the grid and supply grid electricity via the system’s high-voltage transmission lines.

The rivers that have remained untapped for power generation, though they have suitable sites for prospective hydropower development, are significantly removed from areas characterized by high energy demand, which implies sizable increases in the capital and operating costs associated with building new power stations there. Some of these sites are situated on rivers considered to be of great importance for fisheries management and the region’s fishing industry, and construction of hydropower installations is not permitted in these locations. At the same time, grid electricity still remains inaccessible for many outlying villages, fishing settlements, lighthouses, weather stations, and other energy consumers. Construction of overhead power lines to bring grid electricity to these consumers is a costly enterprise, and these populations are forced to rely on fuel deliveries for local diesel-based power stations and heat-generating plants. The need to find a cost-effective off-grid energy source is the driving force behind the ongoing research into the potential and application prospects of local renewable energy sources, including the energy of small rivers.

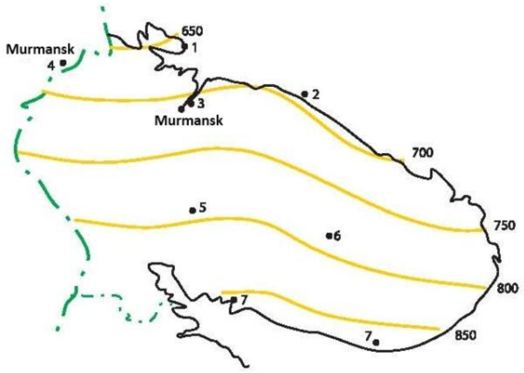
The term “small hydropower” is usually applied to generation facilities with capacities under 30 megawatts, built primarily to supply energy to isolated consumers or groups of small consumers. In Russia’s Arctic regions, because of the low population density – around 3 inhabitants per square kilometer – small hydropower stations can be expected to come with capacities not exceeding 3 to 5 megawatts. In a number of cases, a hydropower plant of a capacity ranging between less than a hundred to a few hundred kilowatts would in fact be viewed as the most appropriate option. Hydropower stations with an installed capacity of less than 100 kilowatts fall under the category of micro hydropower. The flooded area per unit of installed capacity and the overall costs incurred by building a small hydroelectric power station are, as a rule, greater than those involved in the construction of large and medium-sized installations. But the expediency of using a small river for electric power generation is nonetheless determined by local factors.

The notion of small hydropower as a solution to the challenge of electricity supply for off-grid consumers is not a new one. In Murmansk Region, a series of small hydropower plants were built as long ago as the middle of last century. Most of these stations were built from wood and generated power using the conventional dammed method. After 25 or 30 years of operation, these sites gradually fell into disrepair and are now completely derelict. But the appeal of using small hydropower stations for off-grid electricity supply has grown considerably in the past years both in Russia and elsewhere in the world.

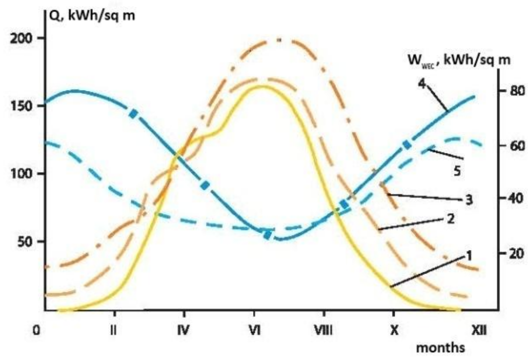
As far as prospects for the development of small hydropower on the Kola Peninsula are concerned, the following can be noted: The hydropower potential of small rivers implies unavoidably a dependence on the stream flow. What possibilities are offered by this renewable energy source are limited to the extent to which suitable sites are available for the construction of small hydropower stations in close vicinity to the prospective consumer. In Murmansk Region, such locations would be coastal communities residing near a river mouth, as well as a number of localities in the region’s central and western parts that are also situated near stable river flows. Transmission of power from small hydropower stations to the grid involves significant additional costs and is considered to be economically ineffective.

3.3. Solar power

To evaluate the potential of solar energy and the prospects of its application in Murmansk Region, one could look at the results of surveys taken at the region's actinometric facilities.[10] There are several actinometric stations in the region, of which three – Dalniye Zelentsy, Khibiny, and Umba – compile data that provide information on the solar radiation conditions in the north, south, and central area of the Kola Peninsula, respectively. An analysis of this information shows that the potential annual values for cumulative solar radiation exposure of Murmansk Region on clear days correspond to between 1,280 and 1,360 kilowatt-hours per square meter. High cloudiness, which is characteristic for Murmansk Region as a whole, decreases direct solar radiation exposure here by 60 to 75 percent. However, the same conditions are responsible for increasing diffuse radiation exposure by more than 50 percent. When actual weather conditions and cloud cover are taken into consideration, the resulting total annual solar radiation exposure fluctuates between 650 and 850 kilowatt-hours per square meter (see Pic. 3.3).



Pic. 3.3. Global solar radiation exposure on the territory of Murmansk Region (in kilowatt-hours per square meter).
1 – Tzyp-Navolok; 2 – Dalniye Zelentzy; 3 – Murmansk; 4 – Yaniskoski; 5 – Khibiny; 6 – Krasnoshchelye; 7 – Umba; 8 – Chavanga.



Pic. 3.4. An annual cycle of mean monthly global solar radiation (Q, in kilowatt-hours per square meter) in the polar (1), middle (2) and southern (3) latitudes; an annual cycle of potential energy production at a wind energy converter (W_{WEC}, in kilowatt-hours per square meter) on the northern (4) and southern (5) coasts of the Kola Peninsula.
1 – Khibiny station; 2 – Minsk; 3 – Sochi; 4 – Dalniye Zelentzy; 5 – Chavanga.

The higher the sun is over the horizon, the less the depth of the atmosphere that sunbeams have to penetrate, and, accordingly, the greater the amount of solar radiation that can reach the Earth's surface. Pic. 3.4 summarizes data on cumulative solar radiation exposure for polar latitudes (as measured at Khibiny actinometric station, 68° north latitude), moderate climate areas (Minsk, Belarus, 54° north latitude), and Russia's south (Sochi, 44° north latitude).[11] As demonstrated in the graph, global solar radiation exposures in the north and south differ most during the winter months. In the summer,

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[10] USSR Climate Reference Book. Vol. 2, Part 1. Solar Radiation, Radiation Balance and Sunshine. – Leningrad, Gidrometeoizdat, 1966. – 62 pages. (Справочник по климату СССР. Вып. 2. ч.1. Солнечная радиация, радиационный баланс и солнечное сияние. – Л.: Гидрометеоиздат, 1966. – 62с.).
[11] Heat Balance // Works of the Chief Geophysical Observatory, Issue No. 179. – Leningrad, Gidrometeoizdat, 1965. – 200 pages. (Тепловой баланс // Труды ГГО, вып. 179. – Л.: Гидрометеоиздат, 1965. – 200с).

exposure values become commensurate on account of the increased length of day in the northern latitudes. In overall annual values, the subpolar areas of the Kola Peninsula will receive 1.3 times less solar radiation than the middle latitudes, and 1.7 times less than the south.

Pic. 3.4 illustrates seasonal changes in both solar energy supply and the potential yield of wind power installations in the examined areas. As solar and wind energy are in an antiphase, they can supplement each other, which serves as a premise for the joint application of their resources.

The diurnal solar radiation cycle is first and foremost determined by the changing values of the Sun's elevation during the day. The highest irradiance values are observed during daylight hours in June through July and reach, on average, between 0.4 and 0.5 kilowatts per square meter. On some days, favorable weather conditions with minimal cloud cover obscuring the sun will allow for an increase in irradiance values to between 0.9 and 1.0 kilowatts per square meter.

When assessing solar energy potential and prospects for its application, sunshine duration becomes an important value as it determines the scope of incoming solar energy and the conditions for the efficient use of solar energy systems. In Murmansk Region, which lies almost entirely above the Arctic Circle, the average monthly number of hours of sunshine fluctuates widely throughout the year – between zero hours in December and 200 to 300 hours in June and July (see Table 7). Cumulative annual sunshine duration is about 1,200 hours in the north of the region, but increases to some 1,600 hours in its southern parts.

Table 7. Monthly breakdown of sunshine duration in various localities of Murmansk Region, in hours.

Locality, name	Month												Total per year
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Tsyp-Navolok	0	27	103	173	169	234	209	145	86	44	6	0	1,195
Dalniye Zelentsy	1	37	114	176	177	225	204	141	84	48	6	0	1,213
Murmansk	1	32	121	203	197	246	236	146	73	43	3	0	1,297
Yaniskoski	3	41	126	200	195	242	258	162	74	48	4	0	1,353
Khibiny	3	37	128	166	200	258	243	176	97	54	10	0	1,372
Krasnoshchelye	4	38	135	186	180	250	256	157	75	45	9	0	1,335
Umba	8	43	151	198	229	293	309	204	115	67	15	0	1,632
Chavanga	10	42	136	200	221	290	302	196	96	63	17	2	1,575

On the whole, the technical resources of solar energy in Murmansk Region are quite considerable – around 10^{13} kilowatt-hours. But these resources are scattered across a vast area and have low density. Significant investment funds will be required to develop practical application of solar energy in the region. Today, the global market price for solar energy installations ranges between EUR 4,000 and EUR 6,000 per kilowatt of installed capacity[12]. This is much higher than the same for, say, wind energy converters (EUR 1,000 to EUR 2,000 per kilowatt of installed capacity). As a result, the prime cost of power produced by solar energy installations is high as well.

The examination of prospects for solar power development in Murmansk Region shows that solar energy resources available to the region are not insignificant. But because this is an Arctic territory located almost completely beyond the Arctic Circle, the region's potential solar energy supply is still 1.5 to 1.7 times less than that available to the country's southern regions. Maximum solar radiation exposure values in Murmansk Region are observed in the summer, while consumer demand for energy reaches its peak in the winter. Furthermore, solar energy installations are for the time being an

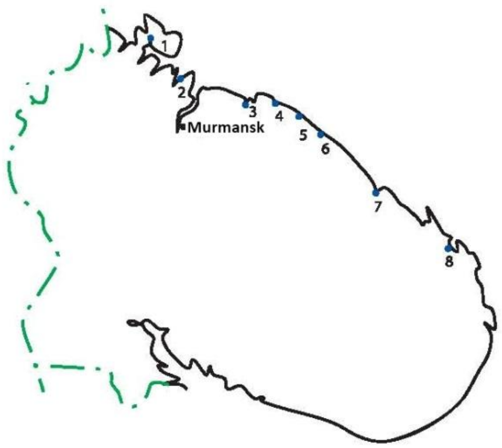
[12] Bezrukikh P.P. On cost indicators of energy-producing installations based on renewable energy sources. // Energeticheskaya Politika, No. 5, 2009. – Pp. 5-11. (Безруких П.П. О стоимостных показателях энергетических установок на базе возобновляемых источников энергии // Энергетическая политика, №5, 2009. – С.5-11.).

expensive option. Their price – taking heat collectors of suitable capacity into account – can be as high as EUR 8,000 per kilowatt of installed capacity.

With all of the above taken into consideration, use of solar power installations in Russia's Arctic regions could be a viable alternative – but only in such isolated cases when other energy supply options are associated with even higher costs. One such case, for instance, is the need to provide uninterruptible telephone communication, via a satellite link, between Murmansk Region's remote localities – weather stations, lighthouses, and similar – and the rest of the Kola Peninsula or Russia's other regions. A Murmansk-based company called RSK-Avtonomniye Tekhnologii has in fact installed solar power systems with capacities of around 1.3 kilowatts, complete with heat collectors of required capacity, in many such outlying localities. Additionally, Norway and a number of other countries have since 1998 provided financial support to the program of installing solar panels in place of radioisotope thermoelectric generators[*****] used as power sources at lighthouses and navigation beacons in Russia's Northwest. Altogether, 180 radioisotope thermoelectric generators have been replaced by solar power installations in the course of this program.

3.4. Tidal power

An important characteristic of tidal energy is the reliability of its average monthly supply both across the yearly and multi-year spans. It is owing to this feature that tidal energy, despite its intermittent availability throughout the diurnal cycle, is a powerful source of energy and can be recommended for use in combined operation with reservoir hydropower plants. In such a combination, the pulsating, intermittent, but nonetheless invariably guaranteed flow of tidal energy, regulated by the energy of hydropower plants, can contribute to power supply to provide for the necessary electric power load.



Pic. 3.5. Possible distribution of tidal power plants on the Kola Peninsula's coastline.
1 – Ozerko; 2 – Kislaya Bay; 3 – Severnaya; 4 – Dalniye Zelentsy; 5 – Porchnikha; 6 – Rynda; 7 – Drozdovka; 8 – Lumbovsky.

In contrast to the energy derived from river flow, assessing the potential of tidal energy is tied with certain peculiarities. Where the capacity of a hydroelectric power plant is determined by the product of water head and flow rate, the average capacity of a tidal power plant will be calculated by multiplying the area of the basin to be dammed off for the future plant by the value of tidal range to the power of two.

A reconnaissance survey of the shorelines of the Barents and White seas to research optimal sites there for the potential construction of tidal power plants was carried out in Russia by Lev Bernstein as long back as 1938 to 1941. Already then, a number of suitable sites for construction of tidal power plants were identified on the coasts of the Kola Peninsula (see Pic. 3.5).

Because of the relatively low height of tides washing against the peninsula's coastline – the average tidal range is 2 to 3 meters – and the limited basin areas that could be cut off by a dam, construction of tidal power plants in many locations proves from the start to be an economically inefficient option. The concept of an efficient tidal power plant suggests that such a plant will have a

[*****] Radioisotope thermoelectric generators are electrical generators that receive power from radioactive decay. See also Bellona's extended article on radioisotope thermoelectric generators here: http://bellona.no/bellona.org/english_import_area/international/russia/navy/northern_fleet/incidents/31772. – Translator.

capacity of hundreds of megawatts, but such capacity range greatly exceeds the levels required to meet the demand of small remote communities whose energy needs are examined in this report.

The following conclusion presents itself: Tidal energy resources available to Murmansk Region are concentrated along the entire 1,000-kilometer coastline of the Kola Peninsula, but successful application of this type of energy is only possible in certain locations where a suitable basin exists, such as a bay, that can offer a higher range of tidal wave (4 or 5 meters or higher).

In that regard, one noteworthy site is Lumbovsky Bay of the White Sea, in the east of the Kola Peninsula, where the average tidal height is 4.2 meters, and the size of the water basin suitable for use by a tidal power plant is between 70 and 90 kilometers. A tidal power plant with a capacity of several hundred megawatts could be built in this location. An installation of such capacity, however, would imply a large, grid-connected energy-generating site and as such, it falls beyond the scope of small-scale power generation and beyond the subject matter studied in this report.

3.5. Wave power

Wave energy possesses a higher energy density than wind and solar energy. Ocean waves accumulate wind energy as they move over significant distances, and it is this advantage that makes them a “natural energy concentrate.” Another advantage of this renewable energy source is the availability of ocean waves to a large group of consumers residing along a coastline. The disadvantages of wave energy, on the other hand, are its periodic instability, dependence on ice conditions, as well as difficulties associated with converting and transmitting the power derived from ocean waves onshore to the consumer.

Table 8 shows different values of wave energy flux in Russia’s seas.[13] The values pertaining to the Barents Sea, which borders on the far northeastern part of the Atlantic, are commensurate with those describing the potential of ocean wave energy available at the shoreline of Norway, where these values reach 25 to 30 kilowatts per meter.[14] Taking this into account, one can conclude that in the Barents Sea, average annual specific wave energy can be within the range of 20 to 25 kilowatts per meter. For the White Sea, the wave energy potential is much lower – no more than 9 to 10 kilowatts per meter.

Table 8. Wave energy flux in Russian seas.

Sea, name	Wave energy flux, in kilowatts per meter
Sea of Azov	3
Black Sea	6-8
Baltic Sea	7-8
Caspian Sea	7-11
White Sea	9-11
Sea of Okhotsk	12-20
Bering Sea	15-44
Sea of Japan	21-31
Barents Sea	20-25

When considering the practical and, especially, economic aspects of using tidal energy for power generation, one can note that the prime cost of electric power produced by ocean wave energy converters is at present still quite high – much higher than the prime cost of power produced by

[13] Sichkaryov V.I., Akulichev V.A. Ocean wave energy converters. – Moscow: Nauka, 1989. – 132 pages. (Сичкарев В.И., Акуличев В.А. Волновые энергетические станции в океане. - М.: Наука, 1989. – 132с.).

[14] Vasiliyev Yu.S, Khrisanov N.I. Environmental aspects of application of renewable energy sources. – Leningrad: Leningrad State University, 1991. – 343 pages. (Васильев Ю.С., Хрисанов Н.И. Экология использования возобновляющихся энергоисточников. –Л.: Изд-во Ленингр. ун-та, 1991. – 343с.).

conventional power facilities. In the future, as fossil fuel prices rise and wave energy converters improve in design and efficiency, this gap in costs will gradually decrease. The prospects of using ocean waves for power production will thus improve accordingly. But this report details options that could be available to the small remote communities of Murmansk Region in the short term; because of this, ocean wave energy as a renewable energy source has been left outside the margins of this study.

The following, however, can be concluded when assessing the possibilities of using ocean wave energy for power generation. The potential of wave energy in the Barents Sea is, on average, 25 kilowatts per one meter of wave front edge. This is comparable to the wave energy flux observed in the Sea of Okhotsk (29 kilowatts per meter) and is two or three times less than that in the Bering Sea (45 kilowatts per meter) or the North Atlantic (70 to 75 kilowatts per meter). In the White Sea, this value is even lower – at around 10 kilowatts per meter.

Furthermore, application of ocean wave energy in the conditions of the Arctic climate presents certain challenges – first and foremost, because ocean waves reach their peak during the colder seasons of the year, when air temperature falls below zero and metal components or structures (such as those that may be used in an ocean wave energy converter) become exposed to icing. For this reason – and also because of the short length of day in the Arctic (the Polar Night) – the operation of wave energy installations will be difficult in Murmansk Region. Another technological problem will be the transmission of power produced by these installations onshore to the consumer. Taken as a whole, this makes application of ocean wave energy a challenging option in Murmansk Region.

3.6. Bioenergy resources

Biodegradable wastes from livestock and poultry breeding farms

The development of agricultural industries worldwide has resulted in a significant concentration of livestock and poultry populations on farms and farming complexes and, by extension, in the accrual of large quantities of organic waste, namely, liquid dung and poultry droppings near the farms. In broad use at present is the method of so-called anaerobic recycling of biodegradable livestock waste, a multi-stage process of decomposition of organic matter in special containers, or digesters, where organic waste is processed in an oxygen-free environment by anaerobic microorganisms and produces methane and carbon dioxide as a result.

The biogas generated as a result of waste fermentation comprises 60 to 80 percent methane, 20 to 25 percent carbon dioxide, and lesser quantities of hydrogen sulfide, hydrogen nitride, and nitrogen oxides. Through a series of relatively simple operations, biogas can be freed from the carbon dioxide and the traces of hydrogen sulfide and thus distilled to the grade of natural gas. As natural gas, purified biogas can be compressed into gas cylinders and used as fuel for automotive vehicles or burned to generate heat energy. The heat-generating capacity of biogas is 5,000 to 6,000 kilocalories per cubic meter.

In Murmansk Region, the severe climate and weather conditions do not allow for a vigorous development of the agricultural and farming industries. Still, there are eleven large and medium-sized pig, poultry, and cattle (dairy) farming complexes in the region. The majority of them are located near the regional center – the agricultural firms Tuloma and Polyarnaya Zvezda, the poultry farms Snezhnaya, Murmanskaya, and other enterprises. Other farms operate in the vicinity of large industrial centers such as Apatity, Kirovsk, Kovdor, or Monchegorsk. All these agricultural and farming complexes are, as a rule, connected to the grid and receive their electric power and heat energy from major external power sources, which solves the problem of independent power and energy supply for these consumers. Some of the farms, such as the agroindustrial firm Tuloma, are just making their first steps toward introducing bioenergy technologies in their operations; other enterprises, such as the agricultural complex

Kovdorsky, are well on their way summarizing the experience they have already gained employing such technologies in practical application.

Wastes from the wood-logging and wood-working industries

A considerable portion of Murmansk Region's wood resources was used up in the 1930s to 1980s. Timber felled in the region nowadays is no longer used for the production of paper or pulp. In the past five years, wood harvesting output has fallen by 3.2 times – from 125,000 to 39,000 solid cubic meters. Part of the lumber resources is sold for export, but the majority of it is used locally to produce sawn timber. For the time being, lumber and woodwork wastes are only used in very insignificant quantities as fuel for electric power supply and heating. A number of various obstacles still hinder the development of full-scale application of wood-logging and woodwork wastes. Lumber camps are often located at great distances from industrial centers or other populated areas, and no developed infrastructure is available to effectively collect, transport, and recycle wood-logging waste.

Fishery and fish processing waste

Waste produced by the fish processing industry was used to a great extent in the 1980s as animal feed at fur farms. For a variety of reasons, the fish processing industry in Murmansk Region has seen a pronounced decline in the past fifteen years, with both the output of seafood and fish products, and, by extension, wastes falling significantly. At the moment, fish processing waste is not considered for application as a power-generating option.

To summarize, Murmansk Region's bioenergy resources – livestock and poultry breeding waste, primarily – are concentrated around large enough populated localities that receive their power supply from the grid. These are the areas where issues of biodegradable waste reprocessing have relevance, and these issues are being dealt with both by the management of the farming enterprises in question – the agricultural companies Kovdorsky and Tuloma, among others – and by representatives of the regional administration. But these communities and the farms and agricultural sites and facilities operated there do not belong to the category of remote off-grid consumers whose power supply needs are at the focus of this study. On the other hand, such localities as weather stations, lighthouses, border outposts, or naval sites do not, as a rule, have agricultural or farming complexes in their immediate vicinity and cannot, therefore, use agricultural or farming wastes as a reliable source of power generation or heat energy supply. In a number of coastal communities such as Chavanga or Chapoma, agricultural production has in the past years effectively shut down because of the prohibitive transport costs and no possibilities to continue selling agricultural produce. Elsewhere, the settlement of Krasnoshchelye, in the central part of the Kola Peninsula, is home to the deer-breeding farm Tundra. But deer grazing takes place on lands quite far from the settlement, and no deer farming waste can be made available for use as a fuel source.

Taking all of the above into account, the prospects of using agricultural and farming wastes, wastes from the wood-logging and woodworking industries, as well as fish processing waste as bioenergy resources for potential power and heat generation in Murmansk Region are not under consideration at the moment.

4. Suggestions for renewable energy application for off-grid energy supply in Murmansk Region

In order to evaluate the prospects of, and develop specific suggestions for, practical application of renewable energy sources for off-grid energy supply, one must bear in mind three principal factors: the potential offered by a particular energy source; the availability of such conditions that would call for and facilitate its development, and the cost of energy-producing installations (solar, wind, or wave energy converters) that could be used at the site in question. Our assessments suggest that the following off-grid localities look most promising today with regard to practical application of renewable energy options in Murmansk Region.

4.1. Wind energy converters for power supply of weather stations and lighthouses in Tsyp-Navolok, Kharlov Island, and Tersko-Orlovsky

Weather stations and lighthouses are, as a rule, situated on significantly high elevations and on an open surface, thus having an increased potential of wind energy at their disposal. A weather station and a navigation beacon will sometimes be in close vicinity to each other and will both receive their electric power supply from the same diesel-based power plant. This is the case with the meteorological stations and lighthouses in the settlements of Tsyp-Navolok, Kharlov Island, and Tersko-Orlovsky, all located on the coast of the Barents Sea (see Pic. 2.1 and 2.2). These are the localities used below as examples for an assessment of the possibility of using wind energy converters for off-grid power supply.

Diesel plant capacities in Tsyp-Navolok, Kharlov Island, and Tersko-Orlovsky total 80, 50, an 35 kilowatts, respectively. Table 9 shows operating and economic specifications – fuel consumption rate, staffing ratio, depreciation rate, and capital investments per unit of production – for diesel power plants in these localities (based on data used earlier in Table 2). The number of hours the installed capacity of a diesel power plant is used over the span of one year has been taken as equal to 3,000; the price of diesel fuel, taking local delivery costs into account, has been taken as equal to RUR 28,000 per ton of fuel equivalent. The component costs of a diesel plant's total operating costs and the prime cost of electric power produced have been calculated based on these parameters. As Table 9 shows, the resulting prime cost of electricity ranges between RUR 17 and RUR 20 per kilowatt-hour.

Table 9. Operating and economic characteristics of diesel power plants, their operating costs, estimated prime cost of electric power produced, and recommended wind energy converter capacity for combined wind-diesel power systems.

Locality	Diesel power plant capacity, in kilowatts	Annual output, in kilowatt-hours	Fuel consumption rate, in grams of fuel equivalent per kilowatt-hour	Staffing ratio, in number of personnel per kilowatt	Depreciation rate, in percent	Capital investments, in thousand roubles per kilowatt	Operating costs, in thousand roubles					Prime cost of electric power, in thousand roubles per kilowatt-hour	Recommended wind energy installation capacity, in kilowatts
							Fuel	Salaries/wages	Depreciation	Other	Total		
Tsyp-Navolok	80	240	415	0.048	15	14	2,789	922	168	218	4,097	17.1	50
Kharlov Island	50	150	430	0.057	17	16	1,806	684	136	164	2,790	18.6	30
Tersko-Orlovsky	35	105	440	0.066	18	19	1,294	554	120	135	2,103	20.0	20

Note: Figures for capital investments per kilowatt of diesel-produced electricity are represented in the table above as based on the price lists detailing 2011 prices for diesel power stations with capacities of 8 to 640 kilowatts sold by Azimut, a Moscow-based group of companies that produce and sell diesel power stations and generators.

Diesel power stations usually employ two or three diesel generators, of which the primary one accounts for 50 to 60 percent of the station's total capacity. It is with this in mind that the following capacities are recommended for wind energy converters to be used in combination with diesel-based plants in Tsyp-Navolok, Kharlov Island, and Tersko-Orlovsky: 50, 30, and 20 kilowatts – which corresponds to 62, 60, and 57 percent of each diesel plant's total power-generating capacity, respectively. This capacity range is represented, for instance, in such German wind turbine models as Krogmann 15/50 (capacity: 50 kilowatts; rotor diameter: 15 meters; hub height: 30 meters[15]), Südwind 1230 (capacity: 30 kilowatts; rotor diameter: 12.5 meters; hub height: 30 meters), and Südwind 1220 (capacity: 20 kilowatts; rotor diameter: 12.5 meters; hub height: 30 meters). The current costs of installing such a wind energy converter, including transportation, construction of the foundation, as well as assembly and installation and pre-commissioning works, range between RUR 80,000 and RUR 90,000 (or about EUR 2,000) per kilowatt of installed capacity.

Table 10. Wind energy converter characteristics, operating costs of combined wind-diesel power production, estimated prime cost of electric power produced, and the resulting environmental benefit (reduction in CO_2 emissions).

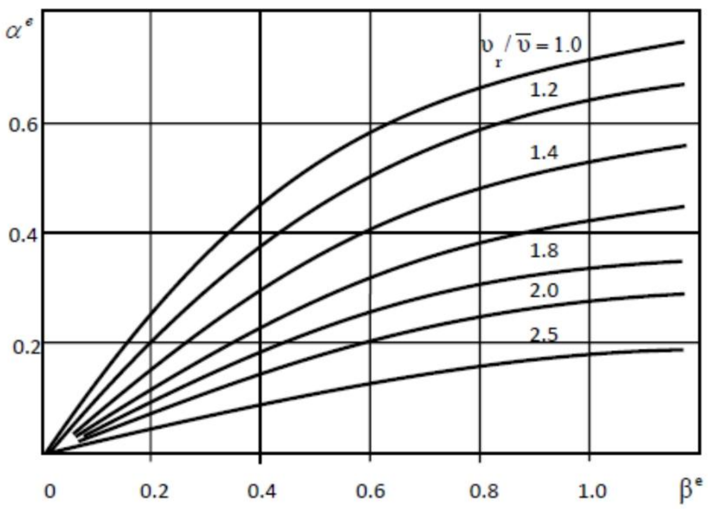
Locality	Capacity, in kilowatts		Output, in thousand kilowatt-hours		Depreciation rate at wind energy converter, in percent	Capital investments in wind energy converter, in thousand roubles per kilowatt	Operating costs, in thousand roubles					Prime cost of electric power, in thousand roubles per kilowatt-hour	Prime cost reduction, in percent	Reduction in carbon dioxide emissions, in tons
	Diesel power plant	Wind energy converter	Diesel power plant	Wind energy converter			Fuel	Salaries/wages	Depreciation	Other	Total			
Tsyp-Navolok	80	50	160.8 (67%)	79.2 (33%)	7	80	1,868	922	448	274	3,512	14.6	14.6	69.0 (↓ 33%)
Kharlov Island	50	30	73.5 (49%)	76.5 (51%)	7	85	885	684	315	200	2,084	13.9	25.3	69.1 (↓ 51%)
Tersko-Orlovsky	35	20	55.9 (53%)	49.1 (47%)	7	90	689	554	246	160	1,649	15.7	21.5	45.4 (↓ 47%)

In the examined localities – Tsyp-Navolok, Kharlov Island, and Tersko-Orlovsky – the average annual wind speeds at an elevation of 10 meters above the ground reach 7.1, 9.2, and 7.3 meters per second, respectively. Using the power-law dependence of the vertical wind profile on elevation – a relationship where the ratio of a value of wind speed at one elevation (V_H, at elevation H) to a value at a different elevation (V_h, at elevation h) is calculated according to $V_H / V_h = (H / h)^m$, where m is the exponent – one can estimate average annual wind speeds at the hub height to be 8.2, 10.3, and 8.4 meters per second, respectively for each of the three locations.

The share of electricity demand that can be covered by wind energy – wind energy penetration – can be determined with the help of data represented in Pic. 4.1, which is based on the results of analyzing extensive amounts of information and superposing the chronological cycle of a wind

[15] European Wind Turbine Catalogue. Energy Centre Denmark. Copenhagen, 1994. – 63 pages.

installation's output onto a diesel plant's electric load. It follows from Pic. 4.1 that the share of the electric load covered by the wind energy converter depends on the ratio of the rated – that which determines the wind energy converter's nominal capacity – to the average annual wind speed, as well as the ratio of the capacity of the wind generator to that of the diesel plant. For the examined localities of Tsyp-Navolok, Kharlov Island, and Tersko-Orlovsky, and the types of wind turbines suggested above, the wind speed ratios would look as follows: 13 : 8.2 = 1.58; 12 : 10.3 = 1.16; and 11 : 8.4 = 1.3. Using these ratios as part of initial data for calculations in Pic. 4.1, we can establish (see Table 10) that the share of wind energy penetration will total 33, 51, and 47 percent, respectively for each of the communities. The economy achieved by employing wind energy with regard to fuel consumption at the diesel plants will be commensurate with these estimates.



Pic. 4.1. Dependence of the share of wind electricity (α^e) in meeting electricity demand on the ratios of wind energy converter (WEC) to diesel power plant (DPP) capacities ($\beta^e = N_{WEC}max / N_{DPP}max$) and rated to average annual wind speeds $\upsilon_r/\bar{\upsilon}$.

Taking into account that one kilogram of diesel fuel, when burning, produces around three kilograms of carbon dioxide[16], reducing diesel fuel consumption by covering part of the electric load with wind energy can help reduce CO_2 emissions significantly. For Tsyp-Navolok, the resulting emissions reduction will be calculated as follows: $79.2 \cdot 10^3$ kilowatt-hours $\cdot$ $415 \cdot 10^{-6}$ tons of fuel equivalent per kilowatt-hour $\cdot$ 0.7 tons of diesel fuel per ton of fuel equivalent $\cdot$ 3 = 69 tons; for Kharlov Island, using the same formula, the achieved reduction will equal 69 tons as well; for Tersko-Orlovsky, 45 tons.

Using wind energy in parallel with a diesel-based power plant to meet consumer load will contribute to optimizing the diesel plant's operating costs by decreasing expenditures incurred on fuel purchase and delivery, which, in turn, will result in a lower prime cost of electric power produced. As demonstrated in Table 10, in Tsyp-Navolok, Kharlov Island, and Tersko-Orlovsky, the prime cost of electric power can be reduced by as much as 15 to 25 percent.

4.2. Wind converters for off-grid power supply of border outposts in Pummanki and Kildin

The border outpost Pummanki is situated in the western part of the Rybachy Peninsula, not far away from the weather station of Vayda-Guba. The outpost Kildin is in the eastern part of Kildin Island, a small island at the entrance to Kola Bay in the Barents Sea. Both sites have considerable wind potential at their disposal. Average annual wind speeds at a 10-meter elevation mark reach 7.0 meters per second in Pummanki, and 7.5 meters per second in Kildin.

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[16] Ravich M.B. Efficiency of fuel use. – Moscow: Nauka, 1977. – 344 pages. (Равич М.Б. Эффективность использования топлива. – М.: Наука, 1977. – 344с.).

The capacities of the diesel power plants in use at these sites are much higher than those that provide power to weather stations and navigation beacons and total 120 kilowatts in Pummanki, and 170 kilowatts in Kildin. These plants operate three or four diesel generators of varying capacities.

Table 11 lists initial operating and economic characteristics – fuel consumption rate, staffing ratio, depreciation rate, and capital investments per unit of production – for diesel power plants in these localities (based on data used earlier in Table 2). The number of diesel plant operating hours has been taken as equal to 3,000; the price of diesel fuel, taking local delivery costs into account, has been taken as equal to RUR 28,000 per ton of fuel equivalent. The component costs of the diesel plants' total operating costs and the prime cost of electric power produced have been calculated based on these parameters. The resulting prime cost of electricity, as shown in the table, ranges between RUR 15 and RUR 16 per kilowatt-hour.

The capacities recommended for wind energy converters to be used in combination with diesel-based plants in Pummanki and Kildin are, respectively, 80 and 100 kilowatts (or 67 and 59 percent of the diesel plant's generating capacity in each case). Among the wind turbine models that offer such capacities are, for example: Lagerwey (capacity: 80 kilowatts; rotor diameter: 18 meters; hub height: 40 meters) and Fuhrlander FL 100 (capacity: 100 kilowatts; rotor diameter: 21 meters; hub height: 35 meters)[17]. The current costs of installing such a wind energy converter will be around RUR 80,000 per kilowatt of installed capacity.

Table 11. Operating and economic characteristics of power supply in the border outposts Pummanki and Kildin, operating costs, prime cost of electric power produced, and recommended wind energy converter capacity for combined wind-diesel power systems.

Locality	Diesel power plant capacity, in kilowatts	Annual output, in kilowatt-hours	Fuel consumption rate, in grams of fuel equivalent per kilowatt-hour	Staffing ratio, in number of personnel per kilowatt	Depreciation rate, in percent	Capital investments, in thousand roubles per kilowatt	Operating costs, in thousand roubles					Prime cost of electric power, in thousand roubles per kilowatt-hour	Recommended wind energy installation capacity, in kilowatts
							Fuel	Salaries/wages	Depreciation	Other	Total		
Pummanki	120	240	450	0.042	14	12	4,082	1,210	202	282	5,776	16.4	80
Kildin	170	150	400	0.038	133	10	5,712	1,550	221	354	7,837	15.4	100

At the outposts of Pummanki and Kildin, the average annual wind speeds at the hub heights specified above will be 8.4 and 8.8 meters per second, respectively. The share of the wind energy converter in covering local electricity demand can be determined, again, with the help of Pic. 4.1. The source data used in this graph are the rated and average annual wind speeds, as well as the ratios of wind energy converters' capacities to those of diesel power plants. For the examined localities, Pummanki and Kildin, and the wind turbines suggested above, the wind speed ratios are as follows:

[17] Wind Energy-2002. – Osnabrueck, Deutschland, Bundesverband WindEnergie – 2002. – 265 pages.

14 : 8.4 = 1.67, and 13 : 8.8 = 1.48. Using these data and resulting calculations from Pic. 4.1, we can establish (see Table 12) that the share of wind energy in meeting the electric load in Pummanki and Kildin will be 32 and 35 percent, respectively. The diesel fuel economy achieved by using wind energy in combination with diesel power will be at commensurate levels.

Table 12. Operating characteristics of wind energy converters at the outposts Pummanki and Kildin, operating costs of combined wind-diesel power production, prime cost of electric power produced, and the resulting environmental benefit (reduction in CO_2 emissions).

Locality	Capacity, in kilowatts		Output, in thousand kilowatt-hours		Depreciation rate at wind energy converter, in percent	Capital investments in wind energy converter, in thousand roubles per kilowatt	Operating costs, in thousand roubles					Prime cost of electric power, in thousand roubles per kilowatt-hour	Prime cost reduction, in percent	Reduction in carbon dioxide emissions, in tons
	Diesel power plant	Wind energy converter	Diesel power plant	Wind energy converter			Fuel	Salaries/wages	Depreciation	Other	Total			
Pummanki	120	80	244.8 (66%)	115.1 (32%)	7	78	2,776	1,210	639	370	4,995	13.9	13.1	98.0 (↓ 32%)
Kildin	80	100	331.5 (65%)	178.5 (35%)	7	78	3,712	1,550	767	463	6,492	12.7	17.5	149.9 (↓ 35%)

Because one kilogram of diesel fuel, when burning, produces three kilograms of carbon dioxide[18], the reduced use of diesel fuel as a result of employing wind energy converters will help achieve the following annual reductions in CO_2 emissions: At the outpost of Pummanki: $115.2 \cdot 10^3$ kilowatt-hours $\cdot$ $405 \cdot 10^{-6}$ tons of fuel equivalent per kilowatt-hour $\cdot$ 0.7 tons of diesel fuel per ton of fuel equivalent $\cdot$ 3 = 98 tons; at the outpost of Kildin: 150 tons.

Using wind energy converters in combination with diesel-based power plants will contribute to optimizing the diesel plants' operating costs by decreasing expenses on fuel purchase and delivery, which, by extension, will reduce the prime cost of electric power produced. As shown in Table 12, in Pummanki and Kildin, using wind energy converters to cover part of local electricity demand will reduce the prime cost of electric power by around 17 and 13 percent, respectively.

4.3. Wind energy converter for the settlement of Chapoma

Chapoma is a settlement located in the mouth of the river Chapoma in the southeastern part of the Kola Peninsula. The wind potential at this locality is higher than average, with annual wind speeds reaching 5.5 meters per second at an elevation of 10 meters above the ground.

Local power supply is provided by a diesel-fired power station with a total capacity of 300 kilowatts (two generator units with a capacity of 120 kilowatts each and one 60-kilowatt generator).

Table 13 shows initial operating and economic characteristics of Chapoma's diesel power plant – fuel consumption rate, staffing ratio, depreciation rate, and capital investments per unit of production.

[18] See Footnote 16.

The number of diesel plant operating hours has been taken as equal to 3,000; the price of diesel fuel, taking local delivery costs into account, has been taken as equal to RUR 28,000 per ton of fuel equivalent. These parameters have been used to calculate the component costs of the diesel plant's total operating costs and the prime cost of electric power produced. The latter, as shown in Table 13, equals RUR 14.2 per kilowatt-hour.

The recommended wind energy converter capacity for wind power integration in Chapoma is 150 kilowatts, which will correspond to 50 percent of the diesel plant's capacity. One such wind turbine model will be, for instance, Nordex N27/150 (rotor diameter: 27 meters; rated wind speed: 11 meters per second; hub height: 30 meters)[19]. The cost of installing such a wind energy converter is around RUR 75,000 per kilowatt of installed capacity.

In Chapoma, the expected average annual wind speed at the hub height of the wind turbine suggested above is relatively low, just 6.6 meters per second. But owing to the design of this particular model, which ensures the turbine's nominal capacity at wind speeds as low as 11 meters per second, the share of the wind energy converter in covering local electricity demand – given the ratio of rated to average annual wind speeds at 11 : 6.6 = 1.67 – will, as per Pic. 4.1 above, equal 25 percent. The share of diesel fuel saved by using wind energy in combination with diesel power in Chapoma will be of the same proportion.

Table 13. Operating and economic characteristics of power supply in Chapoma, operating costs, estimated prime cost of electric power produced, and recommended wind energy converter capacity for combined wind-diesel power production.

Locality	Diesel power plant capacity, in kilowatts	Annual output, in kilowatt-hours	Fuel consumption rate, in grams of fuel equivalent per kilowatt-hour	Staffing ratio, in number of personnel per kilowatt	Depreciation rate, in percent	Capital investments, in thousand roubles per kilowatt	Operating costs, in thousand roubles					Prime cost of electric power, in thousand roubles per kilowatt-hour	Recommended wind energy installation capacity, in kilowatts
							Fuel	Salaries/wages	Depreciation	Other	Total		
Chapoma	300	900	385	0.032	11	9	9,702	2,304	297	520	12,823	14.2	150

As noted above, one kilogram of diesel fuel, when burning, produces three kilograms of carbon dioxide[20]. Consequently, the reduced use of diesel fuel as a result of employing a wind energy converter will help achieve the following annual reduction in CO_2 emissions for Chapoma: $225 \cdot 10^3$ kilowatt-hours $\cdot$ $385 \cdot 10^{-6}$ tons of fuel equivalent per kilowatt-hour $\cdot$ 0.7 tons of diesel fuel per ton of fuel equivalent $\cdot$ 3 = 182 tons.

As with other examples above, using a wind energy converter in combination with the diesel-based power plant will contribute to optimizing the Chapoma diesel plant's operating costs by decreasing expenses on fuel purchase and delivery, which, in turn, will result in a lower prime cost of

[19] See Footnote 15.
[20] See Footnote 16.

electric power produced. As shown in Table 14, using wind energy to cover part of the local electric load will reduce the prime cost of electric power in Chapoma by 11 percent.

Table 14. Wind energy converter parameters, operating costs of combined wind-diesel power production, estimated prime cost of electric power produced, and the resulting environmental benefit (reduction in CO_2 emissions).

Locality	Capacity, in kilowatts		Output, in thousand kilowatt-hours		Depreciation rate at wind energy converter, in percent	Capital investments in wind energy converter, in thousand roubles per kilowatt	Operating costs, in thousand roubles					Prime cost of electric power, in thousand roubles per kilowatt-hour	Prime cost reduction, in percent	Reduction in carbon dioxide emissions, in tons
	Diesel power plant	Wind energy converter	Diesel power plant	Wind energy converter			Fuel	Salaries/wages	Depreciation	Other	Total			
Chapoma	300	150	675 (75%)	225 (25%)	7	74	7,277	2,304	1,074	676	11,331	12.6	11.3	182 (↓ 35%)

4.4. Small hydropower plant on the Yelreka near Krasnoshchelye

Krasnoshchelye is a settlement standing on the River Ponoi, in the central part of the Kola Peninsula. The village is located at a distance of more than 150 kilometers away from the nearest source of grid electricity. Besides air transport, it has no connection to other areas except a sleigh road during winter. Central electric power supply is not planned for this village in the near future. Currently, the main energy source for this place is a diesel power station with a capacity of around 500 kilowatts.

Pic. 4.2. Prospective sites for small hydroelectric power plant projects on the Kola Peninsula.
1— Hydropower plant on the Yelreka; 2 — Hydropower plant on the Chavanga.

Four tributaries to the Ponoi were earlier under consideration as the potential sites for a small-scale hydropower plant to cover energy needs of Krasnoshchelye – Pyatchema, Yelreka, Kuksha, and Sakharnaya. They all are similar in their energy potential specifications, which is why the main criterion for the selection of a waterway and a suitable hydrosite for the small plant for Krasnoshchelye was their distance from the consumer. The site on the Yelreka River is located 12 kilometers from the river estuary and only 6 kilometers from the settlement, which was the major contributing factor when making the choice in favor of this site.

The optimal headrace for the suggested hydropower station is 164 meters, the reservoir's complete area is 12.3 square kilometers, and the effective storage capacity is 37 million cubic meters. A two-unit hydropower plant can be proposed for the site – an option that, compared with that of a one-unit station that would be smaller (in terms of the amount of construction works needed for the plant's building), suggests improved operation reliability and simplified procedures of the plant's operation during planned maintenance works in the summer. With the value of the maximum possible head at 9 meters, the best option for the project is a run-of-river turbine house with pressure turbine pits and vertical Kaplan turbines.

As regards dam types, an earth-and-rock fill dam with a moraine impervious core has been chosen. The dams' top width is 8 meters, and its length is 1,100 meters. No fish ladder is provided for at the hydropower plant since at the site to be dammed off, and further upstream, the river presents no particular value as a fishery resource.

To determine the best installed capacity for the small-scale hydropower plant on the Yelreka, the main energy and economic parameters have been estimated in accordance with five possible capacity values: 300, 500, 600, 800, and 1,000 kilowatts. With regard to operation in combination with Krasnoshchelye's diesel power plant, calculations show that the optimal value for the installed capacity of the hydropower plant would be 500 kilowatts. The diesel power station is expected primarily to cover part of the load during low flow periods, as well as to serve as a load and emergency reserve.

To summarize, the best recommended option to meet the energy demand of the village of Krasnoshchelye will be a small run-of-river hydroelectric power plant with an installed capacity of 500 kilowatts (two units with a rotor diameter of 1 meter each and a rated head of 6 meters) and an expected annual electricity output of 2.7 million kilowatt-hours.

Table 15. Basic specifications of hydropower equipment produced by Russian manufacturers.

Company, name	Head, in meters	Generating unit capacity, in kilowatts	Cost, in thousand roubles per kilowatt
NETRAEL	8–16	160–700	44–18
INSET	7.5–400	200–500	36–19

The evaluation of small hydropower's economic potential in localities under consideration in this report is based on existing prices for primary hydropower equipment for small generating stations as offered by such companies as INSET and the Research and manufacturing association NETRAEL[******] (see Table 15). Experience accumulated in building small and mini-hydropower stations both in Russia and worldwide suggests that the cost of power equipment installed at a given plant will account for 20 to 30 percent of its total costs. Based on these figures, overall capital investments required for a small hydropower plant on the Yelreka as per current prices will be around RUR 90 million. Calculations show that with 5 employees as the necessary number of operating personnel, salaries at RUR 20,000 per employee per month, and depreciation rate at 7 percent, the prime cost of electric power produced by such a station will be around RUR 3.4 per kilowatt-hour. Today, the prime cost of electric power generated by the diesel-based power plant in operation in Krasnoshchelye stands at about RUR 14 to RUR 15 per kilowatt-hour.

[******] For more information on these companies, see http://corp-eeek.ru/index.php?do=static&page=%CD%E5%F2%F0%E0%FD%EB (in Russian) and http://www.inset.ru/e/index.htm. – Translator.

4.5. Small hydropower plant on the river Chavanga

The site for this station was earlier chosen at an 8.5-kilometer mark from the estuary, and at a distance of 7.5 kilometers from the settlement of Chavanga (see Pic. 4.2). The normal headwater level is 54.4 meters; the useful water storage capacity is 8.3 million cubic meters. Such capacity values, in combination with the considerable river water content – the average flow is 15 cubic meters per second – allows for the unrestricted daily and partial seasonal regulation. The head at the hydrosite ranges from 9 meters to 15 meters.

Calculations based on parameters for a combined operation of the hydrosite and a diesel power plant have helped determine the optimal value for the installed capacity of the hydropower plant on the Chavanga, with possible capacity values ranging between 300 kilowatts and 1,500 kilowatts. The optimal installed capacity was finally estimated at 1,250 kilowatts. Such capacity can ensure power supply both to Chavanga and the neighboring villages of Chapoma, Tetrino, Strelna, and Pyalitsa, and provide good groundwork for their future development.

The recommended hydropower plant option – a reservoir-type station with an installed capacity of 1,250 kilowatts – is a project with two turbine units with the rotor diameter of 1.0 meter each and a standard power house with short pressure penstocks and bent suction tubes. The hydrosite's earth-and-rock fill dam with the impervious core made of moraine is 900 meters long; its top width is 8 meters. In order to preserve salmon stock, a 190-meter-long fish ladder is included among the main structures, consisting of 16 pools three by five meters each and two resting pools three by ten meters each.

Based on data from Table 15 above, the total capital investments into a hydropower plant on the river Chavanga could today reach RUR 200 million. Calculations show that the prime cost of electric power produced by the station will be around RUR 3.2 per kilowatt-hour. This is considerably lower than the prime cost of energy generated by the existing diesel-fueled power plant, where that value in 2011 was between RUR 14 and RUR 15 per kilowatt-hour.

Table 16. Basic operating characteristics of first-priority small hydroelectric power plants proposed for electricity supply to off-grid consumers in Murmansk Region.

River, name	Installed hydropower plant capacity, in kilowatts	Average annual output, in million kilowatt-hours	Head, in meters	Flow rate, in cubic meters per second
Yelreka	500	2.7	6	10
Chavanga	1.250	6.3	10	15

Taking all of the above into account, two small hydroelectric power plants can be recommended as first-priority hydropower sites to cover off-grid electricity demand in Murmansk Region. The main operating parameters describing these two projects are listed in Table 16. Both projects are designed for half-peak load conditions and are each proposed as the primary source of electricity supply for the off-grid consumers residing in the neighboring communities.

For the two hydropower projects described above, no particular need exists to prioritize one over the other in terms of construction time frames. Each of the two is important for its own prospective local consumers. It is only the local consumers and the local conditions that can determine the best time to start the implementation of the project. But where time frames are concerned, one point is crucial for all small hydropower plant projects – completing all construction works within one year so as to ensure a speedy and efficient return of the invested funds. Financing for these projects should, in our opinion, come from a variety of sources: consumers' own funds, regional and district administrations, the region's energy supply and distribution system, other state agencies, organizations, and enterprises, and, where possible, private businesses and even foreign capital.

4.6. Premises for application of wind energy in heat generation

A number of factors favor the application of wind energy in heat energy generation in Murmansk Region:

1. high wind energy potential, especially in coastal areas;
2. the lengthy heating season, which on the Kola Peninsula lasts for nine months, or longer;
3. the winter wind speed maximum, which coincides with the seasonal peak in heat energy demand on the part of the consumer;
4. using wind energy converters for heating needs will help turn wind from a climate factor that contributes to increased heat losses into a full-fledged energy source capable of providing a steady flow of energy for the consumer's heating needs exactly during the windiest periods of the year;
5. using wind energy converters will also help cut the considerable fuel expenditures, by reducing both fuel consumption and, by extension, the costs of fuel transportation from other regions and via local delivery;
6. finally, using wind energy converters for heating purposes enables control over the main disadvantage of this energy source, which remains a factor to contend with otherwise – namely, its variability across prolonged periods of time. The brief second- and minute-long lapses in a wind energy converter's capacity are absorbed by the accumulating capability of the heat supply system; fluctuations that last longer – dozens of minutes to several hours – are balanced out by the accumulating capacity of the heated buildings or with the help of backup heating sources based on fossil fuel.

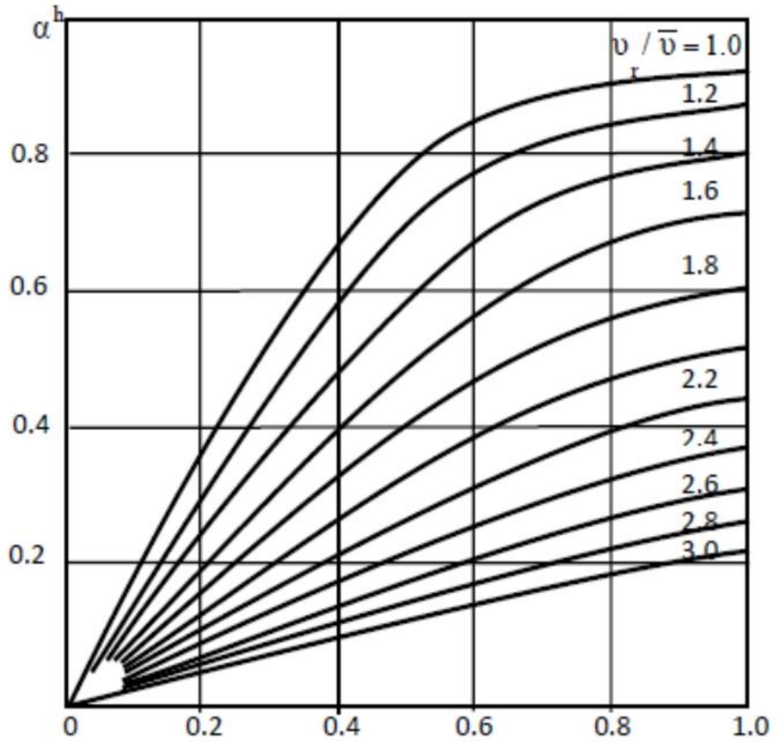
4.7. Using wind energy for heating in Tsyp-Navolok and Kildin

Previous subchapters in this report detailed the option of using wind energy converters in combination with diesel-fired power stations to cover a portion of the electric load in a number of remote coastal communities of Murmansk Region. No less attractive are the prospects of employing wind energy to provide for the heating needs of these consumers, since the fuel they use for heating – firewood, coal, or oil products – are delivered to them by sea, with loading and unloading operations at the point of origin and at the local destination, which means additional transport costs and significant increases in fuel expenses. No option to harvest and stock firewood locally exists for the communities examined above, since Tsyp-Navolok and Kildin are situated in the open tundra, far from the wooded areas of the peninsula. At the same time, these localities experience an increased demand in heat energy owing to the severe climate and weather conditions prevailing in these parts.

Based on the number of residents in Tsyp-Navolok and Kildin – 43 and 80 in each – boiler plants of capacities of 0.2 and 0.4 gigacalories per hour, respectively, will be needed to meet the residential load and provide heating for non-domestic purposes.

Table 17 shows the initial operating and economic characteristics of boiler plants – efficiency ratio, staffing ratio, depreciation rate, and capital investments per unit of production – as per data used earlier in Table 4. The number of boiler plant operating hours has been taken as equal to 3,500, and the price of domestic heating oil – which is less expensive than diesel fuel – has been taken as equal to RUR 24,000 per ton of fuel equivalent, with local transport costs taken into account. Based on these parameters, the boiler plants' operating costs and the component costs have been calculated, as well as the resulting prime cost of heat energy. The latter, as shown in Table 17, comes to RUR 6,500 and RUR 7,700 per gigacalorie produced, for Kildin and Tsyp-Navolok, respectively.

Boiler plants are usually equipped with three or four boilers that are engaged consecutively as the heating load increases. Studies show that the optimal capacity of wind energy converters used for parallel operation with heating plants ranges between 60 and 80 percent of the boiler plant's capacity. In such cases, the wind energy converter can assume all of the heating load and only in certain rare circumstances – such as warm air temperatures or extremely strong winds – will the wind installation's output partially exceed demand. Taking this into consideration, the capacities of wind energy converters recommended for combined operation with boiler plants in Tsyp-Navolok and Kildin will be 150 and 300 kilowatts, respectively, or 65 percent of the boiler plant's capacity in each case.



Pic. 4.3. Dependence of the share of wind energy (α^h) in meeting heat energy demand on the ratio of wind energy converter (WEC) capacity to heating plant (HP) capacity ($\beta^h = N_{WEC} / N_{HP}$).

The suitable wind turbine models that could be suggested for Tsyp-Navolok and Kildin are, for instance, Nordex N27/150 (capacity: 150 kilowatts; rotor diameter: 27 meters; rated wind speed: 11 meters per second; hub height: 30 meters)[21] and ENERCON E-30/3.30 (capacity: 300 kilowatts; rotor diameter: 30 meters; rated wind speed: 12 meters per second; hub height: 49 meters)[22]. In Tsyp-Navolok and Kildin, the average annual wind speeds at the hub height of the recommended wind energy converter models will be 8.2 and 9.2 meters per second, respectively.

The share of wind energy penetration (α_h) – the portion of the heating load that the wind energy converter will assume during the heating season – is the ratio of the wind installation's annual output to the annual heat energy consumption rate. In order to determine the value of α_h, vast amounts of data have been processed that were obtained from wind speed and air temperature observations by weather survey stations of Murmansk Region.[23] The results of this analysis reveal a dependency of α_h on the wind regime (average annual wind speed, $\overline{\upsilon}$), the wind energy converter's specifications (rated wind speed, υ_r), and the ratio of the wind energy converter's capacity to that of the heating plant (see Pic. 4.3).

Using wind energy in combination with a boiler plant helps optimize the latter's operating costs by decreasing fuel costs and thus reducing the prime cost of heat energy produced. In the examined localities of Tsyp-Navolok and Kildin (see Table 18), using wind energy converters to assume a share of the total heating load can reduce the prime cost of heat energy by 33 and 29 percent, respectively.

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[21] See Footnote 15.

[22] Wind Energy – 2004. – Osnabrueck, Deutschland, Bundesverband WindEnergie Service GmbH. – 2004. – 196 pages.

[23] See Footnote 9.

Table 17. Operating and economic characteristics of heat supply in Tsyp-Navolok and Kildin, operating costs, estimated prime cost of heat energy produced, and recommended wind energy converter capacity for combined wind energy and boiler operation.

Locality	Boiler plant capacity, in gigacalories per hour	Annual output, in gigacalories	Efficiency rate, in grams of fuel equivalent per kilowatt-hour	Staffing ratio, in number of personnel per gigacalorie	Depreciation rate, in percent	Capital investments, in thousand roubles per gigacalorie per hour	Operating costs, in thousand roubles					Prime cost of heat energy, in thousand roubles per gigacalorie per hour	Recommended wind energy installation capacity, in kilowatts
							Fuel	Salaries/wages	Depreciation	Other	Total		
Tsyp-Navolok	0.2	700	0.60	23	10	2.23	4,003	1,104	45	230	5,382	7.69	150
Kildin	0.4	1,400	0.65	14	10	2.13	7,392	1,344	85	286	9,107	6.51	300

Table 18. Wind energy converter specifications for Tsyp-Navolok and Kildin, operating costs of heat energy production in combined wind energy and boiler plant operation, estimated prime cost of heat energy produced, and the resulting environmental benefit (reduction in CO_2 emissions).

Locality	Capacity		Output, in gigacalories		Depreciation rate at wind energy converter, in percent	Capital investments in wind energy converter, in thousand roubles per kilowatt	Operating costs, in thousand roubles					Prime cost of heat energy, in thousand roubles per gigacalorie	Prime cost reduction, in percent	Reduction in carbon dioxide emissions, in tons
	Boiler plant, in gigacalorie per hour	Wind energy converter, in kilowatts	Boiler plant	Wind energy converter			Fuel	Salaries/wages	Depreciation	Other	Total			
Tsyp-Navolok	0.2	150	224 (32%)	476 (68%)	7	74	1,281	1,104	822	385	3,592	5.13	33.3	238 (↓ 68%)
Kildin	0.4	300	406 (29%)	994 (71%)	7	67	2,144	1,344	1,492	567	6,492	4.64	28.7	459 (↓ 71%)

Conclusion

Because of the great distances that separate them from the rest of the region and the low rate of energy consumption, several dozen outlying communities on the Kola Peninsula have no access to grid electricity and receive their power supply from small diesel-fueled power plants with capacities ranging between 8 and 500 kilowatts. This category of off-grid consumers includes weather survey stations, lighthouses and navigation beacons, coastal border outposts, fisheries, and deer farms.

Fuel deliveries to these communities are contingent on the condition of the roads and other transport networks and show a clear seasonal dependence on the availability of transport links. Both the lack of a developed transport infrastructure and the complicated multi-stage shipping logistics result in fuel losses during transportation and increased fuel costs for the end consumer. Information collected on the expenses incurred on fuel deliveries to off-grid communities of the Kola Peninsula allows one to conclude that the additional transport costs may cause the final price of fuel for the consumer to rise by as much as 1.5 to 3 times.

The existing power supply sources in these localities show wear, and their technical condition does not meet modern standards. These two factors lead to low economic efficiency and significant additional expenses required for continued operation of these power-generating facilities. Improving power supply systems of small off-grid communities of Murmansk Region is therefore a rather pressing task. Local renewable energy sources are the resource that can offer options to enhance energy efficiency, reduce the financial burden, and ensure a reliable power and heat energy supply in these localities.

This report is an attempt to analyze the economic aspects of using small-scale renewable energy installations in the remote communities of Murmansk Region that have no access to central power supply. Application of renewable energy sources for electricity production and heating purposes can and should play an important role in the sustainable development of the outlying areas of the region, by providing local residents with the necessary heat and electric power supply and thus raising their standard of living.

Studies show that immense resources of renewable energy are available to Murmansk Region, but they are scattered across a vast territory and have, for the most part, low concentration. While evaluating the prospects of practical application of these renewable energy sources, three principal factors were taken into account: the existing potential of a particular energy source, premises that may contribute to its efficient use in a given location, and the cost of energy-generating equipment required to implement such a project. The analysis done in this report demonstrates that wind energy converters and small hydroelectric power stations would be the optimal solutions for off-grid power supply in remote settlements of the Kola Peninsula.

Wind energy could be used both for electric power production, in combined operation with diesel-based power plants, and for heating purposes, to assume part of the load currently covered by boiler plants running on fossil fuel. Calculations performed with regard to the first option – combined wind-diesel power supply for the coastal communities of Tsyp-Navolok, Kharlov Island, Tersko-Orlovsky, and the border outposts Pummanki and Kildin – show that using wind energy converters in these localities could help reduce fuel consumption at diesel power plants by 30 to 50 percent, the prime cost of power produced by 15 to 25 percent, and carbon dioxide emissions by as much as 30 to 50 percent. The second option – using wind energy for heating purposes – offers the advantage of turning wind from a climate factor responsible for high heat losses in severe weather conditions of the Arctic north into a reliable energy source that will supply the much-needed heat energy precisely during the windiest periods of the year. Applying wind energy for heating needs in parallel operation with boiler plants in

Tsyp-Navolok and Kildin will likewise result in considerable savings of the expensive fuel delivered to these localities from other regions, reducing fuel use by 68 to 71 percent and the prime cost of heat energy produced by 29 to 33 percent, with the added ecological effect of reducing CO_2 and black carbon emissions.

Murmansk Region has a great number of small rivers with potential for the development of small-scale hydropower projects. In our view, among the off-grid communities of Murmansk Region that could benefit from using small hydropower for reliable and cost-efficient electricity supply, the settlements of Krasnoshchelye and Chavanga are such localities where mini hydroelectric power plants could be best recommended for these purposes.

The conclusions we made while preparing this report serve to support the economic expediency of integrating renewable energy technologies into the current system of electric power and heat energy supply in remote off-grid communities. Renewable energy has lately seen a stable trend toward lesser capital expenditures needed to get such projects off the ground and lower energy generation costs. The International Energy Agency forecasts a decrease in capital investments into wind energy from $1,100 per kilowatt as of 2005 to $800 per kilowatt by 2030. The prime cost of power produced by wind energy converters is expected to fall by up to 15 percent. Global development of small hydropower has shown a similar tendency, with capital investments decreasing and the prime cost of hydropower likewise falling as a result.

Following the payback period, when the funds invested into a renewable energy project have been recouped, operating costs remain the only factor determining the cost of electric power and heat energy produced by the renewable energy source. And these costs, as follows from the analysis conducted in this report, are significantly lower than those incurred today by using conventional fuel sources for power and heat generation in remote communities. In other words, renewable energy is a competitive alternative to the options currently used to provide electric power and heat to settlements with no access to centralized energy supply.

Finally, bringing renewable energy to off-grid rural localities of Murmansk Region will not only help achieve significant savings in fuel and other costs, but will also contribute to a healthier environment in these communities, thus greatly improving their standard of living overall.

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Translator's note:

For the reader's convenience, non-English titles of sources cited in this report are stated in their English translations first, followed by the original titles in Russian.

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