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PROSPECTS FOR DEVELOPMENT OF NON-CONVENTIONAL AND RENEWABLE SOURCES OF ENERGY ON THE KOLA PENINSULA

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Foreword

Since 1989, Bellona has been concerned with finding a suitable energy alternative to nuclear power produced by the Kola Nuclear Power Plant, which poses an environmental risk for Northwest Russia, as well as its Nordic neighbours. With this goal in mind, a cooperative agreement was signed between Bellona and the Kola Science Centre of the Russian Academy of Sciences in 2006 to evaluate the possibilities for development of clean energy in the region. The current report "Prospects for Development of Non-conventional and Renewable Sources of Energy on the Kola Peninsula" is the product of independent scientific investigation conducted by the Kola Science Centre Institute for Physical and Technological Problems of Energy in Northern Areas. This is a groundbreaking report containing the most comprehensive evaluation of alternative energy sources on the Kola Peninsula. It provides scientific evidence that the region's natural resources are in sufficient quantity to make renewable energy a worthy alternative to nuclear power and fossil fuels. This report is produced and published by Bellona, but its content has not been altered in any manner.

In "Prospects for Development of Non-conventional and Renewable Sources of Energy on the Kola Peninsula" scientists give an overview of the potential for solar, wind, small river hydro, tidal, wave and bio-energy in the Murmansk region. Each renewable resource is outlined in detail including its general information, historical and international experience, advantages and limitations, availability and technical potential, environmental aspects and cost considerations. Specific sites are identified for pilot and large-scale development of renewable energy sources. This report illustrates the potential for renewable energy sources on the Kola Peninsula in a comprehensive and detailed fashion. It is meant to facilitate a transition to clean energy by providing a scientific foundation upon which decision makers, industry and investors, both in Russia and across the border, can develop renewable energy on the Kola Peninsula. But it is also interesting reading for concerned citizens, students and environmental organisations who are engaged in local environmental issues.

This report reveals the potential of renewable energy for supplying electricity to energy users connected to the grid, as well as its value for supplying heating to de-centralised consumers in isolated villages. It concretises potential projects for renewable energy with technical specifications and site-specific information in a manner conducive to their practical implementation. Bellona believes that this report will contribute to the local debate on energy choices in the region and provide officials and business leaders with the necessary impetus to consider implementation of renewables on a large-scale. Moreover, the findings indicate that clean renewable energy, especially wind energy, is indeed in sufficient quantities on the Kola Peninsula to cover both current and future energy demands. Renewable energy can therefore be considered a feasible alternative to nuclear power currently provided by aging reactors at the Kola Nuclear Power Plant.

The Authors

Valery Andreevich Minin, Doctor of Science, is the Deputy Director of scientific work at the Institute for Physical and Technological Problems of Energy in Northern Areas of the Kola Science Centre Russian Academy of Sciences and Director of the Laboratory of Non-conventional and Renewable Energy Sources. V.A. Minin is a specialist in wind energy. His scientific activities include developing a wind energy cadastre for the European part of northern Russia, evaluating wind energy resources of the region and disclosing the most prosperous and practical regions for development of wind energy. He participated in establishing a wind energy testing ground on the coast of the Barents Sea, where experimental research on wind energy converters under conditions of the North was conducted over the course of 20 years. V.A. Minin was awarded the Bronze Medal at the Exposition of Achievements of the National Economy of the USSR. He coordinated the Russian participation in the international scientific- technical project "Kola Wind" under the framework of the European Programme for Non-nuclear Energy. He is the scientific leader of the scientific-investigative work on the problem of supplying electricity and heating to the regions of the North with non-conventional and renewable energy. V. A. Minin is the author of over 140 publications.

Grigory S. Dmitriyev is a senior scientific fellow at the Institute for Physical and Technological Problems of Energy in Northern Areas of the Kola Science Centre Russian Academy of Sciences. A graduate of the Moscow Institute of Energy, G. S. Dmitriyev is a specialist in hydro energy and the application of non-conventional and renewable sources of energy. He has researched the hydro energy resources of the region and evaluated the perspective development of hydro energy, including construction of small hydro electric stations and hydro accumulating electric stations. G. S. Dmitriyev also participates in research on development of wind energy, studying the effectiveness of joint application of large wind parks with hydro electric stations as a part of the energy system. He actively assisted in organising and executing the international scientific-technical project "Kola Wind" under the framework of the European Programme for Non-nuclear Energy. He is one of the initiators and organisers of the practical implementation of wind energy on the Kola Peninsula – the construction of the first grid-connected wind energy converter with a capacity of 200 kWh in the city of Murmansk. G. S. Dmitriyev has been elected to serve as Vice President of the World Wind Energy Association (WWEA) since 2002. He is the author of 130 publications.

Translation

The particular spelling of geographical locations mentioned in the report corresponds to the transliteration of their respective spellings in the original Russian text. Names of power generation sites, or other sites, correspond to those locations that the Russian derivatives take origin from, such as names of rivers for hydroelectric power plants.

The contents of this report are published in English and Russian and will also be made available on the Bellona web. To obtain updates on renewable energy development in Northwest Russia, or to find more information about the Bellona Foundation, visit our website at www.bellona.org or www.bellona.ru.

Acknowledgments

Bellona would like to thank the Norwegian Ministry of Foreign Affairs for providing financial support to the study of renewable energy on the Kola Peninsula. Although the scientific analysis on which this report is based was partially financed by the Norwegian Ministry of Foreign Affairs, the report does not necessarily reflect the views of the Ministry and no official endorsement should be inferred. Bellona would also like to thank the authors of this report Valery A. Minin and Grigory S. Dmitriyev for their careful analysis and concise evaluation of renewable energy potential on the Kola Peninsula. We thank Maria Kaminskaya for her attention to detail in translating the report from Russian to English. In addition, we thank Igor Kolesnikov and Igor Kudrik for their work in formatting the report and publishing it on the internet, and Michele Grønbech for editing the English version. We also want to acknowledge Vladislav Nikiforov for his administrative assistance. Lastly, we would like to

thank our colleague in Murmansk, Nina Lesikhina, for acting as liaison between the Kola Science Centre and Bellona's Oslo office.

The Bellona Foundation

Bellona has worked with the complex and demanding environmental challenges in Northwest Russia since 1989. Initially our attention was focused on radioactive pollution and mapping the threats posed by nuclear installations, radioactive waste storage and spent nuclear fuel. Today our efforts also include projects related to clean energy, oil and gas pollution, environmental information and democratic rights. We are currently developing renewable energy solutions to the Kola Nuclear Power Plant, monitoring oil and gas activities, and organising public participation on ecologically important decisions to increase involvement of civil society. We also gather and disseminate information on environmentally sensitive issues through the Bellona Web. In 1994, we established a sister organisation, Bellona Murmansk, to more closely monitor and influence local activities and political decisions that affect the environment.

The Bellona Foundation was founded as an NGO in 1986. The Foundation is a science-based environmental organisation whose main objective is to combat problems of environmental degradation, pollution-induced dangers to human health and ecological impacts of economic development strategies.

Bellona aims to find feasible solutions that have the least impact on the environment. Bellona strives to inform the public, lawmakers, opinion leaders, industry and the media about environmental hazards, and helps draft policy responses to these problems.

Bellona works towards international co-operation and legislation to protect nature and improve the environment, in support of the public's right to enjoy clean air, soil and water. Bellona also works to guarantee access to information about environmental threats.

Through our offices in Oslo, Murmansk, St. Petersburg and Washington, D.C., Bellona establishes networks and fosters mutual understanding between European, Russian and U.S. authorities and corporations on environmental issues.

Bellona Publications

Bellona has produced a number of useful scientific reports related to the nuclear industry in Russia: "Sources to radioactive contamination in Murmansk and Archangelsk counties" (1994); "The Russian Northern Fleet: Sources of Radioactive Contamination" (1996); "The Arctic Nuclear Challenge" (2001); and "The Russian Nuclear Industry: The Need for Reform" (2004).

Bellona has also produced a report on energy entitled "Green Heat and Power: Eco-effective Energy Solutions in the 21st Century" (1999).

Oslo, October 2007
Michele Grønbech

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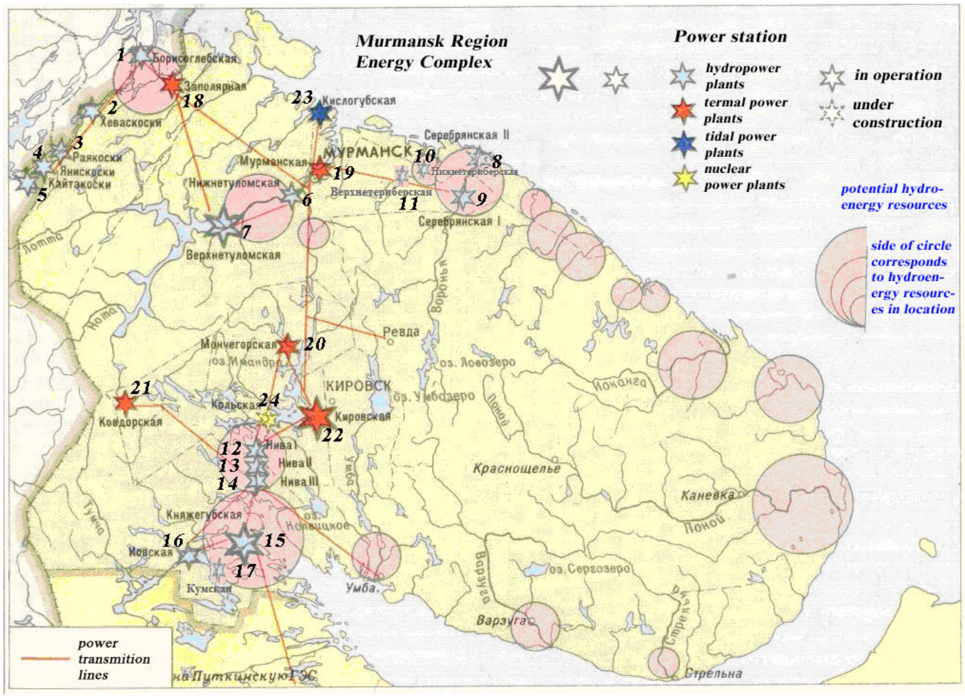
INTRODUCTION

In recent years scholars around the world have concentrated their attention on finding new energy sources and including them into national fuel and energy budgets. A special emphasis has been put on non-conventional renewable energy sources, such as the sun, wind, small rivers, tides, waves and other sources. The range of potential uses for these energy sources is practically unlimited. Their ecological cleanness is unquestionable.

Russia also appreciates the possibilities promised by the application of non-conventional energy sources [1,2]. Their inclusion into the national economy provides a way to cut levels of fossil fuel consumption, introduce better energy efficiency and improve the ecological conditions for the end-user.

Prospects of application of non-conventional renewable energy sources are most encouraging in areas which are inherently rich in these resources, but lacking in traditional fuels. In Russia's European north, one of these areas is the Murmansk region (see picture), whose energy economy avails itself of existing hydropower resources, but is also heavily dependent on fuels supplied from elsewhere in the country, such as nuclear fuel, coal, oil products and liquefied gas.



Power stations of the Murmansk Region:

Hydroelectric power plants:

1. Borisoglebsk Hydropower Plant
2. Hevaskoski Hydropower Plant
3. Rayaskoski Hydropower Plant
4. Yaniskoski Hydropower Plant
5. Kaitakoski Hydropower Plant
6. Lower Tuloma Hydropower Plant
7. Upper Tuloma Hydropower Plant
8. Serebryanka-II Hydropower Plant
9. Serebryanka-I Hydropower Plant
10. Upper Teriberika Hydropower Plant
11. Lower Teriberka Hydropower Plant
12. Niva-I Hydropower Plant
13. Niva-II Hydropower Plant
14. Niva-III Hydropower Plant
15. Knyazhya Guba Hydropower Plant
16. Iova Hydropower Plant
17. Kumskaya Hydropower Plant

Thermal power plants:

18. Polar (Zapolyarny) Thermal Power Plant
19. Murmansk Thermal Power Plant (City of Murmansk)
20. Monchegorsk Thermal Power Plant
21. Kovdor Thermal Power Plant
22. Kirovsk Thermal Power Plant

Tidal power plants:

23. Kislaya Guba Tidal Power Plant

Nuclear power plants:

24. Kola Nuclear Power Plant

The region has at its disposal a wide range of renewable energy sources, such as sun, wind, small rivers, tides and waves. Of these, solar resources are the most significant [3,4]. But the particular conditions of life in the sub-arctic pose a number of difficulties where development of this energy source is concerned. These challenges are primarily the result of the minimal amount – or complete absence – of sunlight reception during the winter months, when consumers' demand for energy is highest. Furthermore, existing technologies capable of converting solar energy into heat or electric power have yet to reach an acceptable degree of efficiency and are expensive, which, from the point of view of economic considerations, makes them seem less impressive compared to traditional energy installations running on fossil fuels. But at the same time, solar energy is a continually developing sector of the power complex with very encouraging possibilities, so an evaluation of the region's solar energy resources merits our attention.

Wind resources on the Kola Peninsula are less abundant than those of the sun, but they are still tremendous [5,6]. The most prominent wind energy potential is found in the coastal areas of the Barents and White seas, as well as in the mountains of Khibiny and the tundra around the city of Monchegorsk. It has been determined that winds here are most intense during the colder seasons of the year, when energy consumption is at its peak. Moreover, wind energy is a perfect complement to another renewable energy source: river energy, whose potential decreases to a minimum level during the winter time.

Hydroenergy has been harvested for more than 70 years on the Kola Peninsula. Six major rivers of the peninsula are harnessed by 17 hydroelectric power plants, which supply more than a third of all electric power consumed in the region. At the same time, the region abounds in small undeveloped rivers, where midget, mini- and micro-hydroelectric power plants could be built to make a significant contribution to power supply in remote and isolated areas.

The Kola Peninsula can also avail itself of the considerate resources it has in tidal energy. Many years of research have given experts a deep insight into the issue of application of this type of energy [7]. A 400-kilowatt experimental tidal power plant has been built in Kislaya Bay, on the coast of the Barents Sea. Cross sections have been evaluated for the construction of larger tidal power plants in Dolgaya Bay near the village of Teriberka and in the Lumbovsky Gulf of the White Sea.

In a number of countries, studies of application of the energy of ocean surface waves have reached a point where it has become possible to build small-capacity experimental and pilot commercial models for wave power generation [8,9]. The Kola Peninsula has among its resources a coastline stretching for more than 1,000 kilometers. An evaluation of the potential of this type of energy and the prospects of using wave power installations in certain shoreline locations deserves attention as well.

The development of non-conventional renewable energy sources in the Murmansk region was consistently held back until very recently due to relatively low prices for fossil fuels on the one hand, and the high costs of equipment necessary to use these energy sources on the other. Today, the situation is changed. Fuel prices have grown significantly, as have electric power and heating rates. The technology needed for full-scale commercial production of power installations operating on energy from the sun, wind, small rivers, tides and surface waves has made great advancements. In countries such as Germany, Spain, the US and Denmark certain branches of the non-conventional energy sector, like wind energy or distributed hydropower generation, have become competitive in comparison with their traditional counterparts, and the scope of their development is now commensurate with that of the conventional power industry.

In light of these factors, the present work aimed at evaluating the potential of non-conventional renewable energy sources in the Murmansk region and assessing their prospective role in the development of the region's energy economy is both relevant and important.

1. SUN ENERGY AND ITS POTENTIAL

1.1. General remarks

Solar rays received at the surface of the Earth are separated into two distinct kinds: direct and scattered, or diffuse. Direct sunlight consists of radiation that reaches Earth as it is generated straight from the sun. The intensity of direct solar radiation is dependent on how clean the atmosphere is (clarity of the sky), how high the Sun is over the horizon (subject to the geographical latitude and time of day), and on the position of the surface with regard to the Sun.

Diffuse solar radiation comes from the upper layers of the atmosphere and is contingent on how the direct solar rays are reflected off the Earth and its atmospheric constituents. Because of the recurrent process of reflection of the sunlight between the snow-covered Earth and the lower side of the clouds, diffuse solar irradiance can fluctuate to high levels.

Sunbeams carry with them an inexhaustible source of energy. They consistently supply the Earth with more energy than we require today. The rate of solar radiation in space – or irradiance – is approximately 1.4 kW/m^2. Of that, around 30% is reflected back into space without ever reaching the Earth's surface. At the surface, solar irradiance reaches around 1 kWt/m^2. When solar energy arrives at the surface of the Earth it transports heat, evaporates water, creates wind, moves water in the Earth's seas and oceans, and gives life to its flora.

Those amounts of solar energy that are not immediately absorbed by the Earth are scattered back into space. The Earth remains in a constant heat balance with the surrounding environment. If that were not the case, the Earth's temperature would have increased exponentially and any life on the planet would have been impossible as a result.

Solar energy resources are extensive – if not unlimited. The problem, however, is that the peak of solar energy exposure takes place in the summer, at the time when consumers' need for it is lowest. In the winter, when energy demand is high, sunshine is only available for a short interval during daytime, and at a low angle at that. Only one solution presents itself: Solar energy needs to be accumulated in the summer and used in the winter.

1.2. Solar radiation: An outline

Solar radiation that reaches the surface of the Earth as a bundle of parallel rays coming directly from the Sun is called direct solar radiation S. The amount of solar radiation that falls on a horizontal plane S' depends on the position of the Sun over the horizon and is determined by this expression [10]:

$$S' = S \cdot \sin h , \tag{1.1}$$

where h is the elevation of the Sun over the horizon.

Global solar irradiance on a horizontal plane, consisting of direct radiation S' and diffuse radiation D, which reaches the Earth's surface as a result of scattering of the solar beam, is equal to:

$$Q = S' + D \ . \tag{1.2}$$

At the Earth's surface, solar radiation is redistributed: Some of it is reflected off the surface into the atmosphere (reflected shortwave radiation R), while the rest is absorbed at the surface (absorbed shortwave radiation B_k):

$$B_k = Q - R \quad . \tag{1.3}$$

The total sum of reflected radiation is contingent on the characteristics of the Earth's surface (color, content of moisture, surface structure etc.). The value characterizing surface reflectance, or surface albedo, A, is determined by the ratio of surface-reflected radiation to total incident radiation and is usually expressed as a percentage:

$$A = \frac{R}{Q} \cdot 100\% \quad . \tag{1.4}$$

Along with shortwave radiation, atmospheric longwave radiation also reaches the Earth's surface (counterradiation) E_a, and, in turn, Earth's surface emits longwave radiation in accordance with its temperature (Earth-emitted radiation) E_3. The difference between the radiation of the Earth's surface and that of the atmosphere is called effective radiation E_{ef} .

The algebraic sum of radiation components determines radiation balance B :

$$B = S' + D + E_a - R - E_3 = Q - R - E_{ef} \quad . \tag{1.5}$$

Depending on the ratio of the incoming and outgoing components, the radiation balance will have a positive value if the Earth's surface absorbs more radiation than it emits, or a negative value if the surface absorbs less radiation than it emits.

The value of the radiation balance can either be determined as the sum total of all components, each of which has been measured separately, or itself directly measured in an actinometric survey.

1.3. Radiation balance of the Kola Peninsula

To evaluate the potential of solar energy and the prospects of its application in the Murmansk region one would need to look at the results of surveys taken at the region's actinometric facilities. The region has three actinometric stations – Dalniye Zelentsy, Khibiny and Umba – which compile data on the radiation conditions in the north, south and central area of the Kola Peninsula, respectively.

The potential annual values for cumulative solar radiation exposure of the Murmansk region on clear days fluctuate between 4,600 and 4,900 MJ/m^2. Due to high cloudiness, which is characteristic for these parts, direct solar radiation exposure is decreased by 60% to 75%. However, the same conditions increase diffuse radiation exposure by more than 50%. When actual weather conditions are taken into consideration, cloudiness results in a 60% decrease of the annual solar radiation exposure deemed as potential, to between 2,300 MJ/m^2 and 3,100 MJ/m^2, or 650 to 850 kWh/m^2.

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 solar radiation that can reach the Earth's surface. If one assumes the vertical path along which a sunbeam is traveling to be equal to 1 (with the sun's elevation equaling 90^0), then at elevation values of 30^0, 5^0 or $0{,}5^0$, this path will be made longer by two, ten or 35 times, respectively. Table 1.1 shows data corresponding to seasonal changes in the position of the Sun over the horizon in the Murmansk region (Khibiny actinometric station, 68^0 N), in moderate climate areas (Minsk, Belarus 54^0 N) and in European southern regions (Sochi, Russia 44^0 N); Fig. 1.1 illustrates data showing global solar radiation exposure observed at the actinometric stations mentioned above [11].

Table 1.1

Solar noon zenith angle on the 15th day of a given month in the polar, middle and southern latitudes (in degrees)

Meteorological station	Month											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Khibiny	0.8	8.9	19.7	31.7	40.8	45.3	43.6	36.2	25.1	13.6	3.6	0
Minsk	14.8	22.9	33.8	45.7	54.8	59.3	57.6	50.2	39.1	27.6	17.6	12.7
Sochi	24.8	32.9	43.8	55.7	64.8	69.3	67.6	60.2	49.1	37.6	27.6	22.7

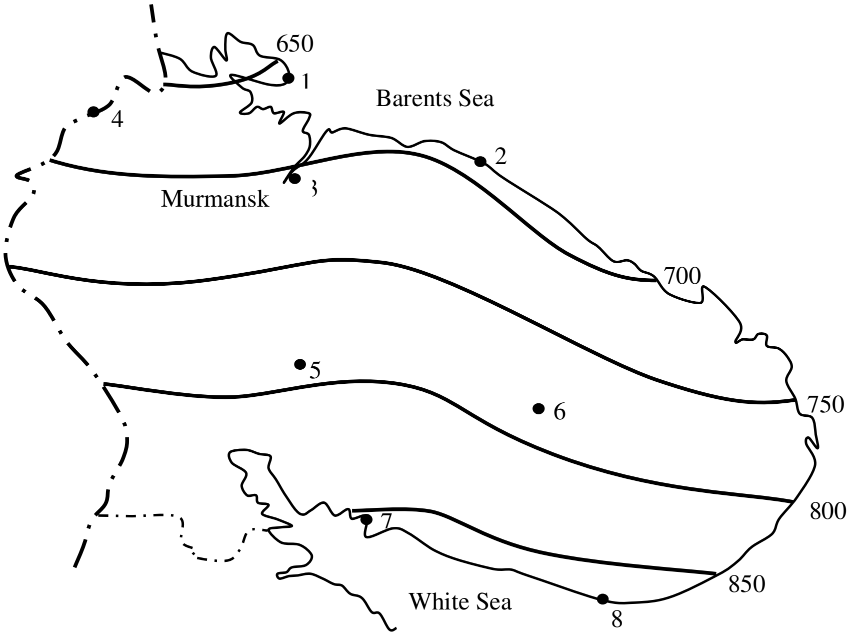


Fig. 1.1. Global solar radiation exposure on the territory of the Murmansk region (kW h/m^2)
1 – Tzyp-Navolok, 2 – Dalniye Zelentzy, 3 – Murmansk, 4 – Yaniskoski, 5 – Khibiny, 6 – Krasnoshchelye, 7 – Umba, 8 – Chavanga

The illustration shows that global solar radiation exposures in the northern and southern areas differ most during winter months. In the summer, exposure values become commensurate because 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. Fig. 1.2 illustrates seasonal changes in both solar energy supply and the potential yield of wind power installations. 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.

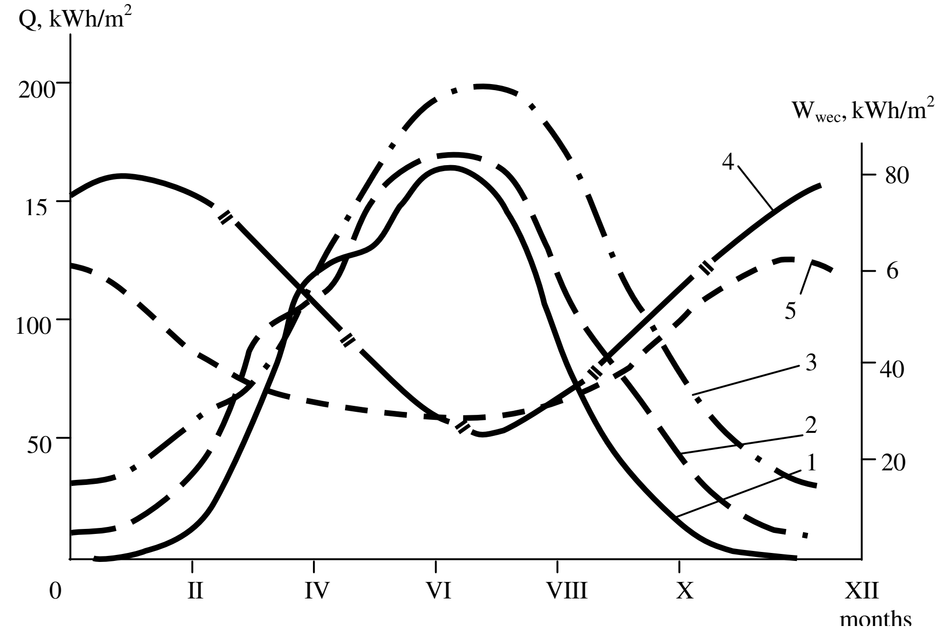


Fig.1.2. An annual cycle of mean monthly global solar radiation in the polar (1), middle (2) and southern (3) latitudes; an annual cycle of potential energy production at a WEC with a 1m² windwheel on the northern (4) and southern (5) coasts of the Kola Peninsula.
1- Khibiny station, 2 - Minsk, 3 - Sochi, 4 - Dalniye Zelentzy, 5 - Chavanga.

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 between 0.4 and 0.5 kW/m² (Table 1.2). On some days, favorable weather conditions with cloudiness levels not obscuring the sun will allow for an increase in irradiance values to between 0.9 and 1.0 kW/m².

If one assumes gross solar energy potential to be equivalent of the Murmansk region's total annual exposure to solar energy, these resources will amount to enormous values of around $1.1 \cdot 10^{14}$kWh. Murmansk's solar energy technical resources can then be estimated at $1 \cdot 10^{13}$ kWh, with the solar-to-electric energy conversion efficiency rate equaling 10%.

1.4. Sunshine durations

When assessing solar energy potential and the 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. The operation of solar energy installations depends not only on the total sunshine duration during a particular interval of time, but also on the recurrent frequency of continuous sunshine and sunless periods of varying durations. Fig. 1.3. is a bar chart illustrating Umba station's data for the variability of sunshine periods in accordance with their durations on a month-to-month basis. Each graph corresponds to a sum total of sunshine hours during the particular month (see also Table 1.3)

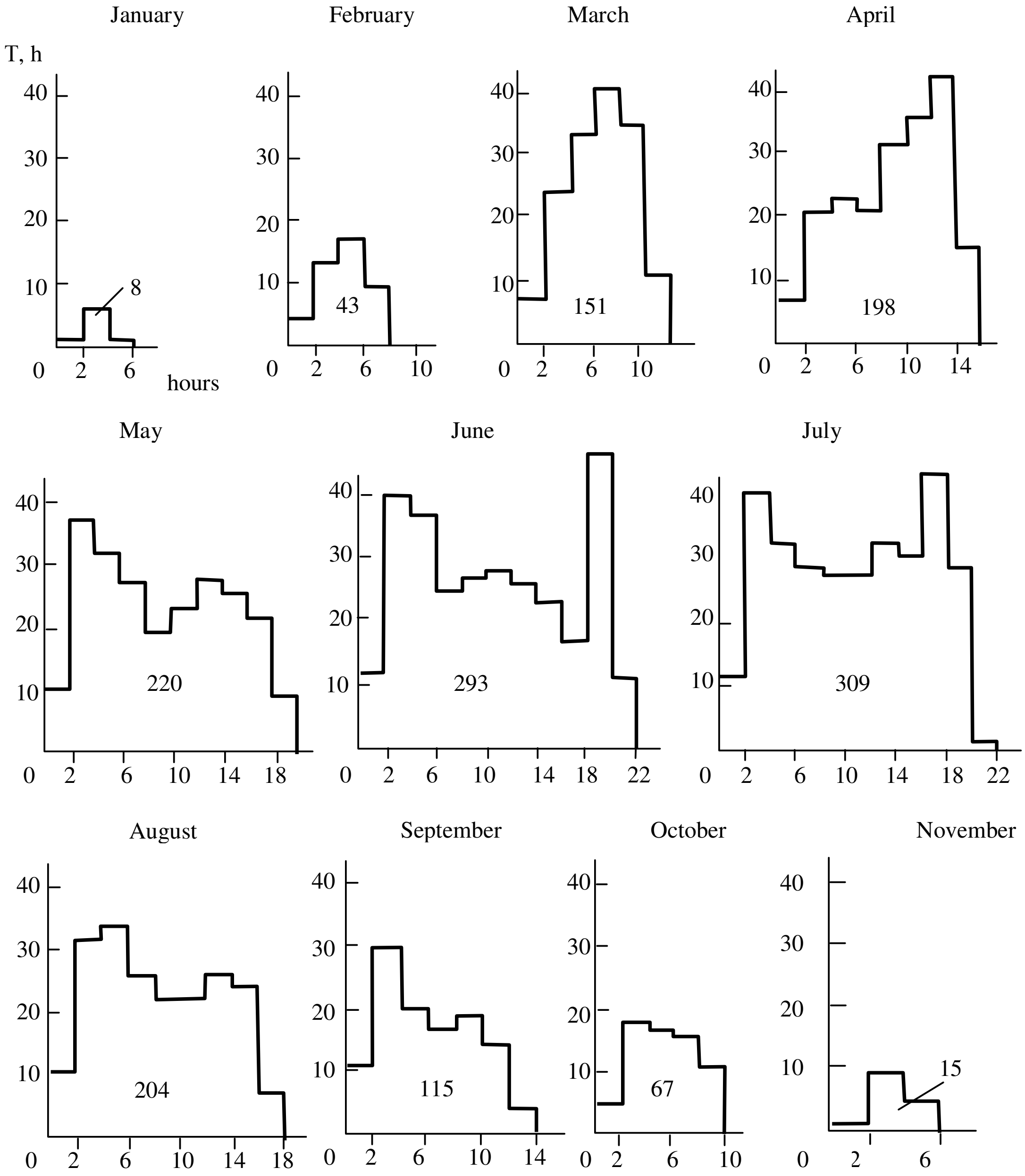


Fig. 1.3. Variability of total sunshine duration periods, according to month of the year (Umba Meteorological Station)

Table 1.3

Sunshine durations in various locations across the Murmansk region, in hours

Locality	Month												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	1195
Dalniye Zelentsy	1	37	114	176	177	225	204	141	84	48	6	0	1213
Murmansk	1	32	121	203	197	246	236	146	73	43	3	0	1297
Yaniskosky	3	41	126	200	195	242	258	162	74	48	4	0	1353
Khibiny	3	37	128	166	200	258	243	176	97	54	10	0	1372
Krasnoshchelye	4	38	135	186	180	250	256	157	75	45	9	0	1335
Umba	8	43	151	198	229	293	309	204	115	67	15	0	1632
Chavanga	10	42	136	200	221	290	302	196	96	63	17	2	1575

The average monthly number of sunshine hours in the Murmansk region – the territory of which is located predominantly beyond the Polar Circle – varies widely throughout the year between zero hours in December and 200 to 300 hours in June and July (Table 1.3.).

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. Fig. 1.4 is a comparative chart showing seasonal changes in sunshine durations in Umba village in the south of the Kola Peninsula against those in the Swedish town of Ingelstad, which is home to a considerably powerful – and successfully operated – solar power installation, providing heat to 52 homes. Data shown for the Kola Peninsula is quite commensurate to that for Sweden. Annual sum total of sunshine duration at 1,632 hours in Umba even exceeds the durations available to Sweden, with 1,550 hours in Ingelstad.

1.5. Prospective uses of solar energy on the Kola Peninsula

Experience gathered by Scandinavian nations demonstrates that solar power installations can be a quite effective solution where a population's demand for heat supply is concerned. However, as is evident from Fig. 1.4., vast amounts of energy need to be accumulated during the summer months for an area to be able to supply its energy users all year round with heat harvested from solar energy. Heat accumulator designs can be based on both underground thermal reservoirs (Swedish experience) and ground-based reservoirs, thoroughly insulated against the surrounding environments.

Fig. 1.5 represents a basic solar heating system based on such a storage tank [12]. The main components of the system are: a collector, a heat reservoir, and a backup (auxiliary) power source employed in case of a protracted absence of sunshine or when the reserve heat capacity has been exhausted. Four possible operation modes for such a system can be outlined:

Mode 1. If solar energy is available, but there is no demand for heating, then all the energy received from the collector is stored in the accumulator.

Mode 2. If solar energy is available, and there is a demand for heating, then all the energy received from the collector is spent to supply heat to cover energy users' needs.

Mode 3. If solar energy is not available, but there is a demand for heating, and there is reserve energy stored in the accumulator, then the heating demand is covered by this accumulated energy.

Mode 4. If solar energy is not available, but there is a demand for heating, and the energy reserve in the storage tank has been exhausted, then the backup energy source is used to cover heating needs.

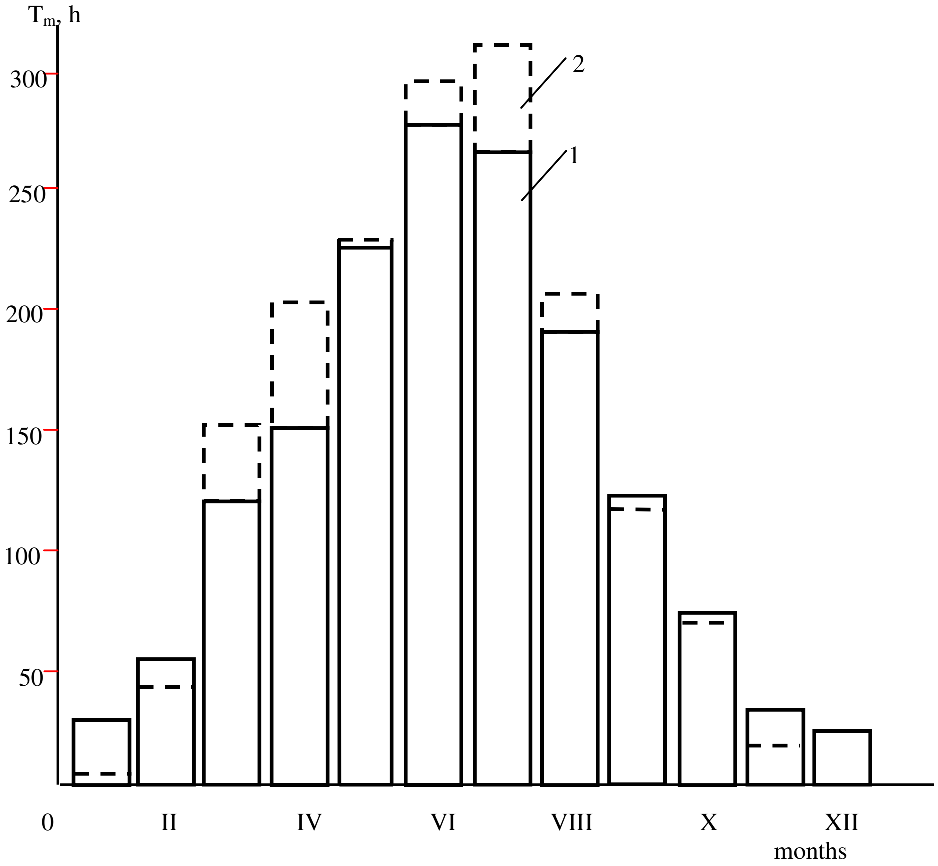


Fig. 1.4. Seasonal changes in sunshine durations in Sweden's Ingelstad (1) and in Umba (2) on the southern coast of the Kola Peninsula

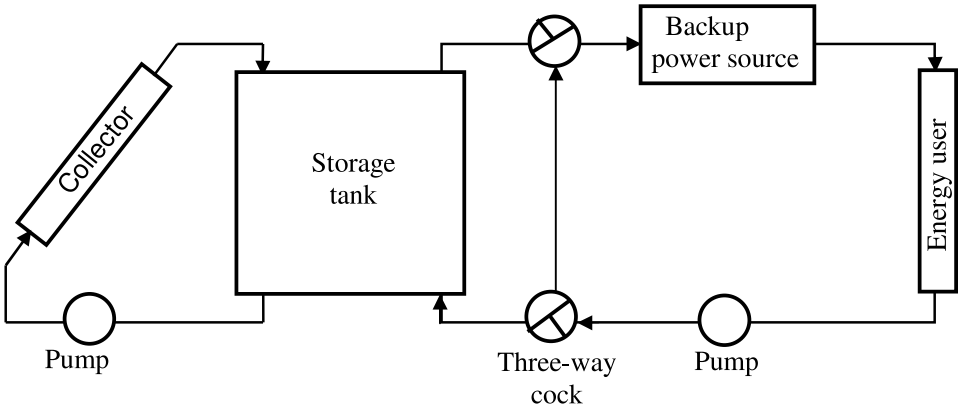


Fig. 1.5. Solar heating system.

Table 1.2

Diurnal cycle of the total solar radiation at the meteorological station in Umba, according to the results of a two-year survey (watt-hour/m^2).

Month	Hours of the day																									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Per 24 hours	Per month
January										0	12	23	23	23	12										93	2883
February								0	23	47	82	105	117	105	70	47	12								608	17024
March						0	23	70	128	175	221	256	268	245	210	152	82	35	12						1877	58187
April				0	23	70	128	198	268	314	350	373	349	326	291	233	186	105	47	12	0				3273	98190
May		0	12	35	82	140	210	280	338	384	419	431	431	385	361	315	256	198	128	70	23	12	0		4510	139810
June	12	12	23	47	93	163	221	291	350	408	443	466	455	420	396	361	303	245	175	117	58	35	23	12	5129	153870
July	0	0	12	35	70	128	186	233	303	350	419	454	466	431	408	350	303	221	151	93	47	23	12	0	4695	145545
August			0	12	35	82	152	221	291	338	373	408	420	420	385	326	245	163	93	35	12	0			4011	124341
September					0	12	47	93	140	175	210	221	210	187	152	105	70	35	12	0					1669	50070
October							0	12	35	58	93	93	105	82	58	23	12	0							571	17701
November									12	23	23	35	35	23	12	0									163	4890
December											12	12	12	0											36	1116
Per year																										813627

The solar heating system represented above allows for certain adjustments in the circuit, which consists of a solar collector and an accumulator. Independently, adjustments can also be made in the system's second part, which comprises a storage tank (accumulator), a backup energy source and the heating load: The water heated with solar energy can enter the accumulator at the same time as hot water can be collected from the accumulator to be delivered to the load, or consumer. This system has a bypass line provided for the storage tank, which prevents the accumulator from warming up with the heat emitted by the backup energy source. In areas that are afforded an increased wind energy potential, this heating system can be complemented with heating elements supplied by a wind energy converter (WEC). The heating elements can be installed directly in the storage tank.

Fig 1.6. represents an outline of the larger solar heating system in operation in Sweden's Ingelstad. Solar energy, concentrated by the collector's mirrors on absorber tubes, is converted into heat and is received by a heat-transfer medium being recirculated in them. The heat-transfer medium brings this heat to a heat exchanger A.

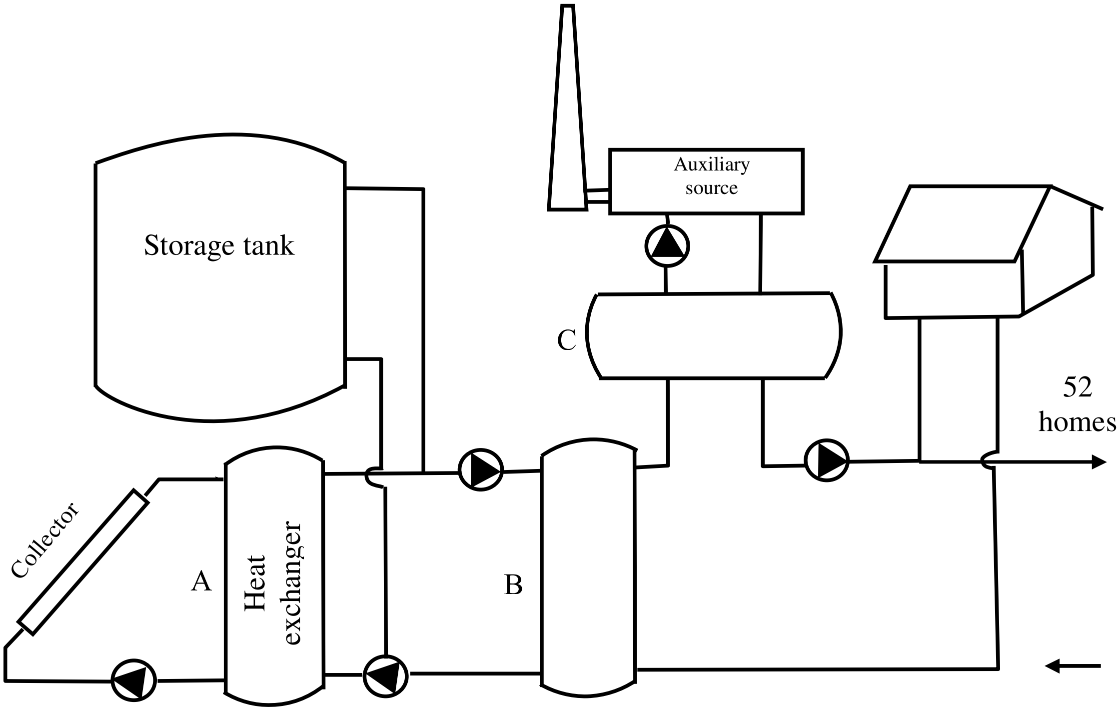


Fig. 1.6. A 52-home heat supply system in Sweden's Ingelstad.

Heat is transferred from the secondary circuit of the heat exchanger either directly to a consumer through heat exchanger B, or to a large-capacity heat storage tank. Water temperature in the storage tank increases slowly throughout the summer and reaches its peak values of about 95°C in September. The heat accumulated in the summer is spent in the following months to cover heating and hot water needs of the consumers. At a certain point, water temperature in the storage tank can decrease to levels which will necessitate engaging the backup heat-generating system (boiler). The heat from the boiler will be transferred to the thermal grid through heat exchanger C. Similar to the heating system described above, wind energy installations can be employed additionally in areas where increased wind energy potential is available. The energy harvested by wind energy converters can be collected from heat exchanger A, and then either directed straight to the consumers, or stored in the storage tank. As spring approaches and periods of continuous sunshine hours gradually increase, solar collectors again begin their efficient operation and provide their input into the energy supply system.

The technical and economic expediency of solar heating supply systems is contingent on a number of factors: the geographic latitude of the system's location; the variables of the location's solar energy exposure; solar collector prices; costs of creating and maintaining conventional energy systems; fuel prices, etc. Solar heating systems offer their best options when applied in remote and isolated locations, where costs incurred by maintaining heat supply through systems based on fossil fuels are high due to challenges imposed by fuel transport. In connection with the rising fuel prices, expenses for fossil fuel supply have increased lately which seems to ensure the efficient introduction of solar energy installations in the very near future. However, as will be demonstrated in [2], today's unit price of one solar cell battery on the international market is $4,000 to $5,000 per kilowatt, while prices for photovoltaic power systems vary between $7,000 and $10,000 per kilowatt (by comparison, the unit price for one wind power installation is only $1,000 to $2,000 per kilowatt). Solar power rates fluctuate between $0.20 and $0.30 per kilowatt-hour (or between RUR 6 and RUR 8 per kilowatt-hour), which is still a considerable hike from rates set for energy produced by conventional power sources. However, as technologies improve and become less costly, solar energy installations can in the future be expected to take their deserved place in the energy sector.

2. WIND ENERGY

A description of wind as an energy source will require a combination of aerological and energy characteristics of wind unified into a concept of wind power cadastre. These cadastral characteristics include [5,13]: average annual wind speed; annual and daily wind cycle; recurrence rate of wind speeds; recurrence rate of wind directions; maximum wind speed; specific wind intensity and specific wind power; and wind power resources of a particular area.

The main source of initial data to be compiled into a wind power cadastre is observations of wind speeds carried out by the basic network of a weather service. These observations, performed several times throughout the day, cover periods of time spanning over decades and therefore represent ample factual material. The advantage offered by such surveys is that they are conducted using a globally accepted array of methods, while the surveillance sites fall into specific categories according to the particular degree to which each can be viewed as an open-air area.

2.1. Average wind speeds

Average annual wind speeds. Data on average annual wind speeds serve as a basic parameter to determine global wind intensity. Using information on the average annual wind speeds can, as a first approximation, give analysts a basic idea of the prospects available for the application of wind energy converters (WECs) in a particular area. One has to keep in mind, however, that wind speeds are contingent on the area's land relief, the roughness of the surface, the presence of any features that can shade the surface, and the wind's elevation above the ground. These conditions can vary considerably from one survey station to another. Therefore, an organized look at average wind speeds will necessitate comparing these parameters under commensurable conditions. It seems reasonable to assume as commensurable conditions such as a flat open surface and an elevation equaling 10 meters above the earth.

Results of an analysis of data compiled from a series of wind speed observations carried out at the Kola Peninsula's 37 weather survey stations [6] over a period of 20 years are summarized in Fig. 2.1. The data are analyzed using these commensurable conditions. In order to make the data on average multi-year wind speeds more convenient for practical use, they are represented as a map. This visualization shows that the highest wind speeds can be observed in the coastal areas of the Barents Sea. On the northern coast of the Kola Peninsula, wind speeds reach 7 to 9 m/s. It is worth noting that wind speeds gradually decrease as the focus of survey moves further from the shoreline.

At the same time, average multi-year wind speeds increase significantly as the elevations change to higher levels. Fig. 2.2 demonstrates a correlation between the increase in average multi-year wind speeds and changes in the wind's elevation over the surface from a 10-meter mark to 20, 30, 50, 70, and 100 meters above the ground.

As far as the average annual, or multi-year, wind speeds are concerned, a notice on one other important factor is in order: In the coastal areas of the Kola Peninsula, average annual wind speeds do not experience significant year-to-year changes, and their fluctuations are limited to within 5% to 8%. At the same time, the variation coefficient estimated for the streamflow rates of the region's rivers ranges between 15% and 20%. Thus, seen in a long-term perspective, wind energy exposure in the region is subject to less variability than the energy of streamflow.

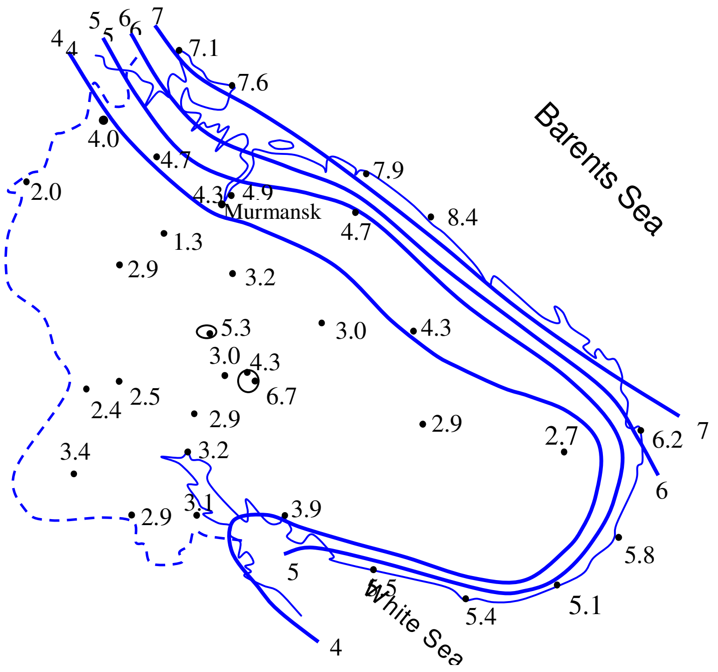


Fig.2.1 Average multi-year wind speeds (m/s) at a 10-meter mark over the ground on a flat open-surface area.

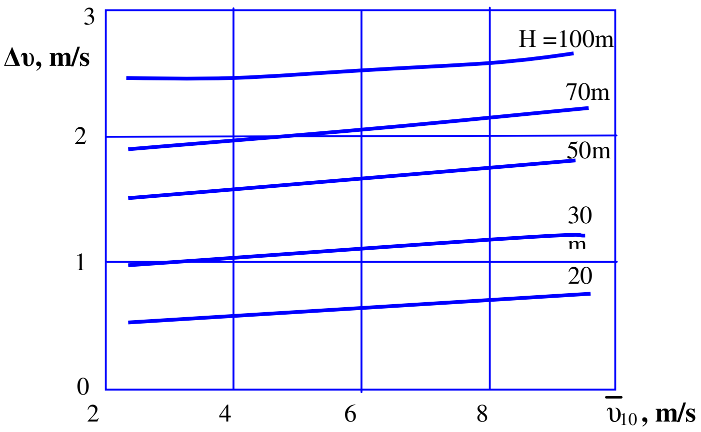


Fig.2.2 Average annual wind speed growth Δυ at wind elevations ranging from 10 m to higher values H.

Annual wind cycle (Fig. 2.3) shows the scope of seasonal variations in the wind's average speed. On the Kola Peninsula, these variations are observed most clearly on the area's northern coast, where the gap between the winter wind speed maximum and the summer wind speed minimum reaches 5 to 6 m/s. The graphs visualizing these data show that in all areas surveyed, rather favorable conditions exist for the 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 in the region. It is notable that the wind speed winter maximum is in antiphase with the annual river flow (Fig. 2.3), that is, wind energy and hydropower can successfully supplement each other. This creates advantageous conditions for a joint application of their resources.

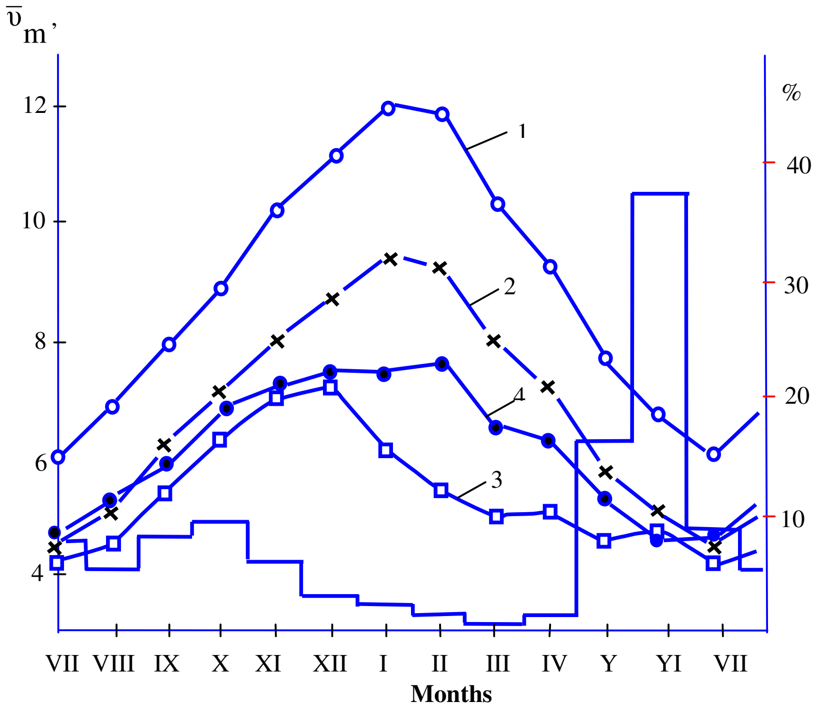


Fig. 2.3 Annual cycle of monthly wind speeds on the islands (1) and in the coastal areas (2) of the Barents Sea, on the coast of the White Sea (3) and in Khibiny (4).
Weather survey stations: 1 - Harlov Island,
2 - Dalniye Zelentsy, 3 - Chavanga, 4 - Central.

Daily wind cycle represents the range of variations in average wind speeds during 24 hours. It is most clearly observed during the summer and is seen little during the winter. In the summer, wind speeds are approximately 1.5 to 2.0 m/s higher during day hours than they are at night. Given the reduced global exposure to wind intensity in the summer, the daily wind speed maximum creates especially favorable prospects for efficient wind energy development, since, as a rule, it is during daytime hours that the consumer's need for energy increases.

2.2 Wind speed and direction frequency.

The recurrence rate of wind speeds shows for how long during a period of time under consideration winds blew at one speed or another. This parameter helps understand how valuable the energy potential of the wind is and reveals the basic energy characteristics that will determine the efficiency and expediency of using this wind as an energy resource.

The practice of wind energy estimations usually requires an approximation of – or leveling out of – wind speed frequency values received empirically, which is done using various analytical correlations. In this context, the two-parameter Weibull equation (14) has acquired the widest recognition. It is suitable for a description of wind speed distribution under the conditions of the Kola Peninsula. Calculations show that the level of concurrence of empirical (factual) and analytical distributions obtained through the Weibull equation is quite high. Fig. 2.4 demonstrates the analytical curves corresponding to wind speed frequencies at differing average annual values (from 4 to 12 m/s). It is obvious that in windier areas, the range of speeds observed is wider, while the share of higher speeds is more significant. The total area encompassed by a curve remains the same for each graph and equals 100% (or 8,760 hours yearly).

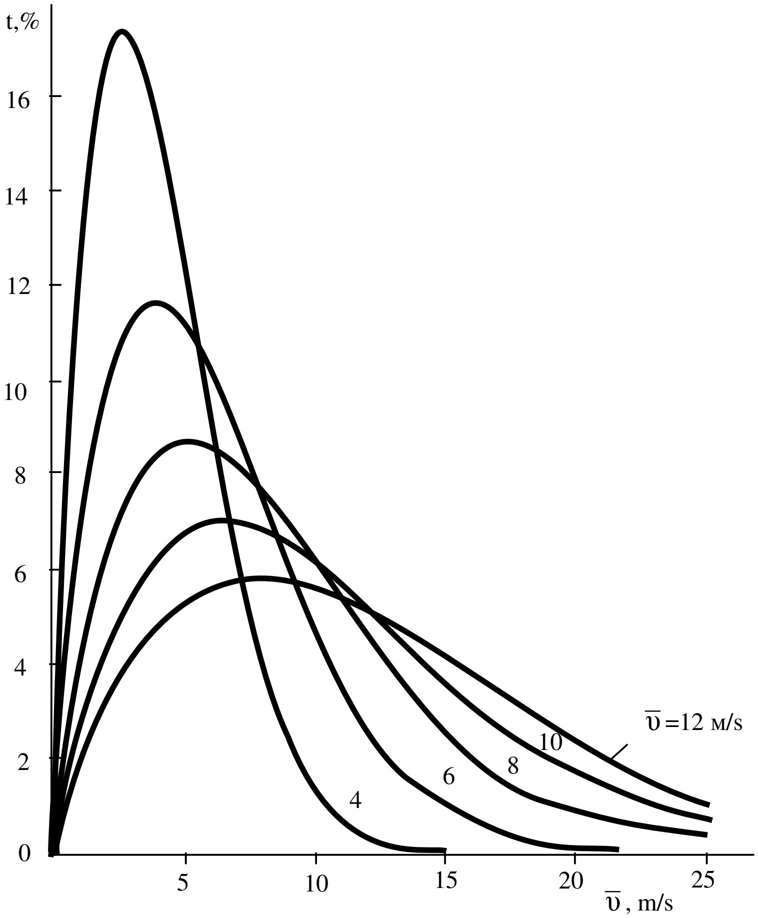


Fig. 2.4 Wind speed frequency curves at different average annual values.

Frequency of wind directions shows for how long during a period of time surveyed – a month or a year – winds blew in a particular direction. A correct registration of wind directions plays a very important role in determining the best location to install a wind power converter in the area in question.

Multi-year wind-related data available in the Climate Reference Book [15], demonstrates that there are areas on the Kola Peninsula which reveal certain prevalences in observed wind directions. These areas include, for instance, the northern coast of the peninsula, where southwest winds account for 50% to 60% of yearly winds. A more detailed research of wind directions in this area – 16 wind directions were studied with consideration given not only to direction frequency, but also to average wind speed for every direction – has allowed for a considerable elaboration on the general picture. Attention was specifically paid to the weather stations at Dalniye Zelentsy and Teriberka. Large wind energy potential can be found in localities around these stations. Furthermore, they are located close to the Serebryanka and Teriberka Hydroelectric Power Plants, which are part of the Kola Energy System and which are capable of facilitating large-scale utilization of wind energy resources in this area. Fig. 2.5 shows the wind rose representing data obtained at the Dalniye Zelentzy weather station across a period of several years, as one example. It clearly demonstrates that southwest winds blow for more than six months of the year.

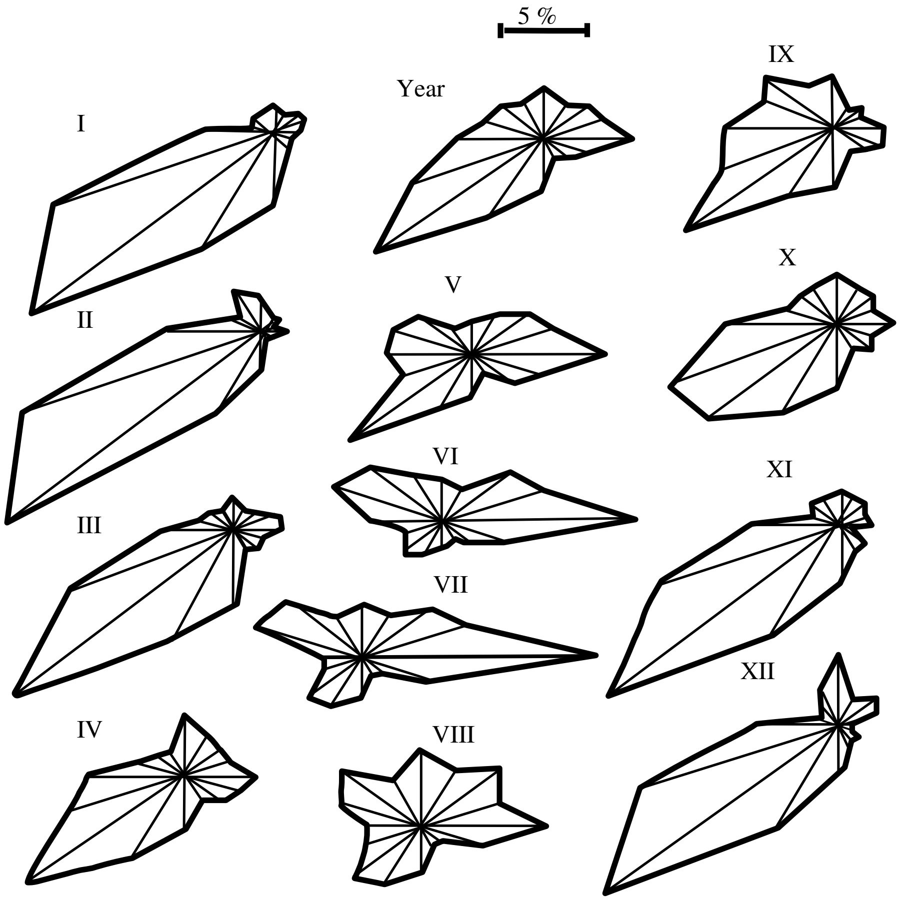


Fig. 2.5 Annual and monthly wind roses at the
Dalniye Zelentsy weather station (data collected from observations of 1975 through 1984).

When analyzing wind direction frequency, it needs to be taken into consideration that, from the point of view of energy efficiency, the importance is placed not so much on the information about which wind directions are prevalent in the area, but on the correct estimation of how much energy value – or potential output – the wind of each particular direction can offer. To assess this value, estimations have been made for the potential output of a wind energy converter on each wind direction, and these estimations have been summarized into corresponding output roses (Fig.2.6). When comparing Figs. 2.5 and 2.6, it becomes obvious that as the graphs for the same months are set against each other in the two pictures, the wind rose and the potential output rose do not have essential differences in their configurations. It means that in the areas observed, prevalent wind directions also have the largest energy capacities.

During the wind direction frequency study, it was also revealed that the wind rose and the factor of prevalence of certain wind directions over others undergo considerable changes depending on the particular season. During the colder months (October through March), southwest winds can account for 70% to 90 % of the time. Winds of these directions have an overwhelming dominance over other winds. The same can be said about energy generation available from winds of these directions (Fig.2.6). During warmer seasons, the picture will alter radically: These dominant winds will become less obvious, or change direction completely, and with a decrease observed in the total wind intensity, the scope of potential energy output will also diminish. The latter is clearly seen in the dimensions of the roses presented in the pictures, which are proportional to the monthly potential energy generation values.

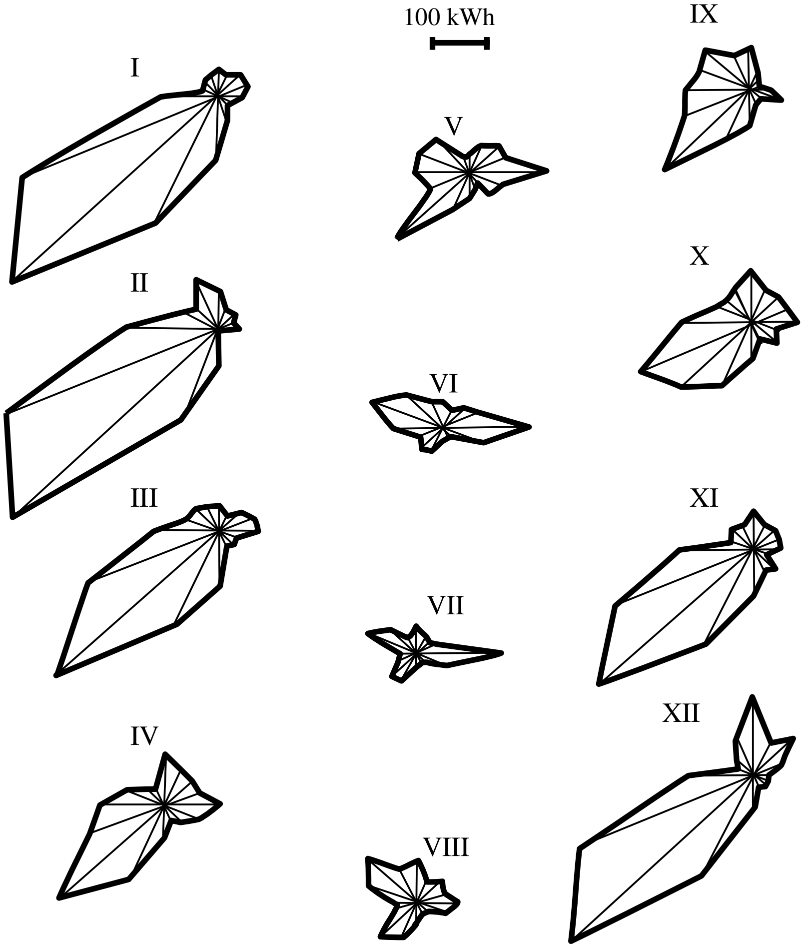


Fig.2.6 Monthly energy output roses, as estimated for the production by a 4 kW wind energy converter in the area surrounding Dalniye Zelentsy.

The presence of prevailing wind directions makes it possible to locate wind energy converters in a particular area in a more space- and cost-efficient way as far as the construction of multi-outfit wind power complexes and stations is concerned. Thus, if in the area surrounding Dalniye Zelentsy, wind energy converters are arranged in several rows at an interval of one single wind wheel diameter, and their facades are adjusted to face the prevailing wind direction, then it will be possible to avoid their blocking, or creating interference with, each other’s wind exposures for 92% of the year. During the winter, this interference-free exposure coefficient can increase to 96% - 97%. Losses in energy output in the case of such compact WEC arrangement are minimal and come to around 6% a year, with their decrease during certain winter months reaching as low as 2.5% to 3%. At the same time, the benefit is apparent when construction of new access roads or cable lines is taken into consideration. This area has definite prospects for the construction of multi-turbine wind parks.

2.3. Maximum wind speeds

Data on maximum wind speeds are an important component of a wind energy cadastre. They are necessary to calculate the strength of particular outfits or parts of a wind energy converter, like towers, blades, wind orientation weathercocks, etc. Any error made in the estimations of maximum wind speeds can result in either excess ruggedness of the structures – and thus, their increased weight – or, vice versa, installations that are insufficiently strong and suffer destruction as a consequence.

The assessment of maximum speeds is based on the results of surveys performed in the previous years and is, in essence, a prognostication of future wind speeds. In applied climatology, it is acceptable to refer to a maximum wind speed as a speed which is capable of occurring once in a given number of years.

The results of surveys studying maximum wind speeds on the Kola Peninsula have shown that the highest values can be observed on the coast of the Barents Sea and in the mountains of Khibiny. In these locations, maximum wind speeds can reach 45 m/s and 48 m/s respectively, during a wind gust (with an average interval of three seconds) once in ten years.

At higher elevations, even higher wind speeds are possible. This is proven by the results of atmospheric probes done at upper-air synoptic stations. However, winds at these elevations have lower gustiness. At the height of 100 meters, wind speed in a gust can reach 49 m/s to 50 m/s every ten years. When the frequency factor is raised from once in ten to once in 20 years, maximum wind speed values grow to between 50 m/s and 52 m/s at a 10m elevation mark and up to between 52 m/s and 55 m/s at a height of 100m.

2.4. Technical wind energy resources of the region

Wind flow intensity is proportional to the density of air, the overall area of the flow's cross-section and the value of wind speed to the power of three. Because it is a function of the cube of the wind speed, wind power is extremely variable and fluctuates within very wide ranges.

Average annual specific wind energy – or energy that flows within one year through one square meter of a cross section – is an integral, or averaging, value. It is also contingent on wind speed frequency, that is, on how long during the year the wind blew at one speed or another.

Fig. 2.7. exemplifies how the total annual specific wind energy value is computed (the area encompassed by the curve of W_{sp}) in the wind conditions of the coast of the Barents Sea at the average annual wind speed of $\bar{\upsilon} = 8$ m/s. Because of the third-power relationship between wind power and wind speed, the biggest contribution to the total wind energy value is made not by the most frequently observed wind speeds and not even by the average wind speeds, but by speeds that exceed the latter by 1.7 to 1.9 times.

When one has all necessary data on the average annual wind speeds (Fig.2.1), the vertical wind profile (Fig. 2.2), and the wind speed frequency (Fig.2.4), one can derive an energy pattern of a particular wind flow in any location and at any wind elevation on the Kola Peninsula.

When assessing energy resources, consideration is usually given specifically to potential, technical and economic resources. Potential wind energy resources are understood to be the total energy of the movement of air mass as it travels over a given area within one year's time.

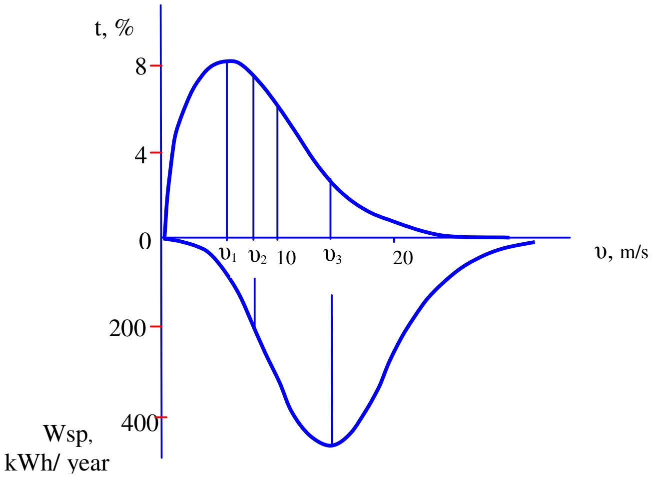


Fig. 2.7. Wind speed frequency t and distribution of specific annual energy W_{sp} on the coast of the Barents Sea at $\bar{\upsilon}$ equaling 8m/s

υ_1 - speed most frequently observed;
υ_2 - average wind speed;
υ_3 – speed that contributes most into annual energy production

Technical wind energy resources refer to that part of the potential resources which can be put to use with the help of technical means available to date. They are determined with considerations allowing for the unavoidable losses when wind energy is converted into power.

According to the so-called ideal wind wheel theory, only that part of energy which passes through the wind wheel's cross section can be converted into net work. Net energy maximum is reached when the wind energy conversion coefficient ξmax equals 0.593. Today, the wind energy conversion coefficient offered by best national and foreign-made wind wheel models is capable of reaching values ranging between 0.45 and 0.48.

Furthermore, practice shows that existing wind energy converter models are not sophisticated enough to be able to employ the whole range of wind speeds. Under speeds below a minimal level, the operating capacity of the wind wheel is not sufficient to even overcome the friction load in the WEC's assembly units. Wind energy is used to its current achievable maximum within the speed range spanning between the minimal operating speed and the design-based speed, where the WEC can develop its installed capacity. As wind power further intensifies, including reaching a maximum operating speed, the converter's capacity is kept at a consistent level with the help of regulating devices. Finally, when wind speed exceeds a maximum operating speed, the WEC is taken out of operation to avoid damaging the installation.

The results of calculations of technical wind energy resources of the Kola Peninsula are shown in Table 2.1. The technical resources were estimated in accordance with four different areas of the peninsula, which had been defined by the different levels of a multi-year wind speed average $\bar{\upsilon}_{10}$ at an elevation of ten meters (Fig. 2.1.). In the first area, the $\bar{\upsilon}_{10}$ is less than 7 m/s; in the second, it fluctuates between 6 m/s and 7 m/s; in the third, the range is between 5 m/s and 6 m/s, and in the fourth it is between 4 m/s and 5 m/s. A design-based wind speed – a speed, at which a WEC develops its nominal capacity – was determined for every area based on 3,000 hours' worth of supply of energy consumption per year out of the installed capacity. Table 2.1. demonstrates that if a "dense forest" of windmills is built in these areas at a step of ten wind wheel diameters from each other, then the total installed capacity of the WECs will reach around 120 million kW, while the annual power output - or the technical wind power resources – will total about 360 TWh.

These estimations are evidence that the Kola Peninsula has at its disposal enormous wind power resources; they exceed greatly the electric power demands that the region currently has.

Application of the accessible part of these resources, and their inclusion into the peninsula's economy, absolutely deserves attention as an objective to be pursued by the region.

Table 2.1.

Wind resources of the Kola Peninsula at the ground-air interface, elevations within 100 m.

Parameter, name	Area				Total
	1	2	3	4	
Average annual wind speed in the area, m/s					
at 10 m	7.5	6.5	5.5	4.5	
at 70 m	9.6	8.6	7.5	6.5	
Specific wind energy, MWh/(m^2/year)					
at 10 m	5.2	3.4	2.4	1.4	
at 70 m	10.7	7.8	5.2	3.4	
Average annual specific wind power, kW/m^2					
at 10 m	0.59	0.39	0.27	0.16	
at 70 m	1.22	0.89	0.59	0.39	
Estimated wind speed, m/s					
at 10 m	12.3	10.4	8.5	7.6	
at 70 m	15.7	13.8	11.6	11.0	
WEC capacity per 1 km^2 of the area, MW	7.2	4.9	2.9	1.9	
WEC annual output per 1 km^2, million kWh	21.6	14.7	8.7	5.7	
Hours of installed capacity use per year	3,000	3,000	3,000	3,000	
Area size, thousands of km^2	3.5	5.9	9.4	20.7	39.5
WEC capacity in the area, thousands MW	25	29	27	39	120
Technical wind energy resources, TWh	75	87	81	117	360

2.5 Types of wind power installations

Historically, the first stationary installation that used the energy of wind was the windmill, for which wind orientation was performed manually. The windmill's main operating component was a multi-blade wheel with a horizontal rotation axis, which was oriented along the current wind direction. Such wind engines were widely used in the Middle Ages and henceforth for grain milling, water pumping and water delivery, as well as to supply energy for other production uses. Large industrial-type windmills could develop capacities of up to 60 kW at high wind speeds. In the 19th century, the number of windmills on Russian territory exceeded 200,000, and their total capacity was around 1.3 million kW. By 1930, the USSR already had over 800,000 wind power converters.

Today, the windmill has evolved into a whole range of different types of wind energy converters. Wind-driven energy converters with impeller-fitted wind wheels and horizontal rotation axes (Fig.2.8) have received wide recognition. Most developed among these are two-blade and three-blade wind wheels. The torque of the wind wheel is produced by a lifting force that is created when air flow streams around the profile of the blade. As a result, the kinetic energy of the air flow within the area swept by the blades is converted into the mechanical energy of the wind wheel rotation.

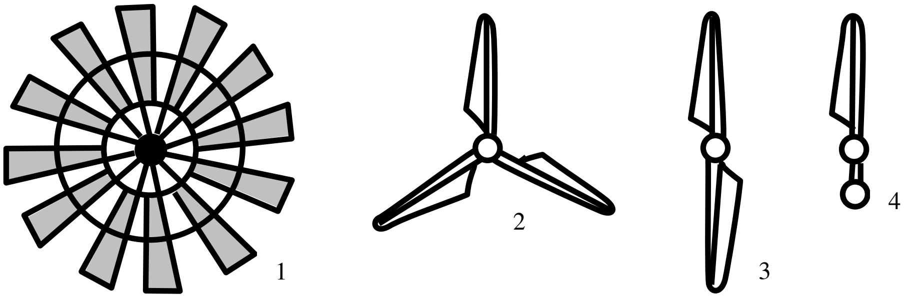


Fig. 2.8. Impeller wind wheels
1- multi-blade, 2 - three-blade,
3 - two-blade, 4 - single-blade with counterbalance.

Power capacity developed on the wind wheel axis is proportional to the square of its diameter value and the wind speed to the power of three. According to the classical theory by Nikolai Zhukovsky, the ideal wind wheel will be defined by the wind energy conversion coefficient ξ equaling 0.593. In other words, an ideal wind wheel – where the number of wheel blades is indefinite – will retrieve an output of 59.3% out of total energy passing through its cross section. In real life, however, best high-speed wheels can achieve a maximum wind energy conversion coefficient of between 0.45 and 0.48; while for low-speed wheels this coefficient only reaches between 0.36 and 0.38.

Specific wheel speed Z is an important parameter for the wind wheel. It is the ratio of the blade tip rotation speed to the speed of wind flow and is also called “tip speed ratio”: The tip of the blade usually moves along the plane of the wind wheel at a speed several times exceeding that of the wind. The optimal values for the tip speed ratios of various rotors are: 5 to 7 for a two-blade, 4 to 5 for a three-blade, and 2.5 to 3.5 for a six-blade.

Among design features that can impact a wind wheel’s capacity, the wheel’s diameter and the shape and profile of the blades have most significance. The number of blades is not too essential for the wheel’s power output. The wind wheel’s rotation frequency is proportional to its tip speed ratio and the speed of wind, and is inversely proportional to its diameter. The height of the wheel axis location also plays a role in how big a capacity value the wheel can achieve, since wind speeds correlate with wind elevations.

Wind energy converter capacity, as was noted above, is proportional to the wind speed to the power of three. With wind speeds equaling the design-based speed, or exceeding it, the WEC operates at a nominal capacity. When wind speeds fall below the design-based speed, the WEC’s capacity is limited to only 20% to 30% of the nominal value, if that. Such operation conditions lead to big energy losses in the generators due to their low efficiency rates at low loads. Furthermore, in the asynchronous generators, such conditions result in big reactive currents, which have to be compensated for. To eliminate this drawback, certain wind energy converters are outfitted with two generators: one with a nominal capacity of 100% and another operating at 20% to 30% of the nominal capacity of the WEC. Under breeze conditions, the smaller generator is switched on, while the 100%-capacity generator is switched off. In some wind energy converters, the smaller generator allows for the installation’s operation at low wind speeds and at reduced rotation speeds, while the wind energy conversion coefficient remains high.

The wind-facing orientation of the wind wheel – or when the wheel’s rotation plane is perpendicular to the wind direction – is done in installations with extreme low capacities with the help of a tail, or tail fins; in medium-capacity converters, the orientation is changed by a wind rose mechanism; and in large up-to-date installations, special orientation systems do the task as they receive the driving impulse from a wind direction sensor, or wind vane, fixed on top of the wind turbine's gondola. The wind rose mechanism is one or two medium-sized wind wheels, which rotate in a plane that is perpendicular to the plane of rotation of the main wind wheel and drive the worm gear, which turns the platform of the windmill headpiece, or gondola, until the wind roses are set in the plane parallel to the wind direction.

Horizontal-axis rotors can be installed either in front or behind the tower. If the latter is the case, the blade is subject to consistent and repeated impact of variable forces when moving through the shadow of the tower, which at the same time increases considerably the levels of noise. To regulate capacity and limit the wind wheel rotation frequency, a number of methods are applied, including spinning the blade or its part around its roll axis, as well as blade flaps, blade valves and other means.

The main advantage of horizontal-axis wind rotors is the consistent condition of a streamline motion of air flow around the blades, which does not change with the wind wheel's rotation, but depends only on the speed of the wind. Because of this, as well as the considerably high coefficient of wind energy conversion, horizontal-axis types of wind energy converters have now become most popular.

The Savonius rotor (Fig. 2.9.) is another type of wind wheel. Torque is obtained through airflow created by the difference between resistances of the convex and concave parts of the rotor. The rotor's advantage is its simplicity, but it has a very low coefficient of wind energy conversion: only 0.1 to 0.15.

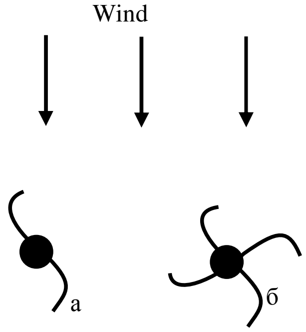


Fig. 2.9. The Savonius rotor
a) - two-bladed, b) - four-bladed

In recent years, studies in certain countries, specifically Canada, have been focused on the development of a wind engine employing the so-called Darrieus rotor, which was proposed in France in 1920. This is a vertical-axis rotor, which consists of two to four curved blades (Fig. 2.10). These airfoils form a spatial framework, which rotates from the impulse of lifting forces created at the blade by the flow of wind. The Darrieus rotor is capable of reaching a wind energy conversion efficiency of 0.30 to 0.35. Lately, designers have been working on developing a straight-blade (Gyromill design) Darrieus rotor (Fig. 2.10. b, c). The main advantage of Darrieus wind turbines is that they do not need a wind-orienting mechanism. In such wind energy converters, the generator and other mechanisms are located at an insignificant height, close to the installation's base. This simplifies the construction greatly. However, a serious inherent disadvantage of such engines is that airflow conditions can vary considerably within one rotation period, and this variation is cyclically repeated under operation. This can cause a fatigue effect and result in destruction of the rotor's components and serious accidents, which have to be taken into consideration when the rotor is mounted (especially when large WEC capacities are concerned). Furthermore, the rotor needs to have a spin-up to enter into operation mode.

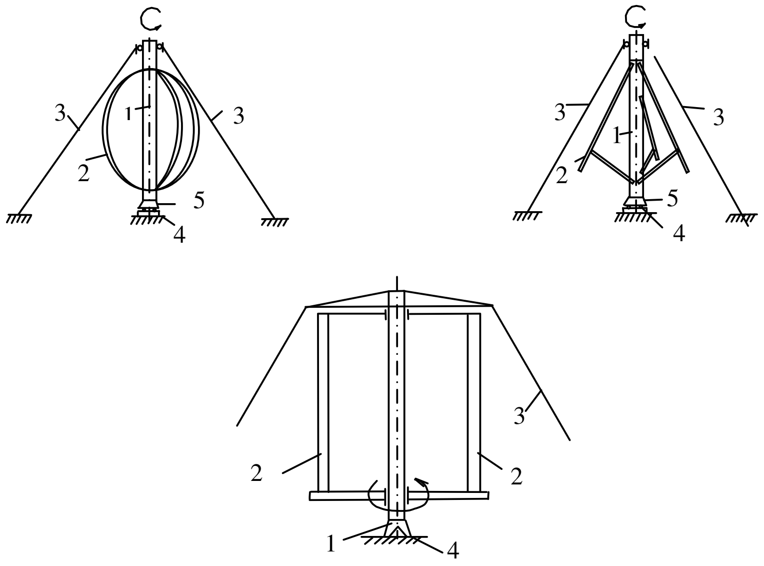


Fig. 2.10. Wind energy converters with the Darrieus vertical-axis turbine: a - Egg-beater (troposkein) design, b - Helical blades, c - Gyromill (H-bar) design.
1 - tower, 2 - rotor, 3 - braces, 4 - frame, 5 - torque

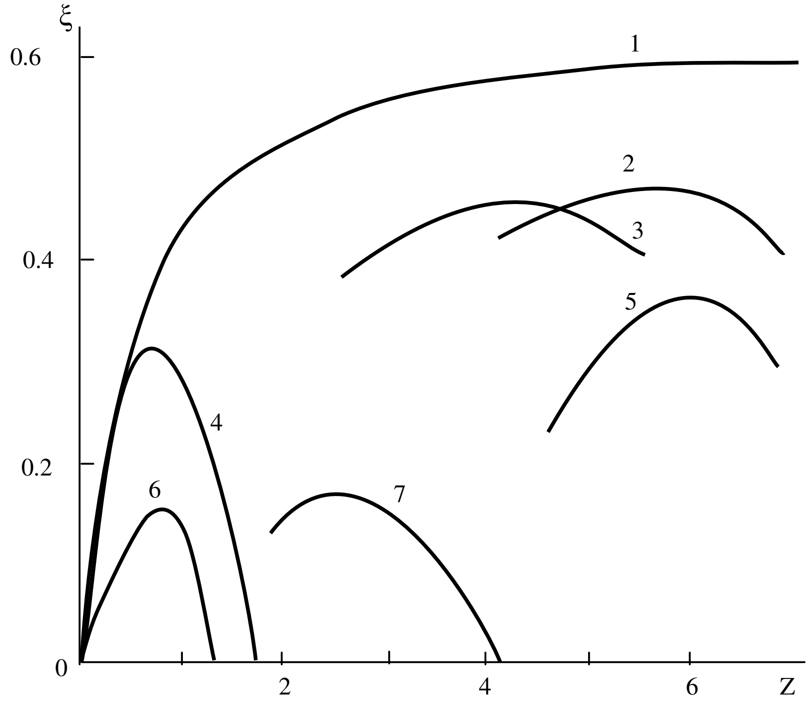


Fig. 2.11. Rotor-type-specific dependence of wind energy conversion coefficient ξ on tip speed ratio Z
1 - ideal blade wind rotor;
2,3 and 4 - two-, three- and multi-blade rotors;
5 - the Darrieus rotor; 6 – the Savonius rotor;
7 - the four-blade rotor of the Danish mill.

Correlations between wind energy conversion efficiency ξ and tip speed ratio Z for different rotor types are demonstrated in Fig. 2.11. It is evident from the diagram that two- and three-blade rotors with a horizontal rotation axis have the highest ξ value. For these rotors, ξ remains high within a wide range of tip speed ratio Z. The latter is especially important since wind energy converters have to operate under widely variable wind speeds. This is why installations of this type have received global recognition in recent years.

2.6. Wind energy application trends

Electric power supply of remote decentralized consumers. The majority of industrial enterprises, cities, and settlements of the Murmansk region receive their energy from the grid of Kola Energy System. Contrary to these users, a large number of remote consumers in the area – small secluded settlements and villages, weather stations, beacons, border patrol quarters, and sites of the Russian Northern Fleet – are isolated from the grid and receive energy from independent diesel power plants (DPPs). The capacity of a DPP ranges between 8 to 16 kW and 300 to 500 kW. The total number of such installations in the region numbers a few dozen.

Because of their decentralization and significant distance to grid-based energy sources, as well as their relatively low power consumption, plugging remote consumers into the central power supply is economically inexpedient. This is why diesel power stations will remain the only energy suppliers for these consumers in the foreseeable future.

A DPP's operation involves considerable costs incurred from burning expensive fuel. Diesel fuel prices are high not only because the fuel is of better quality than fuel oil, but also because its transportation is quite costly.

For instance, the coasts of the Barents and White Seas receive their diesel fuel deliveries by sea. Sea-going oil tankers unload fuel to coastal settlements as they cruise along the shoreline. If no berths can be used for unloading operations, the tankers are unloaded at offshore terminals with the help of small-size vessels. Transportation from the coastline to areas located further from the shore is performed by motor vehicles, tractors, sledge trains, and sometimes by air.

Due to the remoteness of these locations and their poor transport arteries, fuel prices increase by 30% to 70% in the coastal areas of the Kola Peninsula and by 150% to 200%, or even higher, in the more inaccessible inland areas.

Under these conditions, the use of wind energy converters can provide a sizable contribution to cutting high diesel fuel expenses. The degree of economizing depends on local wind potential and the diesel power station's operating load. According to estimations, a wind energy converter operating in an area with favorable wind conditions can replace between 30% and 50% – and in the windiest places, up to 60% or 70% – of the hard-to-obtain fossil fuel. In the long run, introducing WECs will allow for a reduction in the total costs of producing and consuming electric energy.

Wind energy converters' contribution to heat supply. The implication here is the potential use of WECs for the supply of heating to small towns and villages in windy areas that have centralized power supply, but experience difficulties with fuel deliveries. These are the favorable conditions that may warrant such application of wind energy converters:

1. Heating season in the Kola Peninsula lasts for nine months. That said, wind speeds in the winter are noticeably higher than in the summer. The peak in seasonal heat energy demand thus coincides with the energy output a WEC can provide.

2. After outdoor air temperature, wind is known to be the second classic parameter that determines the scope of heat consumption in a region. Application of WECs will allow transforming wind from a climatic factor contributing to increased heat losses into a full-fledged

power source that will provide effective coverage of the population's needs in heating energy exactly during windy periods.

3. It goes for most energy users that the share of heat consumption in their total energy usage is rather high – sometimes, reaching between 70% and 90%. With that in mind, WEC application will facilitate saving on expensive fuel, which has to be transported to the Kola Peninsula from as far as 1,500 to 2,000 kilometers.

4. Using wind power for heating purposes does not necessitate high quality requirements for the energy produced by a WEC. This allows for a simplification of WEC designs, making the installations cheaper and more reliable at the same time.

5. WEC application for heating purposes also provides the possibility to successfully withstand the main challenge of wind energy: the instability of wind exposure and, by extension, power production. Short-term fluctuations of the WEC's capacity – those that last for seconds or minutes at a time – are evened out by the accumulating ability of the heating supply system. Prolonged fluctuations, which last over 20 minutes to several hours, can be leveled out by heat reserves accumulated in the buildings that receive the heating. Special accumulating systems or auxiliary heating sources running on fossil fuels can be switched on during longer wind pauses.

Fig. 2.12 demonstrates the correlation between increasing heat losses of a building and the speed of wind. It is clear that heat losses almost double as wind speeds grow. This correspondence, as well as the multi-year data on average daily outdoor temperatures and wind speeds, was used to compile a diagram of seasonal heat consumption variations under the conditions of the Barents Sea coast (Fig. 2.13). As follows from the diagram, wind increases heat consumption dramatically. During the winter months, this increase reaches 30%. At the same time, one notes the synchronicity of seasonal changes in average levels of windiness (that is, average monthly wind speed V_m) and the changes in heating demand. This also can serve as an important premise for the application of wind as a heat energy source.

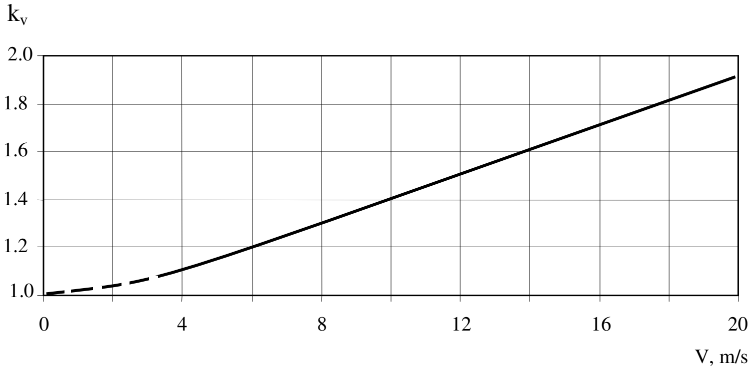


Fig. 2.12. Proportionate correspondence between housing heat losses and wind speeds.

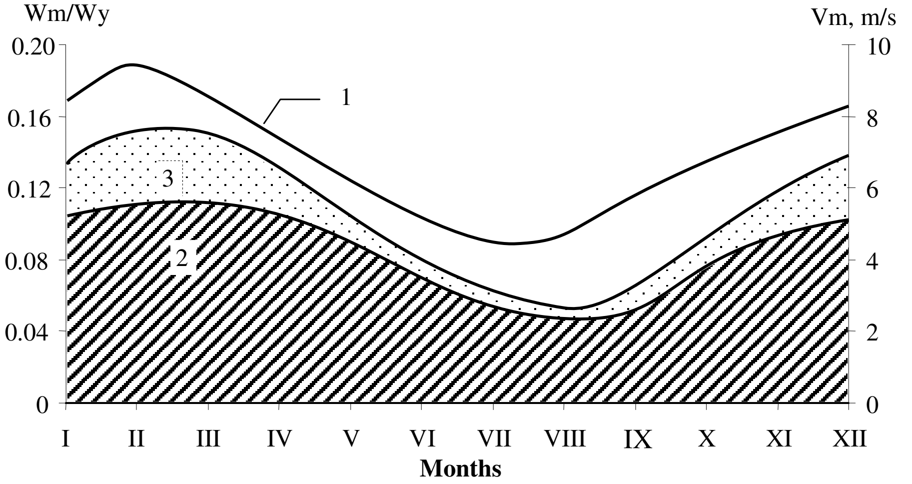


Fig. 2.13. Seasonal changes in average monthly wind speed (1) and heat consumption, contingent on outdoor air temperatures (2) and wind (3), on the northern coast of the Kola Peninsula.

Heat energy demand of a building or a group of buildings is determined by the following expression:

$$Q = qVc_w(t_r - t_o) \tag{2.1}$$

where:

q is the specific heat parameter of the building, kW/m^3·degrees;

V is the exterior volume of the heated building, m^3;

C_W is the coefficient of increasing heat losses caused by wind (Fig. 2.12.);

and t_r and t_o are room and outdoor air temperatures, degrees Celsius.

The volume and heat parameter of the building are constant values, which is why heat consumption depends primarily on the room and outdoor temperatures differential $\Delta t = t_r - t_o$ and on the allowance for wind counted in the heat loss coefficient C_w.

If heating supply is provided by the boiler house in conjunction with a wind energy converter of commensurable capacity, then a certain part of the heating load schedule will be covered by the WEC, and the rest by the boiler. During especially windy periods, the WEC can cover heating needs to a considerable extent, completely, or even produce excess heat energy. As for periods of cold, but less windy weather, almost all the heating load will depend on the boilers.

All the above can be seen in Fig. 2.14., which represents a fragment of the chronological cycle of a WEC's potential contribution into the heating load supply. These calculations provide for cases when WEC capacity equals that of the boiler house: $\beta^T = N_{wec}/N_b = 1$, where N_{wec} is the wind energy converter's capacity and N_b is the capacity of the boiler house. The red black-dotted curve represents variations in heat demand at room temperature t_r equaling $+20^0$C under windless conditions.

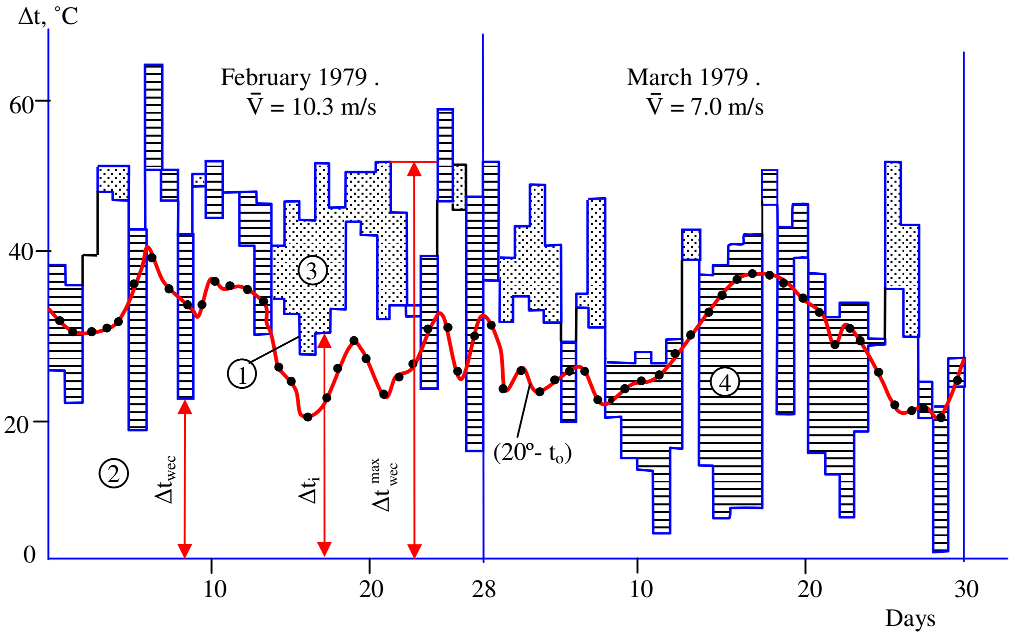


Fig. 2.14. Fragment of the chronological cycle of a WEC's potential contribution into the heating load coverage. Wind field of the Kola Scientific Center of the Russian Academy of Sciences at Dalniye Zelentsy,

1 – heating load curve, 2 – net utilized WEC power,

3 – excess WEC-produced energy, 4 – power produced by the boiler house

Taking the impact of wind into consideration, the real heat consumption curve will be higher (the stronger the wind, the higher it is). In the picture, it is represented by lattice line 1. In reality, energy offered by a WEC will rarely coincide exactly with the demand on the part of the energy user. It will happen more often that either the WEC's energy output, represented in Fig. 2.14.by Position 2, will exceed demand and create excess energy (Position 3), or there will be a lack of energy needed to fully cover demand, and the hatched area of the load diagram (Position 4) will have to be covered by the boiler.

The share α^h provided by a WEC in consumer heating supply will be expressed as the quotient of the consumed yield of the WEC, integrated into the load curve, to the entire heat consumption volume. Synchronous analyses of data on outdoor temperatures (and, by extension, on heating demand) and on wind (energy offered by the WEC) have shown that the value of α^h depends on the capacity of WEC N_{wec}, wind conditions (average annual wind speed $\overline{V}_y$), technical parameters of the WEC (design speed V_d, at which the installation develops its design-based capacity N_{wec}), and the correlation between the capacity of WEC and that of the boiler ($\beta^T = N_{wec}/N_b$).

Analytically, the dependence of α^h on these factors is approximated by the following expression:

$$\alpha^{h} = 1 - \frac{1}{\exp\left[3.2\left(\frac{\overline{V}_{y}}{V_{d}}\right)^{2}\beta^{T}\right]} \qquad (2.2)$$

The graphic illustration of this dependence is provided in Fig. 2.15. It demonstrates that all other parts of the equation remaining the same, an increase in WEC capacity parameter β^{T})leads to an increase of α^{h} as well, but this process is soon saturated. It reaches its limit, after which further growth in WEC capacity N_{wec} is economically inexpedient due to a need for excessive investment funds. Estimations conducted with regard to the wind conditions of the coast of the Barents Sea, have shown that a value within the range of 0.5 to 0.7 of a boiler's capacity is optimal for the capacity envisioned for a wind energy converter. At the same time, the wind energy converter is capable of taking on the equivalent of 50% to 70% of the output provided by the fossil fuel that the boiler house runs on.

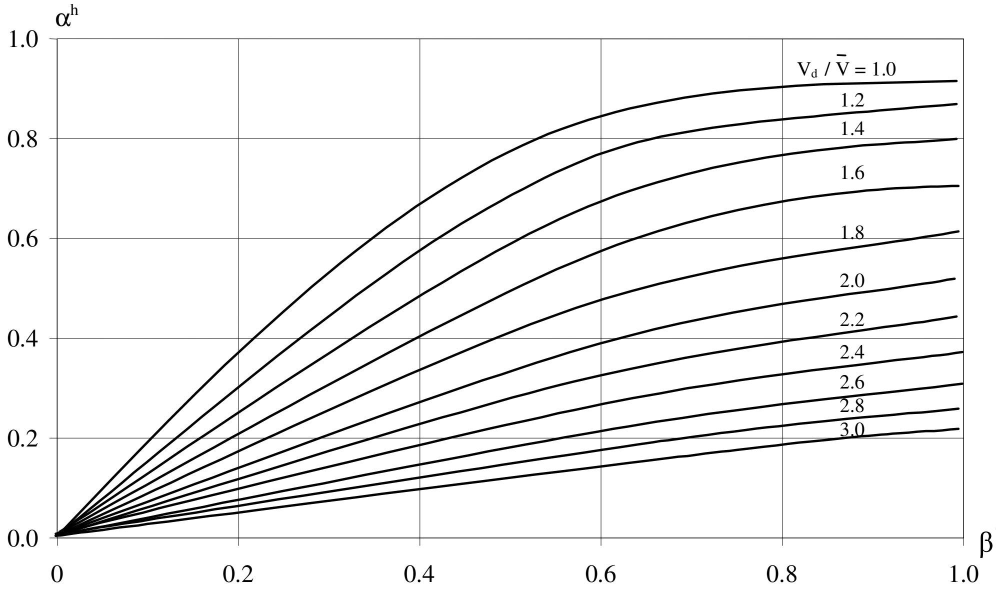


Fig. 2.15. Dependence of WEC share in the heating load coverage on the correlation of capacities $\beta^{T} = N_{wec}/N_{b}$

The efficiency of wind energy application for heating needs can be increased by the use of heat accumulating systems which allow for the diligent conservation and timely and effective use of regularly occurring wind energy excesses, instead of discarding them as unnecessary energy. As a result, WEC contribution to heating supply increases in the winter by 5% to 10 %, and by as much as 20% to 25% during the cool northern summer. Heat accumulation makes it possible to avoid frequent use of the boiler houses. This facilitates the simplification of the heating system maintenance and relieves the burden of operation costs.

Large-scale application of WECs as part of the grid. Europe has accumulated considerable experience in using wind farms as part of national power systems. In Denmark, Germany, and Spain, the total capacity of wind parks numbers millions of kilowatts. One should keep in mind that large-scale wind energy development requires the absolute presence in the power system of other capacities that can provide the necessary flexibility: hydraulic, gas-turbine or pumped-storage power plants. The prospects for large-scale system-integrated wind power development in the Murmansk region are as impressive as in the countries mentioned. There are a range of factors facilitating the wide-scale inclusion of wind resources into the electric and heat energy balance of the region. Among these factors are: high wind potential, which makes it possible to expect bigger WEC output than in Germany or Denmark; winter wind power maximum, which coincides with the seasonal peak in power demand; the availability in the Kola Energy System of 17 hydroelectric power plants with a total capacity of 1,600 MW (including over 1,000 MW near the shoreline of the Barents Sea) and reservoirs with multi-year, seasonal and daily regulation, which will allow for accumulation of water reserves with the help of WECs during windy periods, and the use of this water when winds slacken. It is exactly the hydropower plants at the disposal of the Kola Peninsula that can create unique conditions for a wide-scale wind energy application.

Common sense dictates that system-integrated wind power industry is best to be developed first of all in areas with high wind potential, availability of roads for WEC delivery, and potential connection to the grid. It is preferable that such an area is located close to an existing hydropower plant or one under construction. In the Murmansk region, for instance, all these conditions are applicable to the area of the Serebryanka and Teriberka hydropower plant cascades [6, 16]. This is an approximately square area of 40 kilometers wide and just as long, at the top of which one will find the settlements of Teriberka and Dalniye Zelentsy, as well as the Serebryanka-1 Hydroelectric Power Plant and the 81st kilometer of the Murmansk-Tumanny highway (the Teriberka Exit). Estimations show if WECs are placed within a 3% area of this region – and they are installed in an efficient way that takes the local wind rose into account – then their total capacity will reach about 500 MW.

Power produced by the prospective wind parks of the Murmansk region can be transferred through existing transmission lines under a voltage of 150 kV or 330 kV. To prevent transmission overload, energy transmission can be performed under a compensation policy of sorts: Hydropower plant capacity will decrease during prolonged high wind periods. Thanks to such compensation, hydropower plants' reservoirs can accumulate additional water reserves, transmission lines are not overloaded, and the "wind parks plus hydropower plants" system acquires fundamental operational characteristics. Furthermore, transmission lines receive a steadier load, which improves their economic efficiency.

2.7. Feasible sites for wind parks

Wind parks with a 10 MW capacity in the Teriberka area. When choosing the site for a future wind farm, a location must be found with an area of high wind potential. It should also ensure lower costs for the development of necessary infrastructure and construction of access roads, employees' residential areas and storage sites for mounting gear. The wind farm site should also be located as close as possible to a high-voltage substation to reduce the costs of the farm's connection to the grid.

From the point of view of perceived wind intensity, hill summits seem to be the best locations to install wind power converters. In practice, however, priority is often given to flat open areas with somewhat worse wind conditions but more favorable relief, which both simplifies construction of access ways and WEC installation and makes them considerably cheaper.

Wind park near the settlement of Lodeinoye. The site located close to the settlement of Lodeinoye (three kilometers away from Teriberka) is suggested for several reasons: It is well within an area of high wind speeds, has sea and motor transport connection to Murmansk, infrastructure, and can avail itself of a connection to the Kola Energy System's grid. Here, average annual wind speed at a 10-meter elevation mark reaches about 7.0 m/s. Fig. 2.16 shows a map where a relatively flat area suitable for WEC construction can be seen north of Lodeinoye's residential buildings along the coast of the Barents Sea. At present, the only building at this site is a small structure housing a weather station.

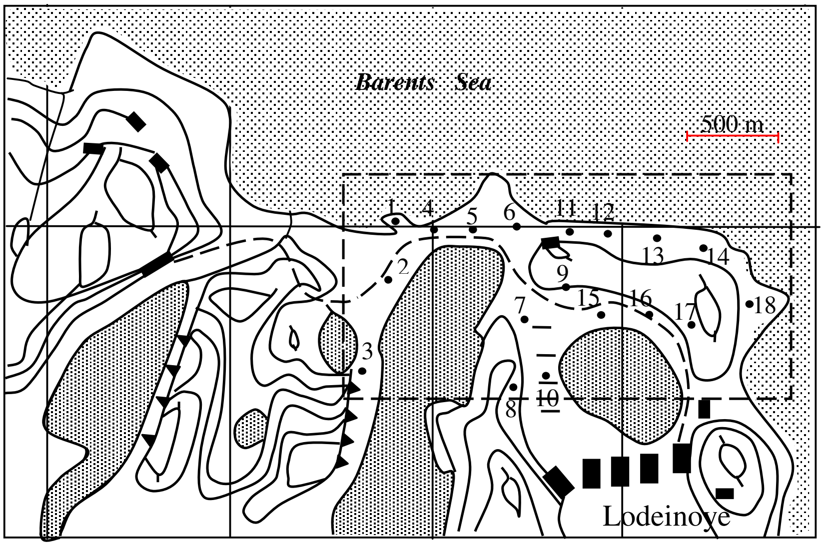


Fig. 2.16. Index map with distributed locations of eighteen 600 kW windmills in a prospective wind park site close to Lodeinoye; the rectangle ⬚ indicates the site.

The site is roughly a rectangle stretching two kilometers west to east and one kilometer south to north. It is foreseeable that infrastructure development will require minimal work here as a dirt road already crosses the site. The area can accommodate several wind energy converters with a total capacity of up to 10 MW. A transformer substation suitable for the wind park's grid connection is located three kilometers away from the site.

The Lodeinoye wind park can comprise a series of up-to-date wind energy converters with capacities ranging between 500 kW and 600 kW. One example is Enercon E – 40/6.44 with a wind rotor 44 meters in diameter and a tower 50 meters high. This is a modern high-efficiency direct-drive windmill manufactured in Germany. A truck crane with a 100-ton lifting capacity will be required for the mounting works on the WEC. As the local wind rose (Fig. 2.17) shows prevailing south wind directions, the wind energy converters can be installed at a distance of ten wind wheel diameters along the line of longitude, and at a distance of three to four rotor diameters from each other in the latitudinal direction. The distribution of the eighteen prospective windmills with a total capacity of 10.8 MW in exactly this pattern is shown in Fig. 2.16

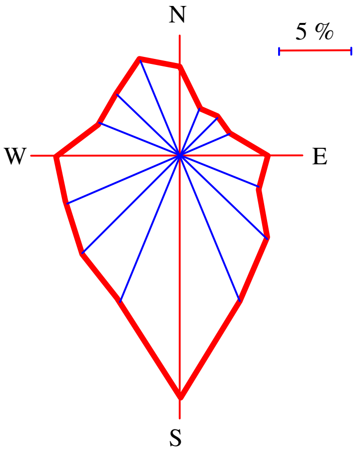


Fig. 2.17. Annual wind rose of the Teriberka weather station.

Wind park site on the bank of the Teriberka Water Storage Reservoir. This site is located 4 km from the Upper Teriberka Hydroelectric Power Plant at the elevation marks of between 140 m and 150 m above sea level. The site includes part of the reservoir's bank and a nearby island and is approximately a two-by-two-kilometer square (Fig. 2.18.). It is located in immediate proximity to the auxiliary hydrotechnical structures of the Upper Teriberka Hydropower Plant and at a small (within four kilometers) distance to the possible location of the wind park's grid connection. The site's total area is a bit smaller than that of the Lodeinoye site. Furthermore, it is 18 km away from the sea, and wind intensity here is expected to be lower than at the coastal site near Lodeinoye. Yet, this site is noteworthy as it stretches over an open area close to a large water storage basin and not far from a good-quality motor road and the structures of the Upper Teriberka Hydropower Plant.

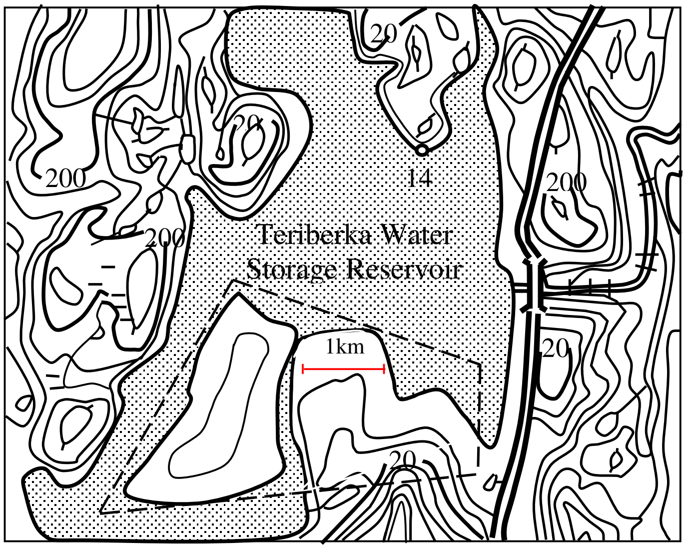


Fig. 2.18. Wind park site on the bank of the Teriberka Water Storage Reservoir.
These lines ═ indicate the Murmansk-Teriberka Motorway.

A 50 MW wind park in the area of the village of Tumanny. The site for this potentially rather large wind park is located along the road connecting Tumanny and the Lower Serebryanka Hydropower Plant (Fig. 2.19). Here, a ridge of flat mounds one to two kilometers wide stretches for almost six kilometers along the right-hand side of the road. The park's location close to the substation of the Lower-Serebryanka Hydropower Plant will facilitate transmitting the park's energy to the grid via a short cable, or an overhead power line. Its proximity to the settlement of Tumanny, where the Serebryanka Cascade employees reside, will help accommodate the work force and the technical equipment needed for the period of construction and installation works.

Large wind parks can be distributed along the existing motorway connecting Murmansk, Teriberka, and Tumanny on both sides of the road and to considerable distances further inland. According to preliminary estimations, a series of wind parks can be built here, each with a capacity of 100 MW or more.

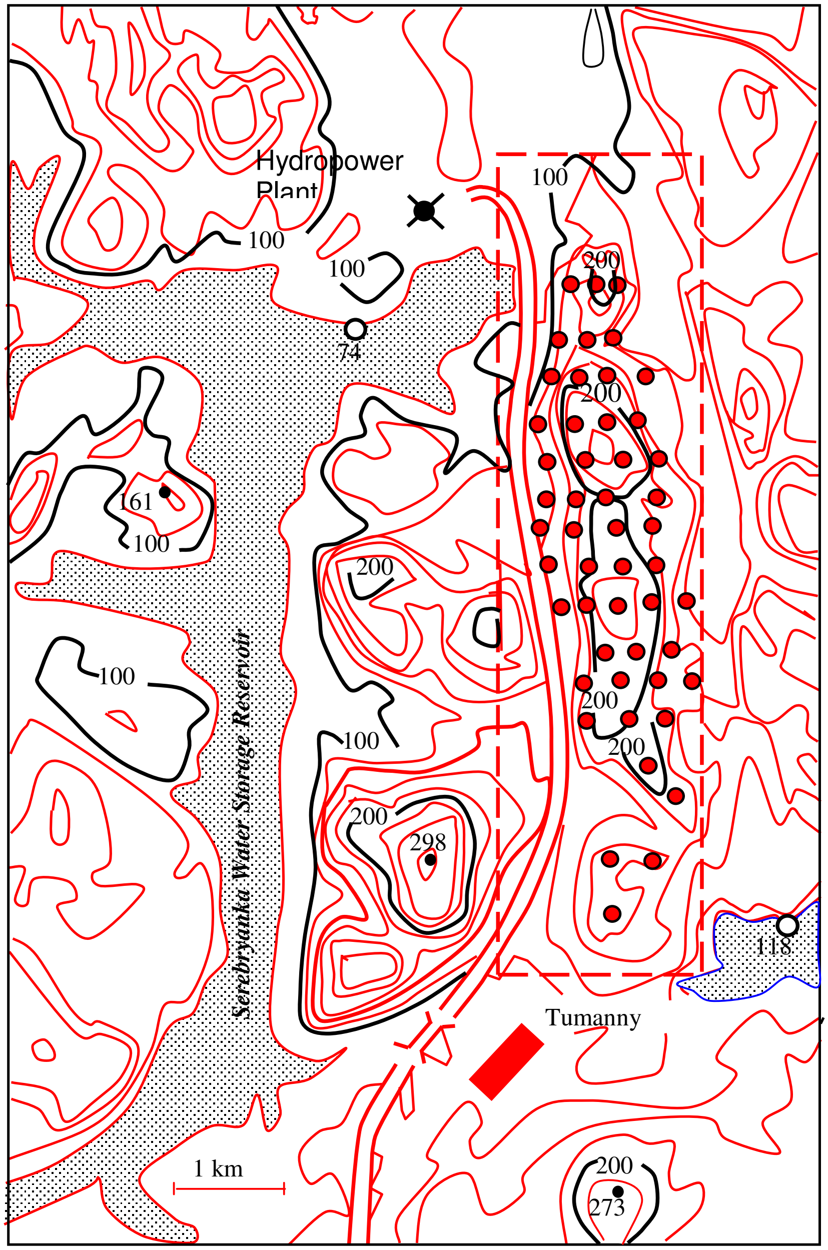


Fig. 2.19. Wind park site near Tumanny for a series of fifty 1 MW wind energy converters; the red rectangle ⬚ indicates the future wind park.

2.8. Technical and economic peculiarities of operating a WEC as part of the grid

Wind park construction costs. Evaluating development of the wind power industry abroad, one can already confirm that it has progressed into a self-sustaining and profitable energy sector. In certain countries of the world, like Denmark, Germany, Spain, the US and other nations, wind power is making a significant contribution to electrical energy production. Unit capacity of wind power installations produced on an industrial basis has increased from 3 MW to 5 MW. Modern wind energy converters are large technical constructions, manufactured with the use of state-of-the-art technologies and advancements made in aerodynamics, electronics, electric and computer engineering. The diameter of wind rotors produced for wind power plants of the megawatt class is between 60 m and 120 m, and tower heights range from 60 m to 100 m, or higher (Table 2.2.). Thanks to a consistent elaboration of production technologies, wind energy installations have also become much cheaper. As of today, the cost of one kilowatt of a WEC's installed output has decreased to between $800 and $1,000. It is expected that construction costs will fall further to some $600 to $700 per kilowatt within the next ten years.

In Russia, the development of systemic wind energy application and industry is still at a beginning stage. Nonetheless, the country already has all the necessary scientific and industrial potential at its disposal [18]. The first experimental WEC models have appeared built to the current day's scientific and technical standards. One wind power installation with a capacity of 1,500 kW (six 250 kW windmills), called the Zapolyarny (Polar) Wind Power Station, is already in operation near the city of Vorkuta in the Russian north. In the south, in the republic of Kalmykia, a 1,000 kW wind energy converter has been put into operation. In the west, the Kaliningrad region boasts of several experimental wind power installations produced in Denmark and arranged in a wind park with a capacity of over 5 MW.

In 2002, a wind park appeared in Russia's Far Northeast, in the area of the settlement of Anadyr, which comprises ten WECs of the ABE-250C type. The wind park's unit construction costs came to $1,800 per one kilowatt, with allowances provided for transportation expenses, taxes, duties, etc. All the pilot installations mentioned above operate in connection with the grid.

On the Kola Peninsula, a project run jointly by Russians and their Norwegian colleagues involves experimental operation of a 200 kW wind power installation located close to Murmansk. The energy this WEC produces is used to supply power to the hotel Ogni Murmanska (Murmansk Lights). This installation is "second-hand" and was previously used at a Danish farm for ten years. In 2000, it was bought by the Norwegian company "VetroEnergo AS" and installed near Murmansk.

Table 2.2

Main technical and cost parameters of WECs of differing capacities
produced in the European Community [16].

WEC type	Capacity, kW	Rotor diameter, m	Hub height , m	Unit cost Euro/kW
NM 110	4,200	110	124	
GE Wind Energy 3,6s	3,600	104	75	
Vestas V-90-3,0MW	3,000	90	80	
Fuhrlander FL 2700	2,700	96	80	
Nordex N-80	2,500	80	60	736
AN BONUS 2,3 MW/82	2,300	82	80	
LW 72	2,000	72	65	866
E-66 Enercon	1,800	70	64	886
NM 64C/1500	1,500	64	68	800
ECOTECNIA 1250	1,250	62	60	840
Fuhrlander FL 1000	1,000	54	70	767
NM 52/900	900	52	61	772
Nordex n-50	800	50	46	780
NM 48/750	750	48	60	771
AN BONUS 600 kW/44-3	600	44	42	792
LW 30	250	30	40	860
VERGNET GEV 26/220	220	26	50	818
Fuhrlander FL 1000	100	21	35	1,260
LW 18	80	18	40	1,212
VERGNET GEV 15/60	60	15	30	1,317
VERGNET GEV 10/20	20	10	18	1,500
INCLIN 6000 neo	6	4	9	1,367
INCLIN 3000 neo	3	4	9	1,600
INCLIN 1500 neo	1.5	2.8	7	1,980

With all costs considered that were derived from capital repairs done in Denmark, the windmill's transportation from Denmark to Murmansk, the construction of its foundation in Murmansk, and mounting works, the WEC came with a price tag of around RUR 4.2 million. This sum corresponds to a unit investment of $750 per one kilowatt. The energy converter's average annual output is 350 kWh to 380 kWh, and annual operating costs are around RUR 300,000. Therefore, with a 7% depreciation taken into account, the WEC's prime costs of power production come to between RUR 0.80 and RUR 0.85 per kilowatt, which is less than the current tariff the hotel will have to pay for the power delivered from the grid (about RUR 1.5 per one kilowatt hour).

Expected costs of WEC-produced energy in the conditions of the Kola Peninsula. When assessing the technical and economic feasibility of wind park construction, first priority is given to the issue of return expected on the invested funds. Estimating the projected costs is done with the understanding that in the absence of self financing, investment will have to come from a bank loan attracted under specific credit rate terms. Current inflation rates will also have to be factored into the costs. As a starting point, if the credit is assumed to be secured at the rate n_r ranging between 18% and 20%, and the inflation rate b is between 11% and 12% (the level estimated as of 2005), then the so-called real interest rate r will reach about 7 %. Such calculation is done using the following formula:

$$r = \frac{n_r - b}{1 + b}, \qquad (2.3)$$

As a criterion to assess the profitability of introducing a new WEC, the net present value (NPV) can be used. This value is expressed as a sum of current effects (incomes) for the whole accounting period, modified to the construction's starting point:

$$NVP = \left[\frac{B_1}{1+r} + \frac{B_2}{(1+r)^2} + \ldots + \frac{B_n}{(1+r)^n} \right] - I_0, \qquad (2.4)$$

where B_1, B_2,…B_n is the current effect (income) received within one year of the wind park operation (beginning from year 1 through to year n) in the course of the whole exploitation period n ;

r is the real interest rate;

and I_0 is the funds invested into the construction.

According to (2.4), the NVP represents the total economic effect, either positive or negative, received from the operation of a site during the whole period of operation and adjusted to the costs at the start of the construction. This value helps make allowances for the changes in the cost of the invested funds within a particular period of time, and compare investments made today with the income expected later during the project run, within one price scale. A positive result of calculations performed in accordance with the formula (2.3) is evidence that the offered project is cost-effective, or that, in other words, the investor of the wind park will be profiting from the endeavor during the exploitation period. The higher the profit value, as a result of the equation, the more profitable the site. If the result is negative, the investor will incur losses.

Calculations made with regard to the wind park project near Lodeinoye have shown the following results: Annual average wind speed at the elevation of 10 m in the area of Lodeinoye is about 7.0 m/s. If the wind park is set up as a series of 600 kW windmills (for example, wind mills of the type Enercon E-40/6.44), then the speed of wind at the height of the hub (50 m) will be 8.7 m/s. Using the performance parameters of the WEC type (borrowed from a catalog) and wind speed frequency data (calculated according to the Weibull equation), the park's annual output W can be estimated, which for a site of these dimensions will reach 2.35 million kWh.

Annual effect (income) B from the site's operation depends not only on the annual output, but also on the tariff "f" that will show for how much this energy could be sold to the grid:

$$B = W f \quad . \qquad (2.5)$$

The Federal Tariffs Service for the Murmansk region fixed the maximum electric power tariffs for 2006 at RUR 0.587 to RUR 0.600 per kilowatt-hour. This means the maximum tariff for WEC-produced energy at which it can be accepted by the grid will be RUR 0.60 RUR per kilowatt-hour. Calculating from that, the annual economic effect from operating an Enercon E-40/6.44 will reach RUR 1.41 million.

Investment outlay for WEC construction is determined by the specific invested capital C_{wec} and the WEC's capacity N_{wec}:

$$\mathbf{I_0 = c_{wec} N_{wec}}. \qquad (2.6)$$

As was specified above, the cost of a newly-installed WEC comes to between \$800 - \$1,000 per kilowatt. Making the necessary allowances for the transportation expenses and custom duties, as well as the costs of the construction of the WEC's foundation, its installation and connection to the grid, the price tag on one installed kilowatt will be between \$1,000 and \$1,400. Fig. 2.20 demonstrates how the NVP is developed across the given period of WEC operation at a fixed tariff on WEC-produced energy set at RUR 0.6 per kilowatt-hour and at a tariff growing yearly due to inflation in accordance with current projections (Fig. 2.21).

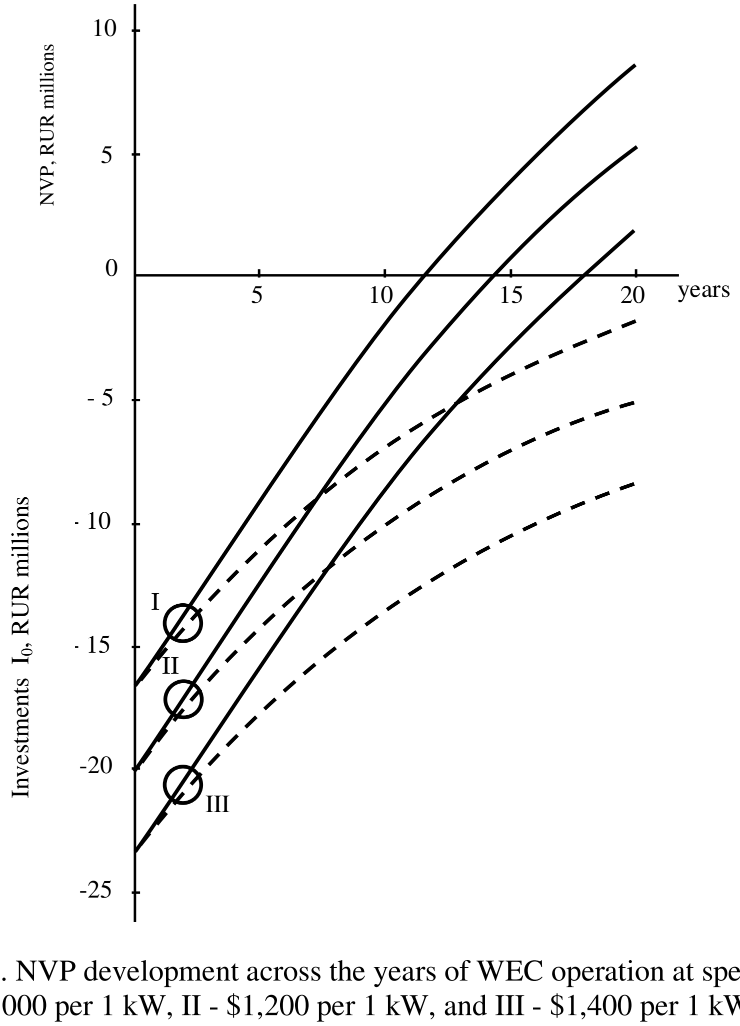


Fig. 2.20. NVP development across the years of WEC operation at specific investments of: I - \$1,000 per 1 kW, II - \$1,200 per 1 kW, and III - \$1,400 per 1 kW. Dashed curves: Return on WEC investment at a stable tariff of RUR 0.6 per 1 kW. Solid curves: Faster payoff at tariffs growing in accordance with inflation levels.

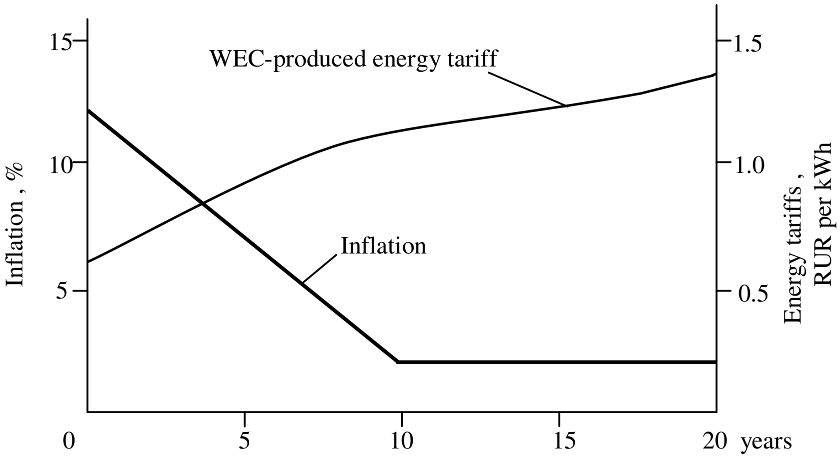


Fig. 2.21. Energy tariff growth in accordance with projected inflation levels.

After WEC construction works are over (zero operation year), only investments I_0 are of concern. This value is graduated along the Y-axis of the coordinate chart. Income developed through the years of WEC operation is determined by the cost of energy produced. Invested funds pay off gradually, year after year, according to the income received, making the NVP curve go up. The dashed curves in Fig. 2.20 correspond to a fixed energy tariff equaling RUR 0.6 per one kilowatt-hour. None of these three curves cross the X-axis within the given period of time, which is evidence that the site is not making profit.

However, it would hardly seem likely that in reality, energy tariffs were to remain unchanged over the next 20 years. Judging by the current inflation levels, tariffs can safely be assumed to be growing higher. In the past years, major efforts have been undertaken by the country to cut inflation down to the European levels of between 1% and 2%. It is a challenging process. But if one takes the premise that within the next ten years inflation will be reduced from the current 12 % to 2%, and will further remain at this level, then the tariff for WEC-produced energy will increase across the next 20 years from RUR 0.60 to RUR 1.37 per kilowatt-hour (or $0.049/kWh), as shown by the curve in Fig. 2.21. At such a rate of tariff growth, the NVP will grow faster (solid curves in Fig 2.20), and the payoff period will not exceed 12 to 18 years, which is quite acceptable, since profitability will reach levels of between 7% - 25 % at the lowest.

As regards the prime cost of power produced by a wind energy converter, the following can be said: Investments into one 600 kW WEC at c_{wec} equaling $1,000, $1,200, and $1,400 per one kilowatt and the dollar exchange rate of RUR 28 per $1 will reach RUR 16.8m, RUR 20.1m, and RUR 23.5m, respectively. Annual WEC operation costs as specified by the Catalog [17] are EUR 4,000 (or RUR 135,000) per year. With the WEC's annual output of 2.35 million kWh, a service period of 20 years, and the specific investments specified above, the production costs of the energy generated by the WEC will equal RUR 0.41, RUR 0.49, and RUR 0.56 per kilowatt-hour, respectively. The same conclusion can be reached if one were to look back at Fig. 2.20 and calculate, taking the upper solid lines as the starting point, what the tariffs should be to transform the curves enough that, by the end of the 20-year period, the NVP would equal zero – an option with zero profitability. The end result will be the same: Levels of between RUR 0.41 and RUR 0.56 (or $0.015 to $0.020) per one kilowatt-hour. These values are not bad indeed, by European standards.

3. SMALL RIVER ENERGY

3.1. A general evaluation of the region's hydroenergy resources

Streamflow energy. Like other kinds of renewable energy, streamflow energy – or hydro energy – is a derivative of solar energy. Of all the irradiance received by Earth from the Sun (173,000 TW), almost a quarter – 40,000 TW – is that part which is evaporated [19]. Only a very small fraction of this capacity (about 0.1%) can be used to man's advantage: It is this part of the transformed solar-to-vapor energy that falls as precipitation on the Earth's surface. Under natural conditions, or without interference from man, this water energy is spent on soil erosion, degradation of land relief, transfer of products of soil erosion, and on overcoming the various forces that resist water flow in rivers.

Unlike most other kinds of renewable energy, hydroenergy technologies, which make use of the energy of streamflow, are highly developed and widely employed at the present time. Hydro energy resources are capable of supplying the energy market with guaranteed capacities of energy available at competitive prices or, at times, even cheaper, like hydroelectric power installations in Russia's Siberia or the major hydropower plants in China or Brazil. Hydroenergy covers approximately 20% of the global energy demand and is the main power source in more than 30 of the world's countries. In the almost two thousand years of its development, hydro power has achieved considerable levels of energy efficiency, advancing from the wooden water wheel with a performance efficiency rate of 10% to the high-speed hydroturbine with efficiency rates reaching 95%.

Hydropower resources: General notions. The force that drives streamflow forward is the weight of the water. The power of streamflow is determined by the scope of its downward movement, i.e. by the difference between water levels at the origin of the stretch surveyed and at its end, as well as the values for the streaming water's weight. If the fall of the stream on a river stretch equaling L meters is H meters, then, with flow rate Q, in m^3/s, equaling its average value at the stretch's beginning and end, the work performed by the streaming water (waterflow power) in one second N, in watts or J/s, on the stretch observed will equal:

$$N = \rho g Q H = 9810 QH \ , \tag{3.1}$$

where ρ is water mass density, in kg/m^3, and g is free fall acceleration, in m/s^2.

Watershed energy E , in kilowatt-hours, is determined by the product of streamflow intensity N by time t , in seconds, and is:

$$E = \frac{9.81QHt}{3600} = \frac{WH}{367} \ , \tag{3.2}$$

where $W=Qt$ is the volume of the waterflow used, in m^3.

The correlation described above determines potential, or theoretical complete**,** hydroenergy resources. When assessing potential water energy resources, consideration is not given to loss of streamflow, water head and water energy as the latter is converted from mechanical to electric power.

Before an evaluation of the potential streamflow resources of a river is performed, a so-called water resource cadastre has to be compiled, which will include a general description of the river and its basin, available hydrometric, hydrological, topographic and geological engineering data, etc. All of these records are summarized in a cadastral chart containing the river's thalweg, a graph representing the accrual of catchment area from the river's headstream to its estuary, a graph of average flow rate across a number of years, and unit power values for each river stretch (in kW/km). Power values for individual river stretches are then summed up and its overall power capacity and annual energy output can be calculated, with the capacity and output contingent on the watershed preserving the levels determined at original measurement. This method helps assess the potential overall hydro energy resources available in rivers and river basins of various regions or a whole country.

The particular quantity of hydro energy resources that can be used by hydroelectric power plants for the generation of electric power is called "technical resources." The technical potential is always smaller than the entire theoretical potential because, for various reasons, not all river stretches can be used for the construction of hydroelectric power plants. Especially in densely populated areas, considerable volumes of water are also collected from many rivers to cover needs other than producing energy. Water stored in water reservoirs built on the sites of hydroelectric power plants is subject to evaporation and filtering, which leads to loss of water volumes. Furthermore, certain loss of water pressure takes place at hydroelectric power plants due to the resistance to the streamflow formed by the water conduits or by the backwater below the hydroelectric dams.

The USSR, with the prolonged stability of the country's financial situation and the unchanging rate of the ruble, was afforded another durable notion: economic hydroenergy resources. Those were assumed to be such resources whose application was economically expedient. The method of comparative economic efficiency in use in Soviet energy economy was based on comparison of hydroelectric power plants under development with conventional thermal electric power plants, while the projected energy effect remained at known levels. Another method applied was the notion of absolute energy efficiency, where payoff period for a new hydroelectric power plant was not to exceed eight years and 44 days.

In today's Russia, no evaluation studies for economic hydro energy resources are performed due to speedy and significant fluctuations in prices for construction materials and fuels. When the need arises for the construction of a power complex site, including a hydroelectric power plant, decision-making regarding the economic feasibility of the project depends on the calculations of its economic efficiency. The ground rule dictates that revenues received from the implementation of the project in question will exceed the revenues the same amount of money would accrue if it were saved in a bank.

***Types of hydroelectric power plants*.** The capacities – and, correspondingly, the output and dimensions – of the modern hydroelectric power installations vary by hundreds of thousands of times, ranging from a few hundred watts to some 12,000 MW. These power plants can be classified by various characteristics and fall into different category types, depending on the levels of water head, power capacity, type of turbines installed, location of the hydroelectric dam and layout of the structures. These breakdowns, of course, are not absolutely independent, which can be seen in figures [3.1] and [3.2]. Therefore, a specification based on one principle will ultimately provide the description of the hydropower plant as a whole. For instance, an increased water head, with flow rate remaining the same, results in a linear increase in the hydropower plant's capacity; its output will grow as well, but will be limited by the levels of the river's stream flow.

If water head is increased from between two and five meters to between 10 and 15 meters, the hydropower plant will change classification from streamflow power plant (Fig. 3.1 a,b) to water reservoir power plant (Fig. 3.2). Accordingly, the type of the hydraulic turbine will change from horizontal downstream to vertical propeller or vertical runner-blade, like Kaplan turbine (Fig. 3.3). With water head exceeding 15 to 20 meters, turbine type changes to radial-axial (Francis turbine, Fig 3.4). Further increase in water head leads to hydropower plant changing its type to diversion power plant (Fig. 3.5). Furthermore, if water head exceeds 100 meters, turbine type may change to free-jet double-bucket (Pelton) turbine (Fig. 3.6). Fig. 3.7 is a chart showing the possible areas of application of different types of hydraulic turbines in accordance with the water head, rate of flow through the turbine and its power capacity. It should be noted, however, that considerations of costs and simpler maintenance and production routines may influence hydropower plant developers to make their choice of turbine type in contradiction to the chart presented in Fig. 3.7. The following rule of thumb applies for changes in dimensions of the main energy installations of a hydroelectric power plant: The higher the rate of flow through the power plant, the larger the scale of the hydraulic installations, including the size of the turbines themselves; and the higher the water pressure, the smaller the size of the main installations of the power plant and its turbines, provided the rate of flow remains the same.

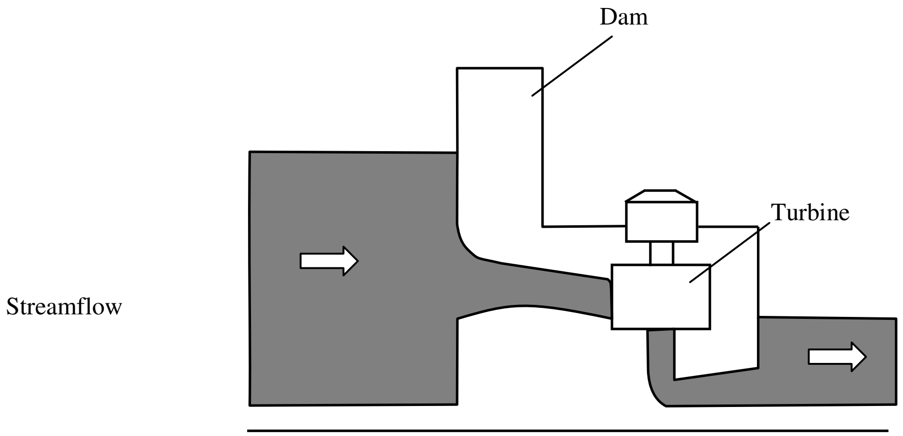


Fig. 3.1a. Run-of-river hydropower plant with a vertical turbine.

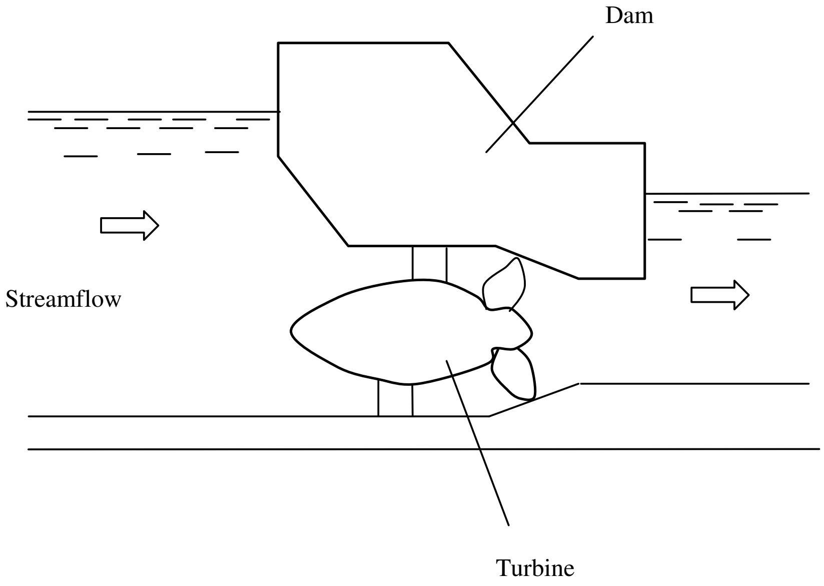


Fig. 3.1b. Run-of-river hydropower plant with a bulb turbine.

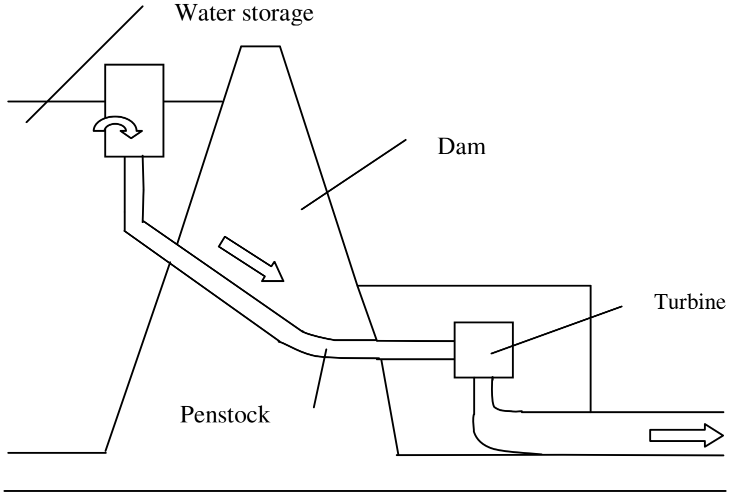


Fig. 3.2. The principal layout of a reservoir-type hydropower plant.

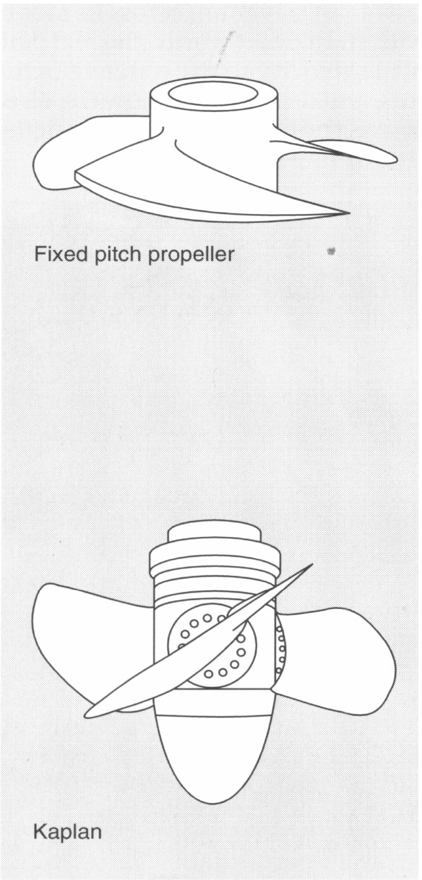


Fig. 3.3. Propeller hydroturbine and Kaplan (runner-blade) turbine

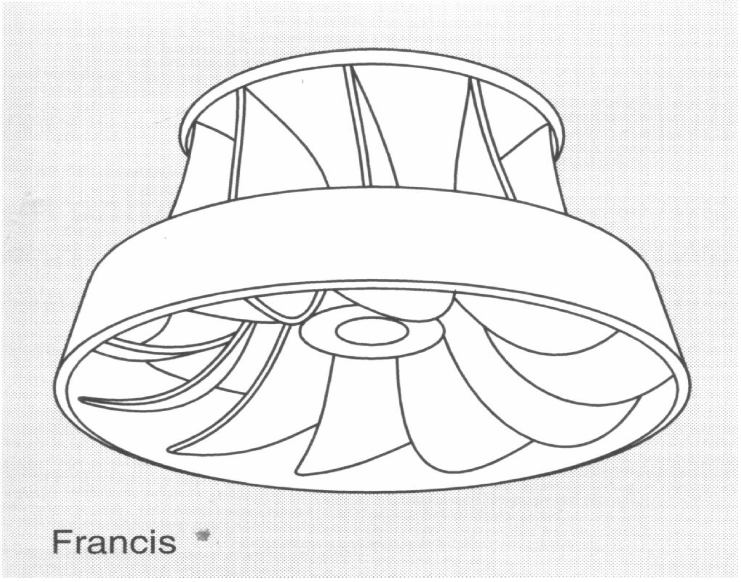


Fig. 3.4. Radial-axial turbine.

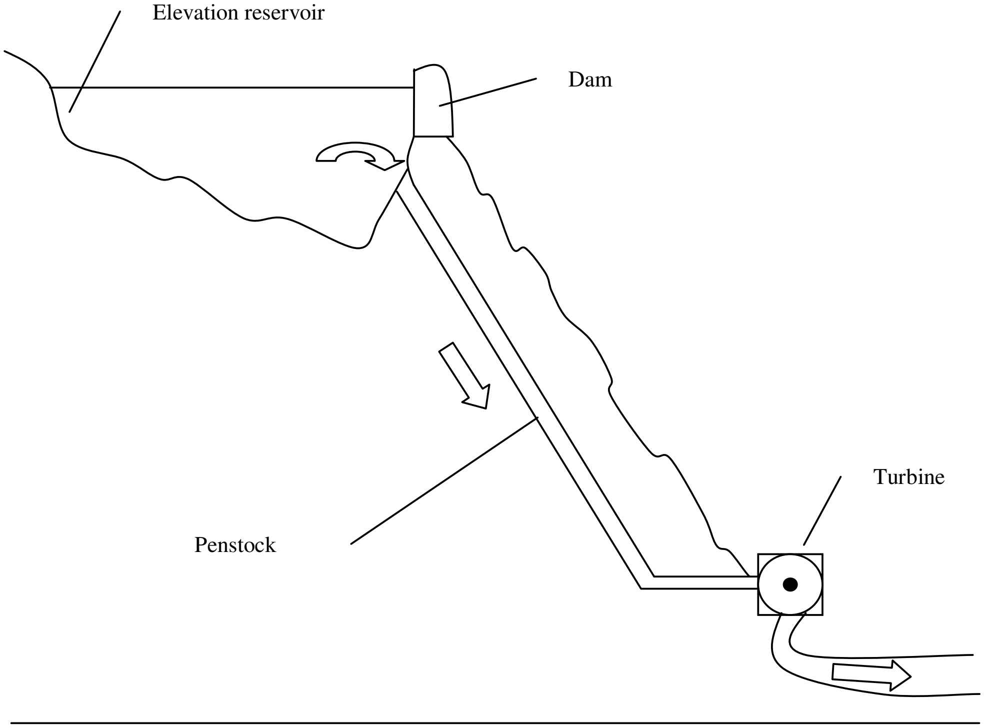


Fig. 3.5. General layout of a diversion-type hydropower plant.

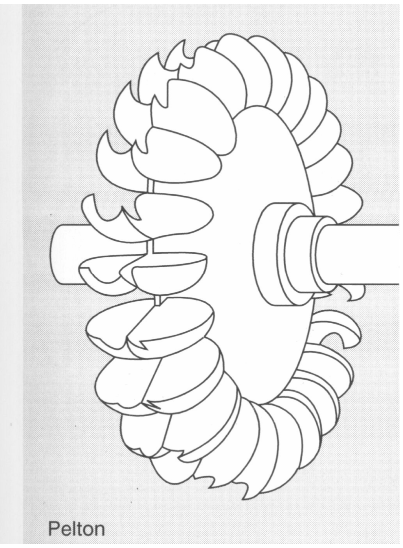


Fig. 3.6. Double-bucket (Pelton) turbine.

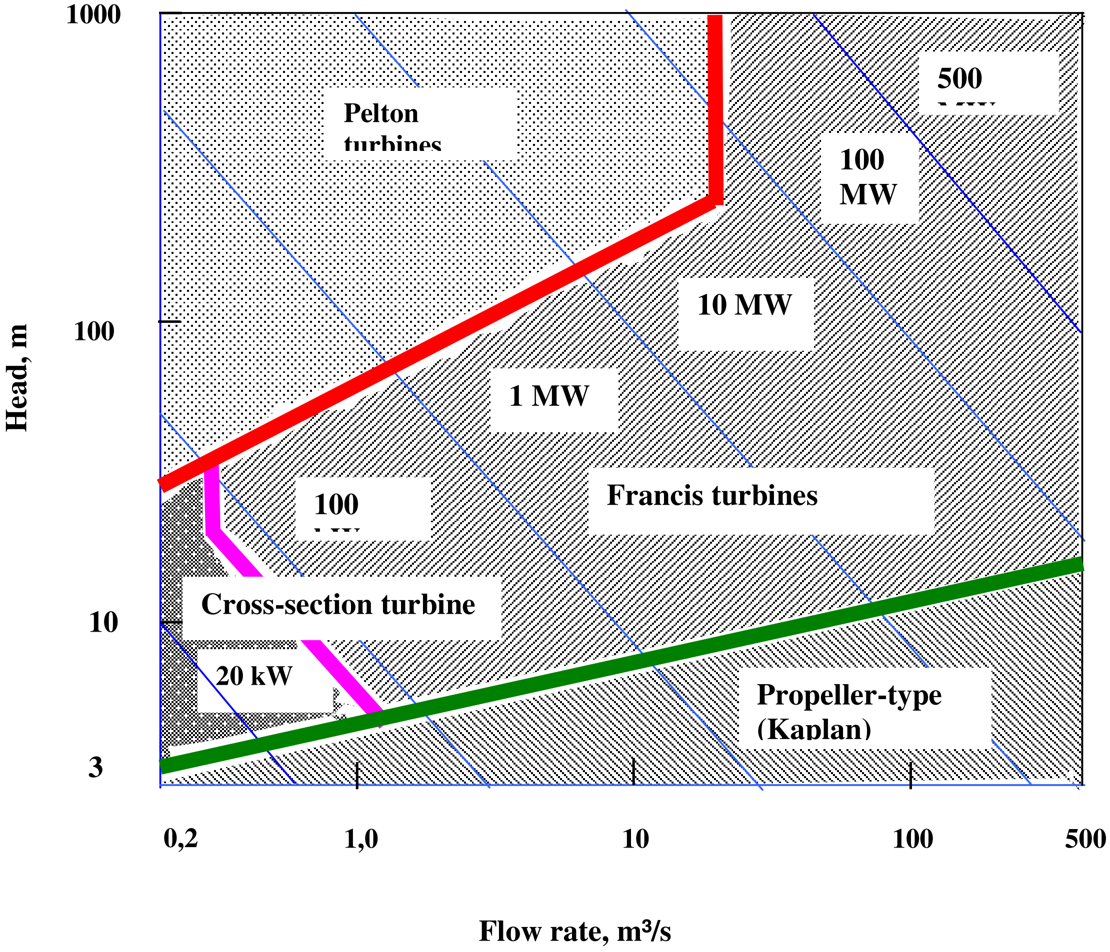


Fig.3.7 Diagram for the determination of hydraulic turbine performance parameters based on different types of turbines.

In addition to distinguishing hydraulic turbines by the types mentioned above, variations can also be found in their main principle of function. Several types of hydraulic turbines listed above are classified as “reaction turbines”, while the turbine based on Pelton buckets is an impulse turbine. Without delving into complicated mathematical descriptions, it is sufficient to say that reaction turbines are turbines which use both the impulse force of the head pressure of the water hitting the turbine blades and the reactive force of the outgoing water as it leaves the turbine’s blades going in the opposite direction. Impulse turbines use only the incoming water’s impulsive force applied against the turbine’s blades.

Hydroenergy resources of the Murmansk region. Complete potential hydroenergy resources of the rivers of the Murmansk region, based on a multi-year average annual output, are estimated at 19.3 TWh [20]. Taking economic reasons into consideration, only about a third of these resources could actually be put to use. This is roughly the level of hydroenergy resources development that the Murmansk region has achieved today. Seventeen hydroenergy power plants in operation in the Kola Energy System have a combined output of around 6 TWh in one average-flow year.

A brief time line of water energy development of the Kola Peninsula. The Kola Energy System was created in 1934 after a high-voltage power line connected the peninsula’s first two hydropower plants, the Niva-2 and the Lower Tuloma Hydroelectric Power Plant. Due to the lack of deposits of organic fuel resources on the peninsula’s territory, the development of the region’s energy economy had to rely heavily on the construction of hydroelectric power plants at the easily accessible and effective streams of the area’s large and medium-size rivers.

The annual growth rate for the installed energy capacity for that period was 50 MW (except in the wartime years, between 1941 and 1945) and was achieved primarily by means of the hydroelectric power plants. The share of thermal electric power plants during that time did not exceed 10%.

Between 1959 and 1973, the growing demand for energy and the impossibility of satisfying it solely using hydroelectric power plants led to the decision to build the Kirovsk State District Power Plant (now, Apatity Combined Heat and Power Plant). As the site reached it design capacity of 500 MW, the share of thermal power plants in the region’s energy system increased to 36%. At the same time, several hydropower plants were also undergoing development. Growth rate for the installed capacity of the region’s energy system was in that period around 100 MW per year, shared roughly half and half by the state district power plant and the hydroelectric sites.

In 1973, the first reactor block of the Kola Nuclear Power Plant went online with an operational capacity of 440 MW, and within a few years’ time, the plant reached its full design capacity of 1,760 MW. Thermal plants increased their share in the capacity balance of the peninsula’s energy system to 59%, and their contribution to the region’s combined energy output to 70%. Those years also saw the construction and development of the cascaded hydropower plants on the Teriberka River. This was the last power plant cascade built on the region’s territory in the 20th century. Installed capacity growth rate for the period of 1973 to 1984 was around 200 MW per year (accounted for, mostly, by nuclear power plants). The year 1990 was a record year for energy consumption in the Murmansk region: With the annual energy output of 19.6 TWh and a 2.9 TWh delivered to the neighboring republic of Karelia, energy demand in the Murmansk region reached its highest peak of 16.6 TWh. Since 1984, the energy system capacity for the region has remained practically unchanged.

3.2. Hydroelectric power plants in operation on the Kola Peninsula

The Murmansk region operates 17 hydroelectric power plants joined into six cascades installed on the rivers Niva, Paz, Kovda (Kuma, Iova), Tuloma, Voronya and Teriberka (Fig. 3.8).

Total installed capacity of these hydroplants is 1,588.8 MW, or around 42% of the combined installed capacity of all the power plants of the region.

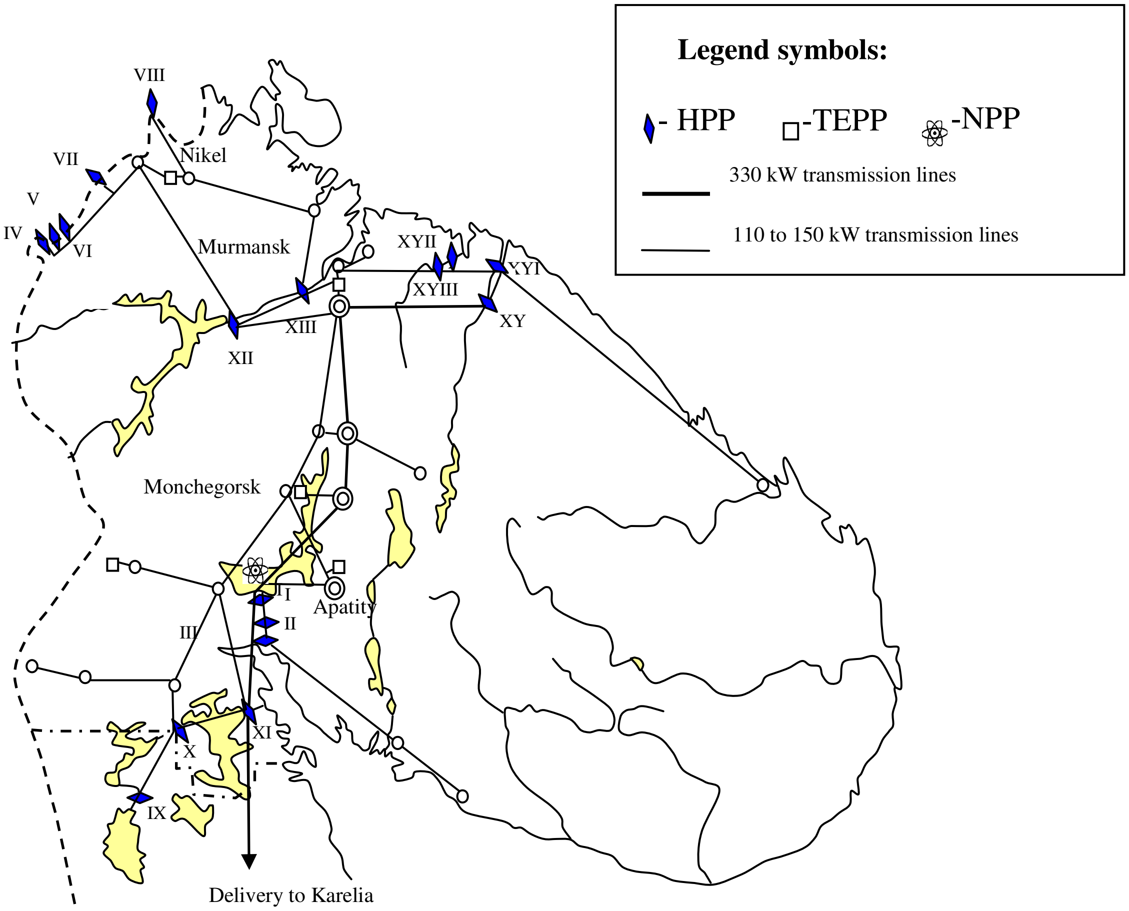


Fig. 3.8. General layout of hydroelectric power plants of the Murmansk region.

The extent to which hydroelectric power plants contribute to the region's annual energy output is not an exact percentage as it depends on river streamflow rate. Its fluctuation range is between 35% and 49%. Due to ongoing administrative reforms in the region's energy economy, the number of hydropower plant cascades has been cut from six to four: The Niva Cascade, which originally only included three hydropower plants, will now have administrative jurisdiction over three more hydroplants, formerly of the Kovda Cascade. The Paz Cascade with its five plants will remain as before. The two hydroplants of the Tuloma Cascade will be joined by the Kislaya Guba Tidal Power Plant. Two more Teriberka hydropower plants will now be added to the Serebryanka River Power Plant Cascade.

As administrative reforms are being introduced across the board in Russian energy economy, all the hydroelectric power plants of the region have been transferred into the ownership, and by extent, management, of the Territorial Generating Company (TGC-1), based in St. Petersburg. However, issues of prospective development of the region's power generation sources and power networks remain within the purview of the Kola Regional Dispatch Office, the regional system operator. It is unclear which of these entities is responsible for making a decision to build a particular electric power plant, and for the consequent funding of the project designs and construction of hydropower and thermal power plants.

The majority of the region's hydropower plants are diversion dam power plants. Seven of these hydrocomplexes employ free-flow diversion works formed by channels of various lengths. These hydropower plants are: Niva-1, Niva-2, Knyazhya Guba, Iova, Kuma, Serebryanka-1 and Serebryanka-2. Three hydroplants with turbine rooms located underground have tunnels used for pressure diversion: Niva-3, Upper Tuloma and Borisoglebsk. Six more hydropower plants are low-head reservoir-type power plants: Kaitakoski, Yaniskoski, Hevoskoski, Lower Tuloma and Lower Teriberka. The hydropower plant on Upper Teriberka is a diversion dam installation using pipeline-based pressure diversion. The main site and energy output specifications for these hydropower installations are listed in Table 3.1.

The region's hydroelectric power plants are primarily low- and medium-head and equipped, as a rule, with Kaplan-type turbines (Fig. 3.3). Only three hydro power plants have a pressure head exceeding 70 meters: Niva-3, Serebryanka-1 and Upper Teriberka.

Altogether, 45 turbogenerator units are installed at these hydroelectric plants with capacities ranging from 5.6 MW to 130 MW. The overwhelming majority of the hydropower plants are built to designs developed by the Leningrad branch of the All-Russian State Design Institute and the Scientific Research Institute Gidroproyekt. Construction was also carried out mostly by domestic contractors with the use of nationally produced equipment. Some hydropower plants, however, have been built by Finnish and Norwegian construction companies, and part of their water power equipment was manufactured by Finland's Tampella and Sweden's KM (Table 3.1).

All of the region's hydropower plants are in working condition. However, as the facilities are aging, and there are insufficient funds available for modernization and renovation, the volume, frequency and duration of repairs is growing and leading to a reduction in the hydropower plants' capabilities to regulate their load.

Prospects and problems of development of the region's conventional hydroenergy. Following a series of economic and political crises both of the latest Soviet period and in contemporary Russia, a significant decline has occurred in the region's consumption of electric power for industrial needs. This resulted in excess capacity and energy output of the Kola Peninsula's energy system. For the same reasons, investments in new energy constructions were cut significantly. Furthermore, environmental restrictions have been imposed on the exploration of the peninsula's remaining undeveloped major rivers. This has also served as a deterrent to the further development of hydro energy on the Kola Peninsula's territory.

As of today, first-priority construction sites include major hydroelectric power plants and hydropower cascades such as the cascade project on the Iokanga River with an installed capacity of 360 MW, another on the Eastern Litsa with a combined capacity of 380 MW, and a cascade on Ponoi River with a combined capacity of 1,800 MW [20, 21]. These hydroplants have been designed as peak and intermediate energy sources with a specific provision made that their construction will take place after a second construction stage at the Kola Nuclear Power Plant has been completed. At the same time, judging from their projected capacity and output specifications, nothing should prevent them from being used in conjunction with major wind energy converters of commensurable capacity.

Table 3.1

Main site and energy output characteristics of the hydroelectric power plants in operation in the Kolenergo energy system

Hydropower plant, name	River	Year of launch	Installed capacity, MW	Turbine type	Number of turbines	Estimated head, m	Expected flow rate, m^3/s	Regulation capability	Type of hydrosite	Electric power output, million kWh
1	2	3	4	5	6	7	8	9	10	11
Niva Cascade										
Niva-1	Niva	1953	26.0	PL Sweden	2	11.5	276	multi-year	diversion	129
Niva-2	-”-	1937	60.0	PO-123-VB-250	4	36.0	200	multi-year	diversion	407
Niva-3	-”-	1950	155.5	PO-32-VM-295	4	74.0	250	multi-year	under-ground diversion	850
Kuma	Kuma	1963	80.0	PL-577-VB-450	2	32.0	290	multi-year	diversion	346
Iova	Iova	1963	96.0	PL-577-VB-450	2	32.0	295	seasonal	diversion	536
Knyazhya Guba	Kovda	1956	152.0	PO-21-VM-410	4	37.0	460	seasonal	diversion	706
Paz Cascade										
Kaitakoski	Paz	1951	11.2	PL Finland	2	7.5	180	multi-year	run-of-river	72
Yaniskoski	-”-	1951	30.5	PL Sweden	2	21.5	166	daily	reservoir	216
Rayakoski	-”-	1956	43.2	PL Finland	3	20.5	255	daily	run-of-river	226
Hevoskoski	-”-	1970	47.0	PL-661-VB-500	2	18.7	325	daily	diversion	227
Borisoglebsk	-”-	1963	56.0	PL-661-VB-500	2	19.3	348	daily	diversion	275
Tuloma Cascade										
Upper Tuloma	Tuloma	1965	268.0	PL-646-VM-410	4	55.0	480	multi-year	under-ground diversion	801
Lower Tuloma	-”-	1949	50.0	PL-245-VB-360	4	17.5	342	daily	run-of-river	280
Kislaya Guba Tidal	Kislaya Bay									
Serebryanka Cascade										
Serebryanka-1	Voronya	1970	204.9	PL-2-80	3	75.7	303	multi-year	diversion	558
Serebryanka-2	-”-	1972	150.0	PL-2-80	3	62.5	276	multi-year	dam diversion	524
Upper Teriberka	Teriberka	1984	130.0	PO-170/803-B-400	2	109.0	236	seasonal	diversion	236
Lower Teriberka	-”-	1987	26.5	PL-40-B-430	2	23.0	117	seasonal	reservoir	54

Further project development of the hydropower plants on the Ponoi and Iokanga has been suspended because of the high probability of an irreparable damage that could be inflicted on the salmon populations inhabiting these rivers. No environmental ban has affected the Eastern Litsa project, but the site is located at a remote distance from prospective consumers and the construction companies expected to work on the site, which is likely to increase construction costs. At the same time, the estimated output of this facility is not significant, while the prime cost of one kilowatt-hour of energy from this plant is expected to be very high. For these reasons, design firms involved in this project have been giving thought to developing various options for piecemeal implementation of this hydropower complex project. For instance, the idea has been floated to build a series of hydropower plants on the Rynda River, which, technically, would still be part of the Eastern Litsa complex.

The joint stock energy company Kolenergo has been carrying out work aimed at enhancing the utilization of the existing capacities of the hydropower plants in operation on the peninsula. Following a suggestion from Kolenergo, the design bureau Lengidroproyekt has prepared project engineering documentation on expanding the Niva-2 hydropower plant by one turbine, which will increase the plant's through-put capacity by 30%. A recently prepared draft design of a further development project for the Lower Tuloma hydroplant will increase the capacity of that facility as well by 30% to 40%. Kolenergo has also put forward a suggestion to enlarge the Iova hydropower plant by a turbine of up to 50 MW of capacity to be installed in a separate building, which would increase Iova's through-put capacity by another 50%. TGK-1 is currently focusing its attention on the possibility of expanding the existing capacities of the Yaniskoski plant and other hydropower installations on the Paz River as well.

On the whole, an upgrade of the existing capacities of the Kola Energy System by 145 MW gained by a modernization of the hydropower plants in operation in the region can be considered both technically and economically feasible.

TGK-1 representatives view as their first priority the construction projects on the Iokanga and Rynda that would see the creation of new hydropower plants with a combined installed capacity of 595 MW. However, figures relating to the economic potential of the prospective hydropower plants are classified, according to recent practices, as commercial secrets and were not made available for the present report.

3.3. Hydroenergy potential of small rivers

Small-scale hydropower systems. The notion of small-scale hydropower plants usually implies that these installations offer a relatively small capacity and are primarily built to cover the energy needs of isolated consumer groups at the expense of the consumers themselves and using their own workforce. Such consumer groups include: agricultural cooperatives, small industrial enterprises, farms, certain large industrial companies with low energy consumption, etc. It is general assumption [19-21] that small hydropower systems are plants whose installed capacity is less than 20 MW to 30 MW. The usual energy capacity reserved for the regions of the Russian North does not exceed 3 MW to 5 MW due to the low population density (less than 3 pers./km^2) and low density of the load. Besides, land relief of the Russian North does not allow for the construction of high-head power plants. Under such conditions, achieving a capacity of 20 MW to 30 MW requires the construction of large water-development works (dams, barrages, canals, and facilities housing hydropower turbines) to manage significant stream flow, at which point these plants leave the category of small-scale hydropower systems. Hydropower plants with the installed capacity of up to 100 kW are classified as micro-power plants.

Small-scale hydropower plants are far from being a new idea for the harnessing of streamflow energy. Even at the dawn of the electricity era, hydropower installations with capacities ranging from one kilowatt to a few hundred kilowatts appeared on small rivers and streams. They were often constructed on the sites of old water mills. All around the world – and especially in Europe and Northern America – most of these installations continued to supply energy to local consumers and to central grids until the 1940s. Over time, as power grids developed, with growing capacities of individual electrical stations and with falling prices for electric power and diesel fuel, small-scale hydro electric stations – just like wind power converters – were forgotten.

Today, small-scale hydro energy owes its gradual comeback to several factors:

1 A more strategic approach to energy sources due to recurrent and intensifying fuel crises.
2 A limitation on the possibilities of building large-scale hydroenergy complexes in many countries of the world – primarily, in developed nations – due to the experience with significant negative environmental impact resulting from building and running such sites in the past.
3 A speedy progress made by the development of miniature self-inclusive electronic devices for the control and management of technological processes, including for the remote control of small-scale hydrogenerators operating as part of a power system, or as an independent source of energy.

Two main trends can currently be observed in the development of small-scale hydro energy in the developed countries of the world.

The first is application of dams and water reservoirs, created to cover water supply needs, for energy. Although many of these are already used for generating energy, the potential for the exploitation of similar undeveloped resources for energy is still significant.

The second is the application of small streamflows with the use of dam-free hydropower plants, or the construction of small-scale hydropower plants of conventional configurations in as-yet undeveloped sites.

China is the world's leader in the construction of small-scale hydropower plants and micropower hydroplants. In the past decade, more than 100,000 small-scale and micropower plants have been built in that country with a combined capacity of around 10,000 MW [19,21]. Furthermore, China is a successful producer of small-size hydroturbines, for which it uses the technical documentation and now-how bought in the former Soviet Union between 30 and 40 years ago. Neither of the two hydro energy development trends mentioned above has been explored in Russia to this day.

Hydroenergy potential of small rivers. The second development trend described above can be seen as most promising in the conditions of Russia's European North, as demand for water supply is not satisfied here with the help of special water reservoirs. Hence, any such systems are completely absent in these parts. Besides, the territory of the Russian European North is characteristic for its absence of high mountains, elevated lakes, and water storage reservoirs, which would otherwise allow for collecting water as additional intake for use in small-scale hydropower plants.

The Institute for Physical and Technological Problems of Energy in Northern Areas, of the Kola Scientific Centre Russian Academy of Sciences, studied 35 small rivers of the Murmansk region from the angle of possible exploitation of their streamflows. The potential hydro resources of these rivers reach an annual average capacity of 790 MW, or 6.9 TWh of average annual energy output, while the technical equivalent of these resources is 516 MW for the average annual capacity and 4.4 TWh of energy per year, respectively [20]. Very small rivers and streamlets of the region have not been included into the study as they number in the hundreds and could only be used as energy sources by micropower hydroplants. The utilisation of these rivers could provide for a significant increase in electric power output in the Murmansk region.

Under consideration with Kolenergo is currently the issue of probability of electric power shortages in the peak and half-peak ranges of the load demand. One of the ways to tackle the brewing crisis is to build new small-scale hydroelectric power plants and include them into the Kolenergo grid, as well as repair and upgrade the existing hydropower plants. These particular considerations account for the growing interest on the part of researchers and those responsible for project designs to use small-scale hydropower plants with a significant installed capacity of over 1 MW.

Another factor that explains the burgeoning interest in the use of cheap hydroenergy even on the part of those energy consumers whose energy needs are already covered by the central grid supply is the consistent – and considerable – increases in tariffs on electricity.

In areas disconnected from the central grid, energy costs are primarily dependent on diesel fuel prices. With transport expenses taken into consideration, the latter have risen to between RUR 25,000 and RUR 28,000 for one ton (around $700 per one ton) as of June 2006. Thermal energy rates are also very high, reaching to about RUR 600 per 1 Gk for consumers receiving heating from a large, coal-based thermal power plant and between RUR 880 and RUR 1800 per 1 Gk for energy users whose heating supply comes from a boiler house running on fuel oil.

It is the hope of obtaining a cheap and independent source of electric and thermal power that drives the energy user to the exploration of the possibilities of application of local renewable energy sources, including the hydroenergy of small rivers.

3.4. First priority river sites for the construction of system-integrated small-scale hydropower plants

Lengidroproyekt in cooperation with The Institute for Physical and Technological Problems of Energy in Northern Areas conducted research [20,22,23], during which 21 sites on 10 rivers of the Murmansk region were examined (Table 3.2, Fig. 3.9). The result was economic efficiency data for 11 sites on seven rivers (Fig. 3.9). During the course of investigation, the Nota, Varzina, and Umba Rivers were excluded from research as rivers of substantial significance for fishery. After adjustments, 12 hydrosites were identified as suitable for a feasibility study. Data for these sites is available below.

Table 3.2

Small and medium-size rivers with prospects for the construction of system-integrated small-scale hydropower plants.

River	Potential hydropower plant sites, number	Recommended for use	Installed capacity, in mW	Energy output, in million kWh
Pirenga	1	1	6.0	29.5
Tumcha	3	3	37.0	170.8
Big Olenka	2	2	9.8	49.1
Ura	2	2	4.6	24.0
Western Litsa	1	1		
Titovka	1	1	3.4	15.8
Lotta, with tributary Kollaniyoki	2	1	2.6	12.4
Umba, including diversion	5	1	4.0	19.7
Varzina	3	-		
Nota	1	-		
Total	21	12	67.4	321.3

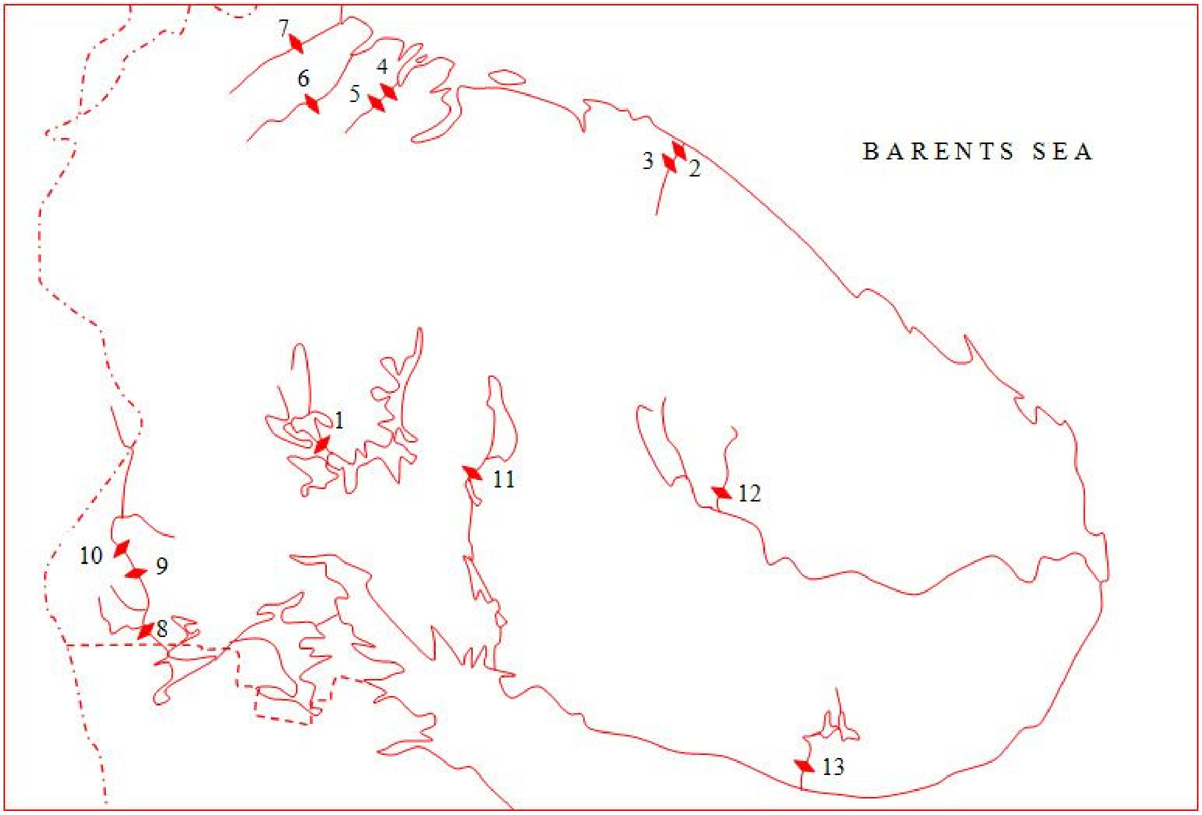


Fig. 3.9. Prospective sites for the small-scale hydroelectric power plant projects on the Kola Peninsula. System-integrated small-scale hydropower plants on rivers: 1- Pirenga; 2,3 - Big Olenka; 4,5 - Ura; 6 - Western Litsa; 7 - Titovka; 8-10 - Tumcha; 11 - Umba. Isolated small-scale hydropower plants on rivers: 12 - Yelreka; 13 - Chavanga.

Small-scale hydropower plant on the Pirenga River (Position 1, Fig.3.9). The Pirenga falls into Lake Imandra. It stretches approximately 160 kilometers, and runs from northwest to southeast. In the lower part of its stream – as it passes the regulation culvert located three kilometers away from the estuary – the river becomes a short canal connecting the Pirenga Lakes with Lake Imandra. The barrage built on the Pirenga in 1938 locks up the 300 km^2 of the water area of the lakes, while the catchment area is around 4,030 km^2.

The Pirenga River is primarily fed by snow. Flooding begins in early May. Bed geology for the construction of a prospective small-scale hydropower plant is estimated as satisfactory. Ledge rocks have poor permeability: The filtration coefficient is 0.02m/day to 1.0m/day. The hydropower plant site is located in an area where seismic activity is estimated to never reach more than 5 points. Seasonal ground frost penetration is 0.5m to 1.5m. Construction can be supplied with sufficient quantities of stone and fluvial soils found within a 5-kilometer radius from the site.

The headrace and the river bed can be used for power production, water supply and the fishing industry. Until 1987, the streamflow was also used for wood rafting. Maximum hydraulic capacity of the site is 170m³/sec. To prevent damage to the fishery, the reservoir drawdown is limited to 5cm per day. In the spawning period – from May through June – no reduction of water levels is allowed.

For safe navigation, water levels of Lake Pirenga cannot be lower than 136.7 m in order to ensure that shipping functions normally on the Tolva River and Lake Chalmozero. At present, the normal headwater level (NHWL) of the Pirenga reservoir is 138m, and the length of the streamflow fall from the dam to Lake Imandra level reaches almost 10 m.

In order to enhance the hydropower plant's capacity and its electric power output, it was originally suggested to raise the NHWL to 138.58m, or by 0.58m. But such an increase would have had a significant impact on the territory of the Lapland nature reserve. The nature reserve's management demanded that a second, more comprehensive, environmental evaluation and a feasibility study be conducted before the water level is increased to the proposed mark. After deliberations at various administrative levels, the NHWL of the Pirenga reservoir for the small-scale hydropower plant in question was finally set at 138.0m.

In order to realize this project requires clearing about three kilometers' worth of the river bed below the hydropower plant from snag, rearranging the water intake of the fishing plant, and dredging the river bed by 2m to 2.5m. This work is expected to take two years, conducted along a dry streambed and only during the winter.

A vertical turbine of the type PL15-B-355 was eventually chosen in preference to a horizontal type of turbine. A further elaboration of the design led to the replacement of the PL15-B-355 with the PL20-B-400 runner; which allowed designers to avoid a deeper submergence of the rotor wheel.

The main specifications of the Minor Pirenga Hydropower Plant were ultimately decided as follows [22,23]:

Site class	II
Normal head water level VB	138.00m
Dead storage level	135.58m
Flow rate	75.20m^2/s
Design-based head	9.90m
Installed capacity	6.00 mW
Firm capacity	1.96 mW
Annual average power output	29.5 million kWh
Number of turbines	1
Runner type	PL20-B-400
Total reservoir capacity	3.12 km^3
Effective reservoir capacity	0.48 km^3

The hydropower system consists of the power house, and the headrace and tailrace canals. The power house is of run-of-river type and is located on the left shore of the Pirenga on the axis of the existing log chute. A bridge running along the power house is designed on the side of the tailrace at the 135.92 m mark. An assembly yard is located in the right flank of the turbine house, on the level of the access driveway. Installed at the left flank of the turbine house is a 150 kW outdoor switchboard and the main step-up transformer TDN-16000/150 VI.

The plant's energy input into the grid will be implemented through a tap connected to the 150 kW transmission line, which runs 600m away from the construction site. The main grid of the Pirenga Hydropower Plant at the voltage of 150kW is the following circuit: transformer – circuit-breaker line; at a generator voltage, the grid is a single unit: generator – transformer without the breaker. In terms of administration and operating management, the plant can fall under the jurisdiction of the Niva Cascade. One operator will be on duty at the plant.

The total construction period is estimated to span over three years, including a one-year preparation period.

Small-scale hydropower cascade on the Big Olenka River (Position 2 and 3, Fig.3.9). The Big Olenka falls into Porchnikha Bay on the Barents Sea 12 kilometers east from the settlement of Dalniye Zelentsy. Lengidroproyekt has determined two sites for the construction of small-scale hydropower plants on the Big Olenka: 13.7 km and 4 km respectively from the river's mouth. At the upper site, located 13.7 km from the estuary, the headwater level of the control structure is 125 m, and the available depth of reservoir drawdown is 10m. With an average multi-year flow of 8.63 m^3/s and an inflow volume of 272 million m^3, the effective reservoir capacity of 27.8 million m^3 will allow for seasonal regulation, which, in turn, will allow for the construction at this site of a small-scale hydropower plant with an installed capacity of 5 MW and an annual power output of 24.9 million kWh.

At the downstream site, which is located 4 km from the estuary, the normal head water level has been set at 55m, and a choice has been made for a synchronized operation of the two power plants on the streamflow regulated by the headrace reservoir. The second hydroplant's capacity will be 4.8 MW with an annual energy production of 24.2 million kWh.

The structures of the first hydroplant include: a 35m-high embankment dam, a 13m-high dam, construction tube, discharge sluice with a chute, and station control point with a penstock of 2.2m in diameter and 2.5 km long.

The structures of the second hydroplant include: a 35m-high embankment dam, construction tube, discharge sluice with a canal, and station control point with a 1,185m headrace canal and a penstock of 2.2m in diameter and 660m long

Each of the two plants will have one turbine with PO45 and PO75 rotor wheels of 1.2m in diameter to match designed head values of 44.5m and 50.8 m, respectively. The site is of Class III. With the voltage of 35 kV, the cascade's power will be transferred through a twin-circuit line of around 30 km to the Serebryanka-2 Hydropower Plant. Between themselves, the plants will be connected by a 35 kV, 10 km power line. Each power plant will have one duty operator on site. The cascade will be managed both in terms of operation and administrative jurisdiction by the Serebryanka Cascade. The construction period is slated to run four years.

Small-scale hydropower plant cascade on the Ura River (Position 4 and 5, Fig.3.9). The Ura River takes its origin from Lake Ur and falls into the Gulf of Ura-guba of the Barents Sea. The bed of the river runs parallel to the Western Litsa River at a consistent average distance of 20 km to the east.

Two sites are suggested on Ura River for the construction of small-scale hydropower plants: on an anabranch near Lake Nelyavr, and on an anabranch of the Ura, which flows out of Lake Kyadelyavr and falls into the river 19 km from its estuary. The headrace reservoir of the first future hydropower plant is Lake Nelyavr itself. The NHWL here has been chosen to be the natural value of the maximum lake level, or 143 m, while the minimum headwater level would be the lake's minimum natural level, or 141.4 m. With an average annual flow rate of 3.8 m^3/s and head of 33 m, the first hydropower plant will have the installed capacity of 1.62 mW and an annual output of 8.77 million kWh.

The second, tailrace hydroplant will use the flow coming from the upper plant and additional flow from Lake Kyadelyavr. A small water reservoir that will be created by these waterworks will have an NHWL of 95 m, a dead storage level of 83 m, and a mean head of 43.6 m. The second plant's installed capacity can reach 3.02 mW, while its annual power output can be 15.27 million kWh.

The structures of the cascade's upper plant will include: an embankment dam 25 m high, a 9.0 m bank, a spillway, a slot with a railway bridge, station control with a pressure penstock 445 m long and 1.2m in diameter.

The lower power plant will consist of: an embankment dam 20m high, a spillway, station control with a 1,500 m long supply channel and a pressure penstock 300m long and 1.7 m in diameter.

Each hydropower plant will be equipped with one turbine unit of the PO45 type. The runner wheels will be 0.84 m and 1.0 m in diameter, respectively, which will ensure the different discharge capacities.

The cascade will transfer the generated power at the voltage of 35 kV to Pervy Mai Substation 98. The length of the transmission line is about 12 km. Operation control over the cascade can be performed remotely by a dispatcher at the Tuloma Hydropower Plant, without the help of any personnel on duty at the site. The construction period is estimated at 3 years. The site will have Class III.

Small-scale hydropower plant on the Western Litsa (Position 6, Fig. 3.9). The Western Litsa classifies as a medium-size river. It runs south to north 50 to 55 kilometers west of the city of Murmansk.

The site chosen for a small-scale hydropower plant on the Western Litsa is located 30.3 km from its estuary. With the NHWL and dead storage level as most optimal values for this site - 95 m and 93 m, respectively – the installed capacity of the plant can reach 1.6 mW, provided the design-based flow rate is 15.1 m^3/s and head is 12.6 m. An annual average power output can then reach about 8 million kWh. However, as calculations of the construction costs of this power plant were finalized, the project had to be rejected and the site was removed from the list of sites recommended for construction [22].

Small-scale hydropower plant on the Titovka River (Position 7, Fig. 3.9). The Titovka River flows out of Lake Chept-yavr and into Titovaya Bay of the Motovsky Gulf of the Barents Sea. The river bed runs parallel to the Western Litsa River 2.5 km west from the latter. The site for the small power plant is located on the Titovka 19.75 km from the river's estuary. Based on optimization estimates, the NHWL was determined at 100m, and dead storage level at 90m, which will ensure the average multi-year flow rate at 13.4 m^3/s and an average head of 20m. The installed capacity of the plant will be 3.38 mW, and its annual energy yield will be 15.8 million kWh. Effective storage capacity will then reach 63.3 million m^3. The site's structures will include: an embankment dam 31 m high, a spillway, and station control with a pressure penstock 162 m long and 3.0 m in diameter. The plant will have one turbine unit of the Kaplan type, a PL30, with the runner wheel 1.8 in diameter.

The power generated by the Titovka Hydropower Plant can be transferred at the voltage of 35 kW through Substation 21 by a 28km-long transmission line. Administration and operation of the power plant will likely be managed by the Tuloma Cascade without the help of duty personnel on site. The plant can be operated remotely by a dispatcher at the Tuloma Cascade. The planned construction period is four years. The structures will have Class III.

Small hydropower plant cascade on the Tumcha River (Position 8 and 9, Fig. 3.9). The Tumcha River originates in Finland, where it is called Tuntsajoki (in Finnish spelling), and then falls into the Iova Hydropower Plant's reservoir built on the Kovda River in 1960. Three hydrosites are suggested as possible construction sites on the river: at the marks of 89 km, 74 km and 18.4 km from the river's estuary. Based on the results of energy efficiency and economic estimates, water surface elevation levels for the hydroturbine units have been determined, for a diversion-type operation.

For the first hydropower plant, located 89 km from the river's mouth, the NHWL is 230m, and dead storage level is 216 m. Average head, created by the dam and diversion, reaches 30 m. At an average multiyear flow of 23.3 m³/s and a head of 37.2 m, an installed capacity of 12.2 mW and an annual power output of 55.9 million kWh can be achieved. The water reservoir to be built at the site will have the effective storage capacity of 148 million m³, which will allow for an increase of the average flow rate up to 38 m³/s.

For the second plant, to be located 74 km from the estuary, the NHWL is 190 m, dead storage level 180m, and average head 24 m. The average flow rate reaches up to 40.1 m³/s, which permits construction of one turbine unit at the site (just like at the headrace hydroplant of the cascade) with a capacity of 8.4 MW. The average annual energy yield of the plant can be 40.4 million kWh.

The tailrace plant of the cascade, to be built 18 km from the river's mouth, will have the NHWL of 100 m, and a dead storage level of 98 m. The average head at the plant is 25 m (obtained by a dam plus diversion), which, at an annual flow rate of 78.2 m³/s, makes it possible to install two turbine units with a total capacity of 16.9 MW and reach an average annual power output of 74.6 million kWh.

The structure of the first plant will consist of: an embankment dam 45 m high, a 120 m bank, a construction tube, water discharge sluice with a spillway, a station control structure with a penstock 300 m long and 3.8 m in diameter. The design of the second hydropower plant is different in that its embankment dam is smaller: 35m high. It will have no bank, and the length of the penstock will be 268 m. The rest of the structures are the same as at the first plant.

The tailrace plant of the cascade has the same set of constructions as the second plant and is only different for the height of the embankment dam (20 m), and for its two banks, each 12 m high. The control structure of this plant has a headrace canal 5.1 km long, two penstocks 3.8 m in diameter, and two hydroturbine units in the power house instead of one, in contrast to the headrace plants of the cascade.

The hydroturbine unit of the headrace plant will be equipped with a Francis turbine of the PO45 type 2.12 m in diameter, and the hydraulic units of the tailrace plants will have three Kaplan-type PL30 turbines 2.65 m in diameter. The hydropower generators of all the three plants of the cascade will have a split stator, which will facilitate their transportation to where they will be mounted on the site.

The total capacity of the system-integrated cascade on the Tumcha is estimated at 38 MW, which will allow transferring its power at a voltage of 150 kV through Substation 95 to the area of the city of Kovdor, where relatively large-scale industrial energy consumers are located. The total length of the 150 kV transmission lines required for the connection of these power plants with the grid is 130 km. The cost of this project reaches RUR 12.5 million in prices relevant to 1991.

The management of the cascade is planned to be put into the purview of the dispatcher at the Niva Cascade, who will be operating the site using remote control. The full construction period of the first two hydropower plants is expected to be seven years. The third power plant is estimated to be built in a period of four years. All structures will have Class III.

The Tumcha Cascade is assumed to be one of the most economically efficient projects of all the small-scale hydropower plants suggested for construction in the region, which estimation is especially applicable to the two upper plants.

Small-scale hydropower plant on the Umba River (Position 11, Fig.3.9). The basin of the Umba, which falls into Kandalaksha Bay on the White sea, is located in the southwest of the Kola Peninsula and abuts the basin of the Niva River in the west. The river's length is 125 km, and its total fall is 151.6 m. The prospects of applying the potential of the Umba for energy uses are significantly complicated by its importance for the fishing industry, and by the requirements imposed on the regulation regime reserved for the water level of Lake Umbozero and the river's flow rate. At the first stages of the river's hydroenergy development study, an alternative was being assessed where river flow would be partially diverted to Lake Lovozero, which feeds the Serebryanka Cascade. No such option is currently under consideration.

For the small hydropower plant suggested for the Umba, an NHWL of 135m has been estimated as the best option, which would allow achieving a head of 10 m. With an average multi-year flow of 42 m³/s, the installed capacity of the plant will be 3.02 mW, and an average annual output will reach 15.27 million kWh. The plant will have: an embankment dam 15.0 m high, two banks with a height of 5 m each, a discharge sluice and a run-of-river-type power house with one turbine unit, equipped with a PL-15 Kaplan turbine 3.35 m in diameter. These will be Class III waterworks.

The plant is expected to transfer its power at a voltage of 35 kV to Substation 76, located 35 km from the site. The installation of the transmission circuit is estimated to cost RUR 2.9 million. The site can be operated without personnel on duty by a dispatcher at the Niva Cascade with the help of remote control. The estimated construction period is three years, and project investments will have to reach RUR 22.6 million, including the construction and assembly costs of RUR 17.3 million. The economic efficiency of the site, with prices and power rates taken at the level of those pertinent to the mid-1990s, is demonstrated in [22]. But following the demand brought forward by fishery inspections, further works on the Umba project were halted.

Of the small-scale hydroelectric power plants highlighted in Table 3.2, the site suggested for the river Lotta has so far remained outside the scope of this overview. This hydropower plant is planned to supply energy to the settlement of Svetly, which is currently not connected with a central energy grid. The Lotta site will be examined further in the report, in the section outlining the use of small-scale hydropower plants for the needs of remote and isolated energy users.

The main energy efficiency characteristics of small system-integrated hydroelectric power plants described above are summarized in Table 3.2. It is the first six rivers presented in the table that are currently slated as construction sites for small-scale hydropower plants in accordance with the official development strategy of Kolenergo and TGK-1. Total installed capacity of these small hydropower plants is 61 mW, and a total energy output is 300 million kWh. The Pirenga and Tumcha projects are now estimated to be the most efficient and most elaborated in design. On the whole, however, the overall volumes of investment required for the construction of any of these power plants, though modest in comparison with funds needed for a site related to the "major" industry, will still outreach those that small settlements or small companies like cooperatives or collective farms could attract.

3.5. Small hydroelectric power plants for remote and isolated consumer groups

In the 1950s, the Murmansk region was home to around 10 small hydropower plants that provided electric power to remote settlements and villages of the area [20] However, information about them is partially lost, and it was possible to ascertain only three sites of former hydropower plants: one on the Chavanga river, one on the Kolvitza and one on a nameless river in the Kovdor district. All of these small hydropower plants have been completely destroyed since the 1950s, and the Kolvitsa has been announced off limits for energy exploration because of its importance for the fishing industry.

At present, around 80 to 100 population areas and isolated localities in the Murmansk region fall outside the coverage of the central electric power supply. Their power consumption ranges from between 5 kW and 10 kW to between 500 kW and 800 kW. The process of selecting priority hydrosites for the construction of small hydropower plants has to be based on the technical potential of small rivers, their remoteness to the consumer and the latter's demand in energy.

When considered in these terms, the village of Krasnoshchelye happens to be one of the most characteristic in the Murmansk region. It is located in the center of the Kola Peninsula at a distance of more than 150 km from the nearest central energy supply source. Besides air transport, the village has no connection to other areas except a sleigh road during winter. Central electric power supply is not planned for this village even in the remote future. Currently, the main energy source for this place is a diesel power station with a capacity of 800 kW and an average annual output of 1.25 million kWh. The village's maximum daily load in December is 320 kW, with a potential future growth to 500 kW [20].

Other typical decentralized consumers in the Murmansk region are the villages of Chavanga and Chapoma on the coast of the south-western part of the Kola Peninsula. Each is located at the estuary of a river bearing the same name. Fuel supply is a serious challenge here due to lack of a motor road and is only possible by ship transport during the summer. Electric power consumption in Chavanga is currently about 1 million kWh. The maximum load reaches 235 kW. Energy consumption in Chapoma is commensurable with that of Chavanga, and its load approaches the Chavanga values [20].

Remote military and border patrol settlements are another example of isolated consumers. The village of Svetly is located near the bed of the Lotta River and has no centralized power coverage. A small-scale hydropower plant on the Lotta is suggested [22] to supply energy to this location and other consumers residing close to the river.

Four tributaries to the Ponoi were under consideration as the potential sites for a small-scale hydropower plant to cover energy needs of Krasnoshchelye. 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 has been their distance from the consumer. The site on the Yelreka River is located only 6 km from Krasnoshchelye, which was the major contributing factor when the decision was made to choose it for construction.

Sites for small hydropower plants in the south-western coast of the Kola Peninsula were determined in [20]. Five rivers were evaluated for potential construction: Varzuga, Chavanga, Strelna, Chapoma, and Pyalitsa. The Varzuga and Strelna options have been rejected as too important for fishery (these two rivers account for about 52% of the entire region's salmon catch). The Pyalitsa, with its significantly smaller hydropower potential compared to those of the rivers Chavanga and Chapoma – 11.6 mW against 17.6 mW and 20.3 mW, respectively – is furthermore located at a considerable distance from prospective consumers and offers fewer advantages in topographic and hydrological terms. Consequently, the final choice was made in favor of the rivers Chavanga and Chapoma. Given the geological and hydrological conditions and the integrity of the unique waterfalls that these rivers boast, a site located 8.5 km from the Chavanga's estuary was given first priority.

Attention should also be given to the prospects of construction of a small hydropower plant on the Lotta, a river in the western part of the Murmansk region, not far from the state border. After crossing the Russian-Finnish border, a long stretch of this river runs southwest to northeast parallel to the Raya-Yoseppi-Upper Tuloma highway. A suitable hydrosite for a small hydropower plant has been chosen at the 38th km mark from the river's estuary. Energy and economic efficiency assessments revealed that the optimal high-water elevation of the plant's reservoir is likely to be 93m [22].

Outlined below are three available small hydropower sites capable of providing energy supply for remote isolated consumers.

Small-scale hydropower plant on the Yelreka River (Position 12, Fig. 3.9). The arrangement of the main components of the small-scaled hydropower plant on the Yelreka, as well as the calculation of its main parameters, has been performed with regard to the preliminary stage of the project's feasibility study [20,24].

When selecting the arrangement and type of structures to be included into the plant, the significant remoteness of the construction area, availability of building materials locally, and a maximum possible unification of concrete and metal construction elements were taken into consideration.

The site has been chosen at the 12 km mark away from the river's estuary. The optimal headrace is 164 m, the reservoir's complete area is 12.3 million m^2, and the effective storage capacity is 37 million m^3. The selection of and calculations for the unified types of buildings needed for the small-scale hydroplant on the Yelreka (also called Yelyok) were performed in accordance with recommendations [24] based on a requirement specifying minimal amount of construction works with a given water wheel diameter and maximum head. A decision was also made that a two-unit hydropower plant will be built instead of one that would be smaller (in terms of the amount of construction works needed for the plant's building). This decision was based on considerations of improved operation reliability and simplified procedures of its operation during planned repair works in the summer.

All options considered for the possible estimated installed capacities of the future plant were based on the same arrangement of the main hydraulic structures. The value of the maximum possible head – nine meters – determined the type of the future power house. A run-of-river turbine house was chosen with pressure turbine pits and vertical Kaplan turbines. For use in turbine houses of the run-of-river type, such pits are made within the concrete block of the plant's underwater part. Here, a typical configuration was chosen, with the turbine house's underwater part equipped with a straight draft tube. All variants of the dam were assumed as earth-and-rock fill dams with a moraine impervious core. The dams' top width is 8 m, and slope base is 1:1.3. The site's width is 1,100 m at an NHWL of 164 m. A concrete wide-crest overfall dam was considered for use as the spillway.

To determine the best installed capacity for the small-scale hydropower plant on the Yelreka, the main energy and power parameters were estimated in accordance with five possible output values: 300, 500, 600, 800 and 1,000 kW. Potential construction and operation costs were estimated also in case the option of a combined operation of the small hydropower plant and a diesel power plant was chosen. The optimal value for the installed capacity of the hydropower plant on the Yelreka was finally set at 500 kW, provided it is operated in combination with the diesel power plant, with the latter's installed capacity of 300 kW. 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.

In conclusion, the solution to supplying electric power coverage for the village of Krasnoshchelye can be provided by a run-of-river small-scale hydropower plant with a recommended installed capacity of 500kW and two turbine units with the rotor diameter of 1m and an estimated head of 6m.

Small-scale hydropower plant on the Chavanga River (Position 13, Fig. 3.9). The future hydropower plant's site is 8.5 km from the estuary of the river and 7.5 km away from the nearest settlement. The NHWL is 54.4 m. The useful water storage capacity is 8.3 million m^3. Such capacity values, in combination with the considerable river water content – the average flow is $15m^3/s$ – allows for the unrestricted daily and partial seasonal regulation. The head at the hydrosite ranges from 9 m to 15 m [24].

To determine the optimal value for the installed capacity of the hydropower plant, a combined operation of the hydrosite and a diesel power plant was again examined, with a range of capacity values of between 300 kW and 1500 kW taken into consideration. The optimal installed capacity was finally estimated at 1,250 kW. Such capacity can also ensure power supply to neighboring villages of Chapoma, Tetrino, Strelna and Pyalitsa, and provide good groundwork for their future development

The accepted hydropower plant project option – a reservoir-type hydropower plant with the installed capacity of 1,250 kW – will have two turbine units with the rotor diameter of 1.0 m and a standard power house with short pressure penstocks and bent suction tubes. The intake chamber will be equipped with suspended motor-driven cranes, slide gates and intake screens. The length of the power house is 12m, and its width is 7 m. A chute will be used as the spillway, coupled with the fish pass. In order to preserve salmon stock, the fish ladder will consist of 16 pools three by five meters each and two resting pools three by ten meters each. The fish ladder is designed for a 10m head. The fish ladder's total length is 190 m.

The hydrosite's earth-and-rock fill dam with the impervious core made of moraine is 903 m long; its top width is 8 m, and slope base 1:1.3. The structures' main parameters are shown in Table 3.3.

Table 3.3.

Main parameters of the small-scale hydrosite on the river Chavanga.

Item	Parameter	Value
1	Width of river bed, m	37
2	Base valley width, m	150
3	Right bank height, m	15
4	Left bank height, m	15
5	Right bank slope, %	4.41
6	Left bank slope, %	2.79
7	Top valley width, m	709
8	Base type	Gneiss
9	Right bank formation	Clay with boulders
10	Left bank formation	Glacial origin

Small-scale hydropower plant on the Lotta River. Average head at this site is estimated at 8.7 m, and average flow rate at 34 m³/s. Under these parameters, the installed capacity of one turbine unit of the future site will be 2.68 mW, and average annual output will reach 12.4 million kWh. The turbine wheel of the PL15 type will be 2.65 m in diameter and will have a rotation speed of 166.7 rpm [22]. The hydropower plant's structures will include: an 11 m embankment dam, a spillway, and a station control building with the run-of-river-type power house. The site will be of Class III.

Because of the considerable distance from the prospective consumers, the generated power is expected to be transferred by a 28 km transmission line at a voltage of 35 kV to the village of Svetly, where a step-down substation of 35/10 kV will have to be built. The Lotta Hydropower Plant can be managed, both operation-wise and administratively, by the Tuloma Cascade. The construction period is slated to run three years.

Altogether, three hydropower sites are suggested as first priority small-scale hydroelectric power plants for the areas of decentralized power supply in the Murmansk region. Their specific parameters are summarized in Table 3.4. All hydrosites are designed for half-peak and half-off-peak load conditions and are assumed to serve as main sources of energy for the remote consumer. This results in a certain decrease in the installed capacities of these plants, and technically, a decrease in their economic efficiency when compared to the system-integrated small-scale hydropower plants. However, this will not mean that they are inferior to their system-based counterparts. Their indispensability as energy sources in remote locations can outweigh the demand of the grid for additional capacity and output for the energy system. There is no necessity to determine a fixed construction priority list for the sites outlined in Table 3.4. Each of them is important for the needs of its local consumers, and only these particular energy needs and the local conditions of the site can serve as basis for a decision on the time frames of the construction start. However, it is of utmost importance to complete construction works on all these small-scale hydrosites within one year without allowing the capital investment to dry up. In our opinion, funding for the construction of these hydropower plants should be attracted from several different sources: prospective energy consumers, municipal and regional administrations, the region's energy system, other state organizations and enterprises, and private businesses, including foreign investment, where possible.

Table 3.4

Main technical and economic parameters of small-scale hydroelectric power plants suggested for use as electric power suppliers for isolated consumer groups in the Murmansk region.

River, name	Installed capacity, kW	Average annual output, kWh	Head, m	Average flow rate, м³/s	Unit capital costs, US dollars/kW	Construction period, years
Yelreka	500	2.7	6	10	870	Up to 2
Chavanga	1250	6.3	10	15	352	1
Lotta	2680	12.4	8.7	34	287	3

Along with the small hydropower plant projects described above, potential construction was also considered on the following rivers of the Murmansk region: Pecha (Lebyazhya), Srednyaya (Shchuchya), Big Tyuva and Small Tyuva, Uritsa, Seidyavryok, Sergivan, and Nevga. Potentially suitable hydro sites are determined for the construction of small-scale hydropower plants on these rivers. Their technical specifications will be elaborated later. Some of these sites are preferable for use as system-integrated power plants. Others warrant the construction of isolated hydropower plants due to the remote location of their sites, with regard to substations and transmission lines, and due to their closeness to small isolated consumer groups.

4. TIDAL ENERGY

4.1. Tidal energy's distinctive features

The possibility of harvesting tidal energy on the Russian coastlines was first brought to attention by Valerian Lyakhnitsky in his work "Blue coal," published in 1926 [25]. Since 1938, further research on this issue was carried out in Russia by Lev Bernstein, who conducted a reconnaissance survey of the shorelines of the Barents and White seas to identify optimal sites there for the potential construction of tidal power plants (TPPs). Bernstein is also credited with having developed an efficient tidal energy converter design – the floating power plant [7] – which allows for more cost-effective construction. Later, he supervised the creation of the experimental Kislaya Bay TPP, where his design was first put into use. Bernstein was also in charge of design projects involving developing large-capacity TPPs at the Scientific Research Institute Gidroproyekt.

The new design's main attraction is based on the application of such an important feature of tidal energy as the invariability of its average monthly capacity, which does not depend on the fluctuations of water content or dryness throughout the year or across a number of years. Because of this, tidal energy – despite its intermittence within the daily cycle and its instability in the course of the lunar month – remains a powerful energy source, which can be harnessed in combination with river-based hydropower plants outfitted with water reservoirs.

Merged with the capability of streamflow energy, the pulsating and interrupted, but invariably guaranteed flow of tidal power, regulated by the energy of the river hydropower plants, can make very tangible contributions to the variable part of the energy system's load. Thus it will both make the existing thermal power plants and nuclear power plants easier and more effective to operate, and less taxing on the environment, and make the necessity to build new power stations that run on fossil fuels and pollute the environment obsolete.

4.2. Recommended TPP sites and their energy potential

Evaluating the power potential of tidal energy according to a specific geographical area is distinctively different from such assessments done with regard to gross theoretical potentials of the hydropower of rivers. Where a river's streamflow is concerned, the gross theoretical potential is estimated as a coefficient-modified product of average normal water flow rate across a multi-year period by gross head along the whole river's water fall. In the case of river flow taken in its natural condition, the energy is spent on friction, turbulent exchange and erosive treatment of the bed. But with the tidal basin, the energy potential is expressed in the work performed by the tide within a year's time as the levels rise and fall during every tidal cycle. With that in mind, the main arguments governing the estimation of a tidal installation's capacity are not the flow rate or the head, but the area of the basin and the tidal height.

The weight of water lifted and dropped by the tide is calculated as:

$$G = AS\gamma , \tag{4.1}$$

where A is tidal height, m;

S is the area of the basin, m^2; and

γ is the specific weight of sea water, κN/m^3.

The work performed by a tide within one tidal cycle assuming no surface slopes are present – that is, when the basin is filled instantaneously – will be expressed by the product of the weight of water G lifted and dropped by the tide by the height A/2 of gravity center elevation [7]:

$$P = \frac{A}{2} \cdot A \cdot S \cdot \gamma \quad . \qquad (4.2)$$

The value of work executed in 24 hours is 3.87·P (3.87 being the number of half-cycles of tide fluctuations per 24 hours). Dividing daily tidal work by the number of seconds in 24 hours and taking into consideration the specific weight of sea water γ equaling 10.05 kN/m³, will give the average daily potential of tidal capacity:

$$N_p = \frac{3.87 \cdot A^2 \cdot S \cdot 10.05}{2 \cdot 24 \cdot 3600} = 2.25 \cdot 10^{-4} \cdot A_{av}^2 \cdot S \text{, kW} \qquad (4.3)$$

This capacity can not be assumed as the basis for the estimation of the installed capacity of the TPP, since this value is average. That being said, potential capacity value can be used to estimate the annual reserves of potential energy of the tidal basin:

$$E_p = 8760 \cdot 2.25 \cdot 10^{-4} \cdot A_{av}^2 \cdot S = 1.97 \cdot A_{av}^2 \cdot S \text{, kWh} \qquad (4.4)$$

The initial survey of the coastline of the Barents and White seas to reveal sites suitable for possible construction of tidal power plants was done by Berstein in 1938 through 1941. Already then, first sites for TPP construction on the coasts of the Kola Peninsula were originally chosen (Fig. 4.1).

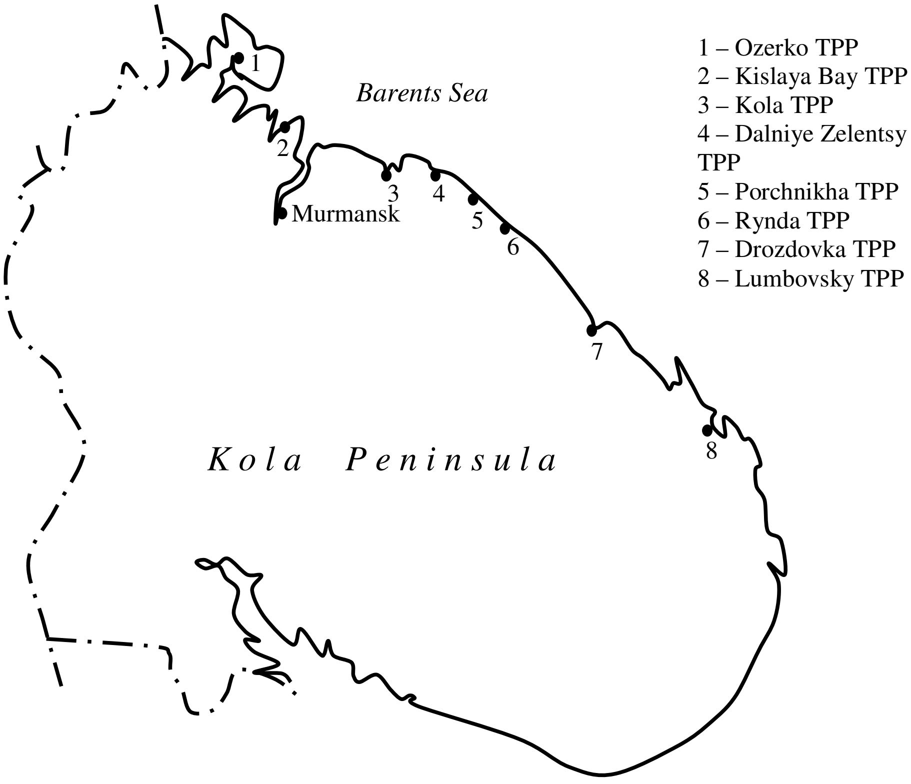


Fig. 4.1. Possible distribution of TPPs on the Kola Peninsula's coastline.

Because of the relatively small tidal range on the coasts of the Kola Peninsula ($A_{av} = 2-3m$) and a limited number of water basins that can be cut off by a dam, construction on some of the suggested TPP sites will prove from the very outset to be economically inexpedient. Among the perceived exceptions is Lumbovsky Bay, where the average tidal height is 4.2 m, and the size of the water basin that can be cut off by the dam is between 70 and 90 km^2. Different options for the use of the bay (Fig. 4.2) for TPP construction will allow building a TPP here with a capacity ranging between 320 MW and 670 MW and an average annual output of between 750 MWh and 2,000 MWh, respectively.

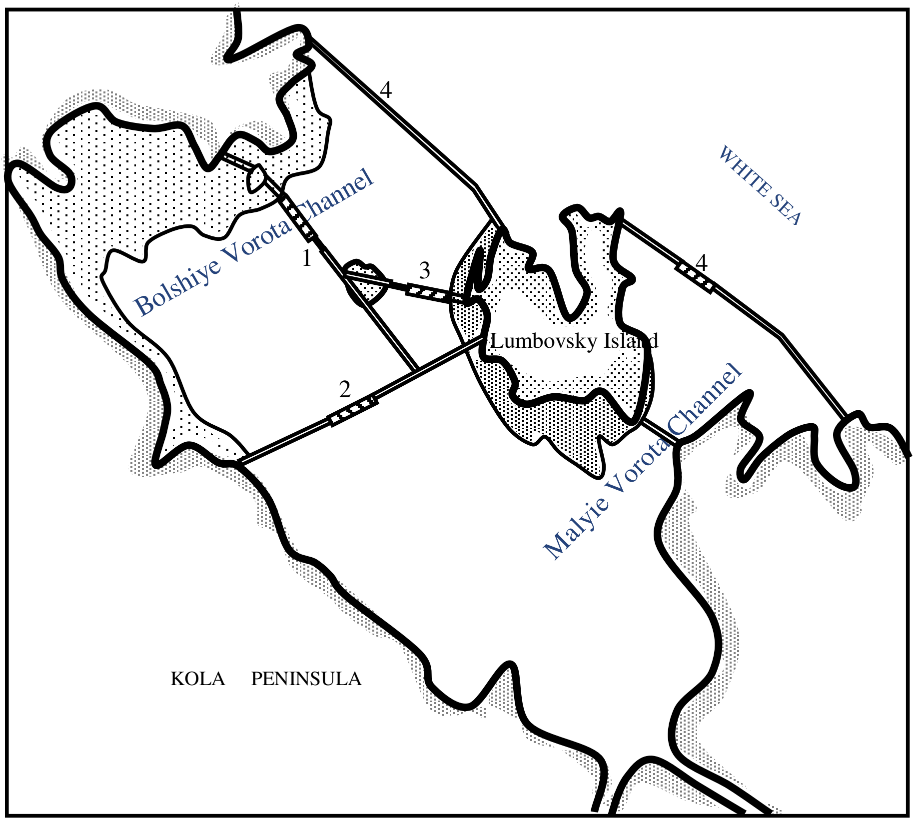


Fig. 4.2. Different options for Lumbovsky TPP construction [7]

.1 – one-basin TPP of one-way operation, N = 200 mW, 20 vertical units, D_1 = 9 m,
2 – small one-basin TPP, 13 units, N = 143 mW, E = 415 GWh;
1 – 2 – two-basin TPP, Dekker cycle, 22 units; N = 95 mW; E = 460 GWh;
1 – 2 – 3 – two-basin TPP, Bernstein cycle, 45 units, N = 190 mW; E = 640 GWh;
4 – one-basin TPP, design of 1977 – 1983, 64 units, N = 670 mW; E = 2 TWh.

However, the remote location of the Lumbovsky site was the reason construction priorities were shifted toward a system of tidal power plants at Mezen, where tidal height reaches 10 m (A_{av} = 5.6 m). The blocking of the bay in the cross section between the capes of Abramov and Mikhailovsky (Fig.4.3) will require building a dam 90 km long. A dam of such length is justified by the estimation that the basin area to be cut off – 2,300 km^2 – and the available water height will allow reaching 15 million kW in annual capacity and generating 50 TWh in electric power output per year.

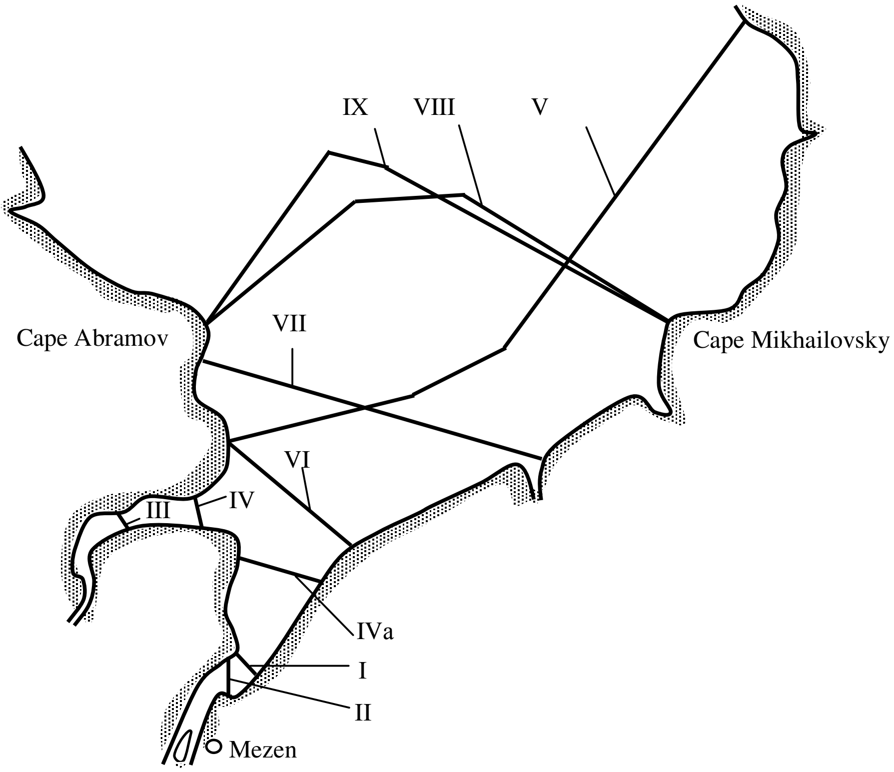


Fig. 4.3 Different options for Mezen TPP construction [7]

I – 1935, L_a = 2.8 km; 45 2.5 mW units and 40 openings; two-way operation system;
N = 112 mW; E = 0.48 TWh;
II – 1940, L_a = 3.5 km; one-way operation system; N = 350 mW; E = 1.0 TWh;
III – 1940, N = 250 mW; E = 0.67 TWh;
IV – 1960 –1962, L_a = 4 km; N = 500 mW; E = 1.35 TWh;
IVa – 1960 – 1962, L_a = 9 km; N = 1000 mW; E = 3 TWh;
V – 500 mW; E = 1.35 TWh;
VI and VII – 1976; L_a = 50 km; S = 860 km^2; N = 6 GW; E = 10 TWh;
VIII – 1976, L_a = 87 km; S = 2,215 km^2; 400 units; D (rotor diameter) = 8.5m; N = 8.8 GW;
E = 25 to 30 TWh
IX – 1983; L_a = 74.5 km; S = 2,330 km^2; N = 15.2 GW; E = 50 TWh; 800 units;
D = 10 m; two-way operation system

Because of the instability of tidal energy supply, the Gidroproyekt Institute was developing the project of powerful TPP installations at Mezen in conjunction with the construction of a pumped storage power station (PSPS) in the area of the peninsula of Rybachy, part of the Kola Peninsula, where such a project is warranted by exceptionally favorable conditions. Placed at economically acceptable distances from the electric grid and the projected TPP (100 km away from Murmansk, 1,200 km from St. Petersburg, and 680 km from the Mezen TPP), this PSPS will allow for the use of the efficient water storage capacity of 150 million m³, provided primarily by the lakes of Tsherskali and Yarvi, which are located on the territory of the Rybachy Peninsula at an approximate elevation of 200 m over sea level (Fig. 4.4). With the availability of powerful high-voltage links, the PSPS will enable operating the Mezen TPP at a half-peak load demand, at the same time supplying the Central-Northwest Russia grid with an additional capacity of over 3 million kW, the economically acceptable energy losses of less than 10% taken into consideration.

The electric circuit layout developed by Gidroproyekt for the application of tidal energy with the use of the Mezen TPP, is shown below in Fig. 4.4.

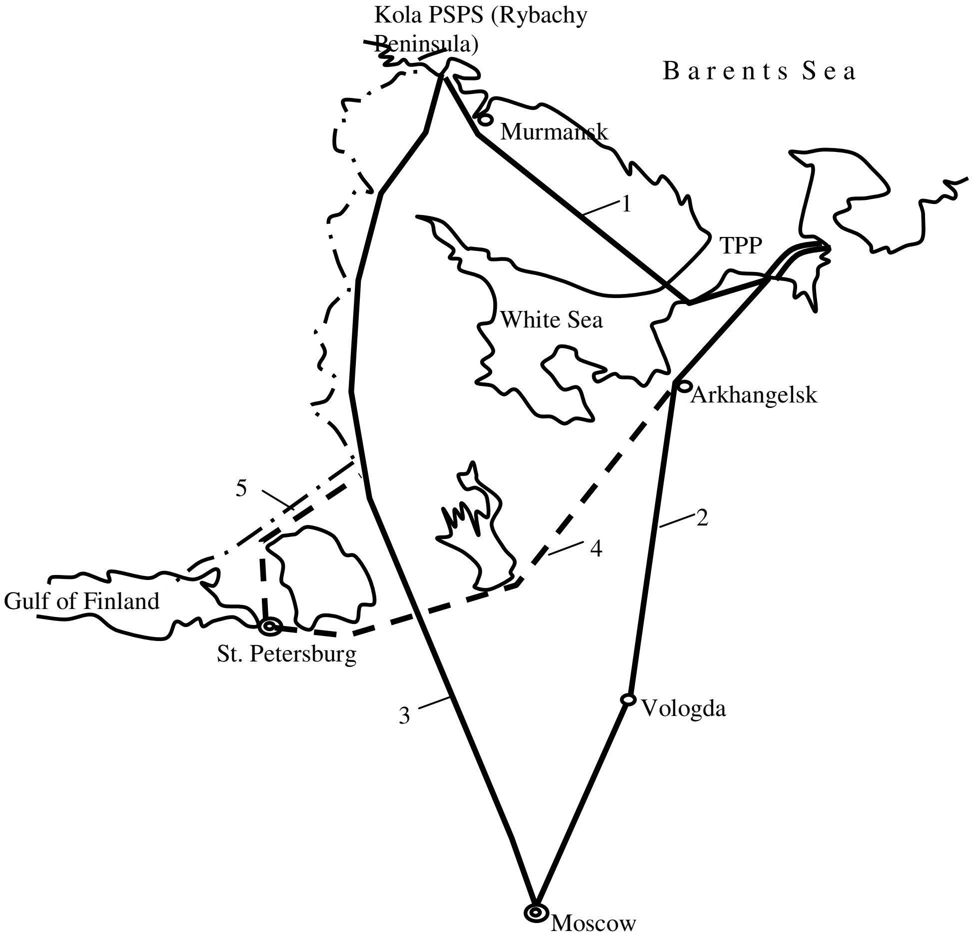


Fig. 4.4. Layout of the Mezen TPP-PSPS-Central Russia energy grid.

1 - Power transmission line between the PSPS and the Mezen TPP, 680 km;
2 - Power transmission line between Moscow and the Mezen TPP, 1,237 km;
3 - Power transmission line between the PSPS and Moscow, 1,620 km;
4 - Power transmission line between St. Petersburg and the Mezen TPP, 1,030 km;
5 - Power transmission line between St. Petersburg and the PSPS, 1,115 km.

Estimations of technical tidal energy resources at various sites chosen on the coasts of the Barents and White seas are summarized in Table 4.1. Estimations performed for the Mezen project show that, at a capacity of approximately 15 million kW, the site's annual output can reach 50 TWh.

Table 4.1

Technical tidal energy resources of the Barents and White seas

TPP, name	Tidal height A_{av} , m	Basin area S, km^2	Installed capacity N, mW	Annual energy output E, million kWh
Kislaya Bay	2.	1.1	0.4	1.0
Kola	2.36	4.9	40	28
Lumbovsky	4.2	92	670	2,000
Mezen	5.66	2,330	15,200	50,000

4.3. Readiness levels for the technical application of tidal energy

Kislaya Bay Experimental TPP Model. Construction of such a powerful TPP as the site at Mezen requires first the implementation of a comprehensive, complex program of scientific research and experimental and design works aimed at studying the energy of the tide and the development of relevant hydrotechnical equipment, new designs and construction methods. Such were the considerations that determined the decision to build an experimental tidal power plant in Kislaya Bay on the northern shore of the Kola Peninsula.

The choice of the site was impelled by the favorable nature conditions, the convenient land relief, and its closeness to industrially developed areas and high-voltage transmission lines. The small water area of the bay (1 km^2) connects to the sea by a narrow – 50 meters – and shallow channel (Fig. 4.5).

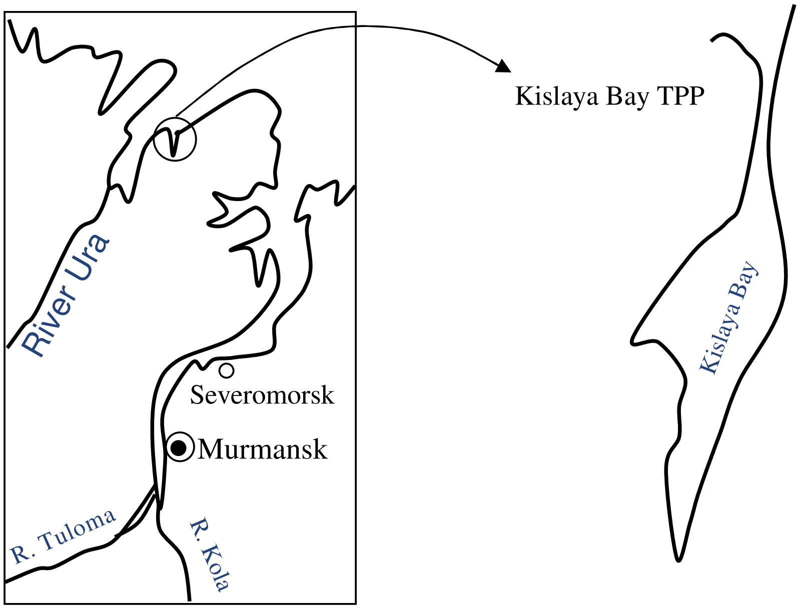


Fig. 4.5. Kislaya Bay TPP location.

The main task before TPP designers was achieving successful results of testing – and receiving a go-ahead on using – the thin-walled blocks that the TPP structures would consist of, to facilitate the station's towing by sea from Murmansk to the site and its installation on top of a ready-made underwater foundation. This task was expanded by the need to further examine the efficiency of the structures and TPP equipment under operation.

The floating carcass of the future building of the Kislaya Bay TPP was erected between 1964 and 1968 in Murmansk, in a building dock on the coast of Kola Bay. The building's dimensions are: 36 by 18 by 15 meters. The carcass is made of reinforced concrete elements 15 centimeters thick, its deadweight is 5,000 tons and its floating draft is 8.34 meters. While the floating unit was still in the building dock, it was outfitted with a 400 kW bulb turbine with a rotor 3.3 meters in diameter, which had been produced by the French company Neyrpic. Since the tidal power plant at La Rance in France, this type of turbine has become classic for tidal power installations. After the floating building of the TPP finished its 65-mile journey from Murmansk to Kislaya Bay – towed first along Kola Bay, then across the Barents Sea – it was erected on top of its foundation, prepared for it beforehand.

Long-term testing and studies of the operation of the Kislaya Bay TPP have proved the reliability of the thin-walled structures and the floating TPP construction design with regard to its durability, stability and filtration. The results of these studies have made crucial influence on further development of tidal power plant designs both in Russia and abroad.

Today, the Kislaya Bay Tidal Power Plant is administratively under the jurisdiction of the Tuloma Hydropower Plant Cascade. Its experimental operation was terminated in 1994 as all scientific objectives associated with running such a pilot model were achieved. Statistical data on the operation of the Kislaya Bay TPP show that its maximum annual energy output within the operation period was 1 GWh. Given an installed capacity of 400 kW, this value is in correspondence with the annual number of hours the installed capacity was put to use, which equaled 2,500. However, the average value of annual energy production at the TPP fell below the maximum mentioned above because of experimental works carried out on the plant's turbine unit.

After the Kislaya Bay TPP was taken out of operation, the sluices were closed for 12 months, which led to fish kill in the upper part of Kislaya Bay, enclosed by the TPP's power house. The reservoir started to get desalted due to the flow of fresh water from small rivers that stream into the upper part of the bay, which was resulting in the demise of fish fauna and underwater plants. In view of this, an idle water conduit at the TPP power house was opened in 1995 to restore water circulation.

By now, the French bulb turbine manufactured by Neyrpic has been shut down and dismantled. In March 2005, a new turbine of the so-called orthogonal type was installed into the idle conduit. The rotor looks like a sort of a wheel hub, where the impeller components – the airfoils that create the tractive effort, which drives the rotation of the wheel – are located on the radial frames (Fig. 4.6). The orthogonal rotor designed for the type of tidal turbine at the Kislaya Bay TPP has a diameter of 2.5 m. According to representatives of the Kola Energy System, Kolenergo, the maximum efficiency rate of the rotor as shown by testing has reached 63%. The capacity of the asynchronous generator linked to the turbine is 200 kW. The maximum operational capacity developed by the new rotor has been estimated at 143 kW. The speed of the turbine is 72 RPM. The unit is equipped with a gearbox with a reduction transmission ratio of between 16 and 20. The rotor was manufactured at Zvyozdochka shipyard in Severodvinsk, Arkhangelsk region.

The same yard is currently building a rotor prototype for the Mezen site, a tidal power plant under development. This is a 12-meter rotor with flow section regulation and a diameter of 5 m. The first rotor sample, envisioned for a pilot study, will be attached to the old unit of the Kislaya Bay TPP and will remain under long-term testing. Rotor designers and engineers have made a decision to reject the old concept where turbine units were installed into concrete blocks, as was done at the Kislaya Bay plant, and have chosen steel caissons instead with following dimensions: length of 30 m, width of 11 m, and height of 15 m. The main advantage of orthogonal turbines is the simplicity of their manufacturing and their cost-efficiency as compared to the Kaplan turbines and the horizontal-axis bulb turbines traditionally in use at tidal power plants in France and Canada.

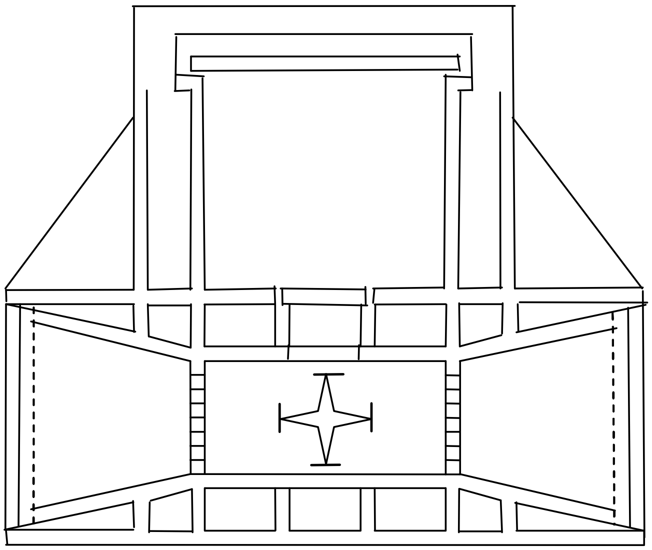


Fig. 4.6. An orthogonal TPP hydroturbine.

Kola TPP Pilot Model. As a next step in the development of practical application of tidal power, Gidroproyekt suggested the construction of an operational experimental model for the Kola TPP. The construction of the operational experimental Kola TPP on the Kola Peninsula is warranted by economic reasons: Here, the project's implementation will require significantly smaller costs than the unexplored coasts of Tugur Bay of the sea of Okhotsk, where the site's remote location from the centralized electric grid beats any reasoning behind building or running an industrially-used experimental TPP. When choosing a site for such a TPP among the coastal locations of the Kola Peninsula, several already acquired coastal areas of the peninsula were evaluated. First and foremost, these were the tailrace, or sea-based, ponds of the existing Lower Tuloma and Teriberka hydroelectric power plants. Yet, both projects were rejected as calculations showed that during the site's operation, the levels of the TPP's basin could reduce the output of the hydropower plants, which would have been located on higher grounds. Another project, in Drozdovka Bay, was examined and discarded, as certain unsuitable geological conditions were found at the suggested site.

The Kola TPP found its future location at a site in Dolgaya Bay, which is located 6 km from the village of Teriberka and 11 km from the Lower Teriberka Hydropower Plant

(Fig. 4.7). The project envisions installing two bulb turbines, each with a rotor diameter of 10m and an estimated capacity of 20 mW. The Kola TPP design was also suggested to become a prototype for the Tugur and Mezen TPPs.

But as the area of the basin to be cut off by the dam (A_{max} is 4m) and the tidal height (A_{av} of 2 to 3 m) in Dolgaya Bay are not sufficient for the fulfillment of all the potential capacity available in these hydrogenerating units – which are designed for commercial use at such large-scale TPPs as mentioned above – the annual output of the Kola TPP will only reach 30 million kWh at an installed capacity of 40 mW. Strictly speaking, the construction of this TPP in Dolgaya Bay is economically inexpedient exactly on account of these factors. But it is justified by the economic effect and the energy efficiency that can be achieved by using such bulb turbines at the Tugur and Mezen TPPs. This has been evidenced by the foreign experience gained in developing a powerful tidal power site in the Bay of Fundy, where the testing of a hydropower unit of new design necessitated the construction and operation of a new pilot TPP, the Annapolis Tidal Power Plant.

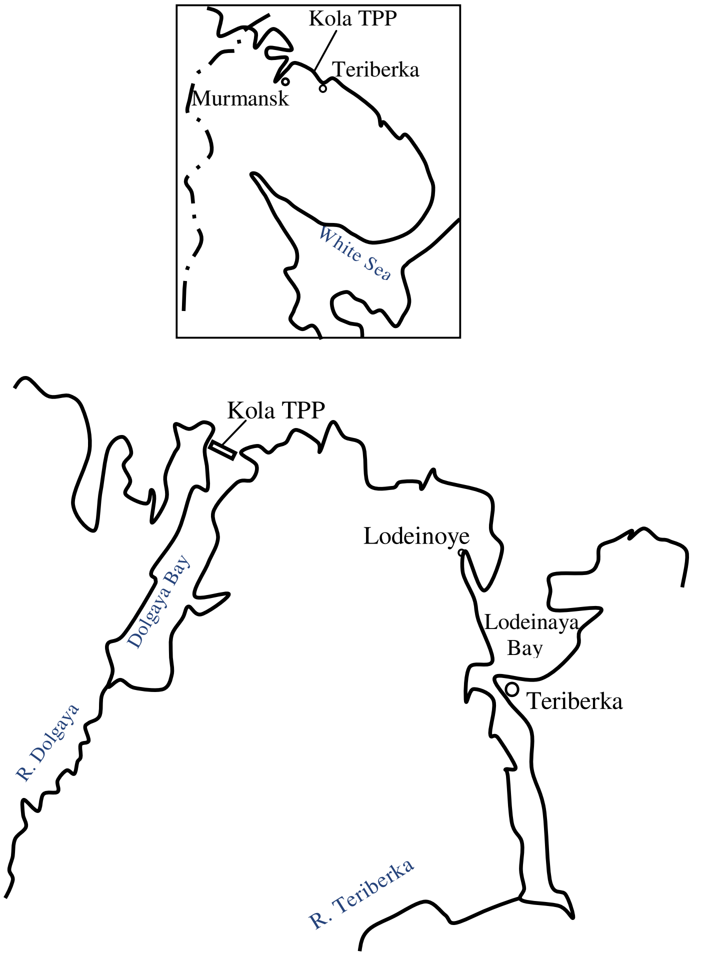


Fig. 4.7. Kola Pilot TPP's location.

Tugur TPP. It was the successful application of diversified large-scale floating constructions – such as the protective anti-flood dam in St. Petersburg or the 250 kV and 750 kV transmission line bridges across the river of Dnieper – that has allowed for a transition to the development of large tidal power plant projects. The Tugur TPP project was among the first to attract designers' consideration. This plant can be built by damming Tugur Bay, located in the southwestern part of the Sea of Okhotsk

The Tugur project, developed in conjunction with the hydroelectric power plants on the rivers Bureya and Uchur, can help the Russian Far East avoid the construction of a new coal-based thermal power plant, which would have to use the low-grade brown coal delivered from the Kansk-Achinsk coal basin in the Krasnoyark region, and by extension, the annual emissions of 40 million tons of CO_2 and other damaging pollutants. This TPP with an estimated capacity of 6.8 million kW can produce 16.2 TWh of energy per year. Further development of the project will involve field studies and a research into new designs of hydrogenerating units with rotor diameters unique for the site.

4.4. Environmental aspects of application of tidal energy

Tidal power plants are a source of ecologically clean energy. This fundamental notion stems from the fact that a TPP's operation is based on a one-basin, two-way system, which allows for the natural rhythm of the tide to remain unchanged. Application of tidal power plants excludes environmental pollution, which is an inevitable consequence of operating thermal power plants. Nor do TPPs require any submerging works, which are unavoidable where construction of hydroelectric power plants on lowland rivers is concerned.

Nearly 40 years of experience gained in operating the La Rance TPP in France demonstrates that the dam of a tidal power plant protects rivers from storm waves and water surges, which result in damage to river banks, and contributes to the improvement of the area's environmental conditions, decreasing muddiness and stimulating the development of marine culture and plankton biosynthesis. The regulated operation of this TPP has enhanced shipping conditions, while the barrage has become a convenient traffic artery which reduces distances between coastal cities.

The experience of operating the Kislaya Bay TPP will help uncover the scope of potential environmental consequences of the plant on Kislaya Bay and formulate recommendations for designers and developers aimed at keeping any negative effects of the TPP's construction to a minimum.

4.5. Tidal energy application prospects: A general assessment

Following a period of slack demand, electric energy needs in many Russian regions have started growing again in the past decade. Cold, and at times freezing weather, in January 2006 revealed an apparent lack of electric power capacities in the Central, Northwestern and other regions of the country. It is obvious that as industry and production continue to pick up, energy demand will keep growing as well, and so will deficits in electric power supply. It is possible to solve this problem by building new power plants running on fossil fuels, such as thermal stations and heat and electric power plants, or combined-cycle plants. However, one should not dismiss the possibilities of introducing renewable energy sources, such as tidal energy, into the country's energy economy.

A series of energy efficiency and economy studies has shown that economically, tidal energy prospects are more promising when using medium- and large-scale tidal power plants as these reduce specific fixed costs incurred when assembling the construction infrastructure, setting up housing for construction workers and arranging their energy supply. Furthermore, the larger the tidal power plant project, the lower the unit costs derived from smoothing out the fluctuations in the TPP's energy conversion.

Engineering and feasibility research performed for the Kola and Lumbovsky TPPs, as well as for the sites in Tugur Bay and at Mezen, demonstrate that the economic effect grows significantly if the energy produced by the TPP, which is subject to cycles of daily and monthly variations, is transformed into a controlled, guaranteed supply with the help of reservoirs used by hydroelectric or pumped-storage power plants. A return on additional costs invested into the construction of regulating water storage facilities and electric grids connecting hydropower sites with TPPs is provided for by the possibility of lossless load rearrangement, where TPP-generated energy will replace part of the installed capacity of the hydropower plant (up to 20% per 1 kW of the TPP's installed capacity).

Project studies on Russian and foreign-based tidal power plants have shown that the construction of tidal power plants of unique capacity (such as the Mezen and Tugur Bay sites in Russia, and the Bay of Fundy project in Canada) requires installation of small experimental TPPs first in order to enable preliminary testing of the hydroturbine. For this purpose, construction was warranted for Canada's TPP Annapolis (78 mW) and Russia's two pilot sites: first, the Kislaya Bay TPP with a 0.4 MW bulb turbine, and later, the ongoing project of the Kola TPP, to operate two generating units of 16.2 MW each.

5. WAVE ENERGY

5.1. General information on utilizing the energy of ocean surface waves

The energy potential available in the power of ocean surface waves is considerably high. Researchers estimate the total potential power of wind-induced waves of the world's oceans to be between 30 million MW and 1 billion MW [8]. However, the energy that man can capture from waves to do useful work is significantly less and is estimated to range between 2.7 MW and 5 million MW [26].

Wave energy, as compared to wind or solar energy, has a higher energy density. Ocean waves accumulate energy they receive from wind across a sizable acceleration space. Therefore, they are a natural energy concentrate. Another advantage of ocean waves is their omnipresence throughout the world, thanks to which they are readily accessible to wide populations of coastal energy users. Disadvantages of ocean wave energy include its instability across time, its dependence on ice conditions, and the challenges posed by converting it into power and supplying it to the consumer.

Research aimed at understanding the opportunities for application of ocean wave energy started over 200 years ago and intensified notably since the beginning of the 1970s. Today, over a thousand different suggestions are registered in a number of the world's countries that offer methods for converting wave energy, power take-off designs, and designs of specific equipment for wave power installations. The problem of practical application of ocean wave energy is a highly challenging one. Solving it requires the development of specific equipment for energy reception and conversion, and powerful moorings capable of withstanding significant stresses, especially under extreme conditions. Other prerequisites include an evaluation of wind-induced wave parameters and the pattern of their variation, as well as a research on the potential impact of wave energy installations on the environment, such as shoreline erosion or formation, interaction with shipping, etc. [26].

A number of countries have ongoing programs aimed at developing wave energy installations, which include the creation and testing of pilot models. Today, more than 300 autonomous navigation buoys, produced in Japan and India, which use the energy of ocean waves are in operation across the world. A first commercial-scale ocean wave power converter has been launched on the Scottish island of Islay. Up to 250 MW in power capacity can be achieved on just a 10-km stretch of the western coast of Great Britain. A demonstration ocean power plant with a power capacity of 6 MW is slated to be built on the Hebrides in Scotland.

One prototype wave energy converter in Scotland has already provided electric energy to the Scottish energy system. During storms, the turbine is capable of developing up to 875 kW in capacity; under normal conditions its capacity reaches about 35 kW. Design-wise, this installation is a concrete chamber 5 meters wide, 10 meters long and 9 meters high [28].

Field testing is reported to have been conducted on an experimental wave energy converter in Japan. This installation is 24.5 meters long, 27 meters high and is submerged 18 meters below sea level. Its air turbine with a 1.33 m diameter starts to produce energy at a wave height of 0.7 meters, while at a wave height of 3 meters its capacity reaches around 60 kW [29].

Reports and presentations on wave energy application have been given at more than 30 international congresses and symposia on energy, ocean physics, shipbuilding, shoreline protection, engineering, etc. Several international conferences have been dedicated solely to the discussion of the problem of utilizing the energy of ocean waves.

Estimation of wave energy potential has special significance for determining what prospects there are for its application as an energy source. There are certain proven theoretical formulations that help calculate the potential and practical application of energy of wind-induced ocean waves. An evaluation of wave energy resources with regard to the coastal areas of the Murmansk region is presented in this chapter.

5.2. Energy of surface waves.

Wind-induced waves are traditionally divided into three types [30]: Waves that are under the immediate impact of wind; ripples that can be seen after the wind has subsided, or after the waves have traveled out of the area of wind activity, and mixed waves, which occurs when wind-induced waves overlap ripples.

Because winds blowing over the ocean surface vary in their speeds and directions, wind-induced waves are also heterogeneous across space and significantly changeable over time. Moreover, wave fields are even less homogeneous than wind fields as waves can reach one area or another simultaneously even though they originated in different places.

In the past years, scientists have made considerable progress in understanding wind-induced waves and developed a number of methods – such as statistical and spectral methods – to quantify the probability structure of the inhomogeneity and inconsistency of wave fields. These works involved a wide application of various achievements in probability theory, hydromechanics, and mathematical statistics.

According to the hydrodynamic theory, the energy of waves is formed from the kinetic energy E_k of fluid particles that participate in the movement of the wave and potential energy E_p, which is determined by the position of the liquid's mass as it is elevated over the level of a calm surface. In low-amplitude waves, the energy that corresponds to an area as long as the length of the wave and with a width that equals 1, will be [8]:

$$\mathrm{E_k} = \mathrm{E_p} = \frac{1}{16}\rho g h^2 \lambda, \tag{5.1}$$

where ρ is water density, g is free fall acceleration, h is wave height, and λ is the length of the wave.

Total mechanical energy of the fluid corresponding to one unit of length is:

$$E = E_{\mathrm{k}} + E_{\mathrm{p}} = \frac{1}{8}\rho g h^2. \tag{5.2}$$

A flux of energy through a vertical plane strip with a width equaling 1 and an infinite depth, which is perpendicular to the direction the wave is distributing, is determined as the average value of work performed by forces of pressure along the chosen direction within one unit of time during the wave period, or as the speed of transfer of the energy of the wave:

$$F = \frac{E_{\mathrm{s}}}{2} = \frac{1}{32\pi}\rho g h^2 T, \tag{5.3}$$

where F is the flux of energy of the wave, T is the wave period, and $s = gT/4\pi$ is the group speed, or envelope velocity, of wave distribution.

The result of this equation is that the power distributed by waves in deep water is proportional to the square of their amplitude and the wave period. This is why long-period (T~10 seconds) waves of large amplitudes (2 meters and over) are of the most interest as they allow harvesting up to between 50 and 70 kW/m or more from one unit of the wave crest length.

The above expressions (5.1 through 5.3) are applicable to the description of energy characteristics of regular waves in a wave basin or in dead swells. In nature, wind waves are a stochastic process characterized by highly scattered amplitudes and wide variations of harmonic waves that constitute it. To describe this process, the classic theory is modified with the use of the statistical and spectral methods.

Under the former, suggested by N. N. Paniker[1] [31, 32], the parameters of H_s and T_s designating significant undulation are adopted as estimation values for irregular waves. Significant undulation is assumed to be an average of one third of the largest waves, that is, undulation with an occurrence rate of 12.5%.

This approach was used to evaluate wave energy resources of the coastal areas of the world's oceans. The basis of evaluation consisted of visual observations of the waves adjusted later to incorporate calculations of wave conditions based on meteorological data. In practically all areas surveyed, the value of energy contained in the waves exceeds 15 kW/m. The highest values of undulation power in the world's oceans are found in the polar latitudes of the northern and southern hemispheres – up to between 70 and 90 kW/m.

The main disadvantage of the method described is that the calculations are made with regard to a particular and fixed moment in time. Furthermore, parameters of significant undulation do not reflect all of the undulation statistics. To level out this inadequacy, G. V. Matushevsky [33] suggested an approach which involves the application of average multi-year values for various characteristics of waves observed in a particular slot[2] across a number of years. A climatic function ψ (h, T) specific to observed hydraulic wave behavior was introduced, which describes the diversity of individual wave heights in a long-term unstable sample [34, 35]. The wave energy flux, taking this bivariate function of frequency of distribution of heights and periods into consideration, can be presented as the following equation:

$$F = \frac{\rho g^2}{32\pi} \int_0^\infty \int_0^\infty \psi(\mathrm{h},\mathrm{T})\, \mathrm{h}^2 T dh dT \,. \tag{5.4}$$

The different values of wave energy flux in Russia's seas as calculated by the Matushevsky method [34] are shown in Table 5.1:

Table 5.1

Wave energy flux in Russia's seas

Sea, name	F (kW/m)	Sea, name	F (kW/m)
Azov Sea	3	Sea of Okhotsk	12-20
Black Sea	6-8	Bering Sea	15-44
Baltic Sea	7-8	Sea of Japan	21-31
Caspian Sea	7-11	Barents Sea	20-25

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[1] From here on, names of Russian researchers mentioned in the text are given as they appear in the Russian original, with just initials preceding the last names. With one exception, the first names of these researchers are unavailable.

[2] See 5.3. Undulation's renewable energy.

Under the spectral approach used to assess the power of waves, the basic wave energy dF, the frequency of which lies in spectral band $d\omega$, and distribution direction in spectral band $d\theta$, will be expressed as follows:

$$dF = \frac{\rho g^2}{2}\frac{1}{\omega}S(\omega,\theta)d\omega\, d\theta . \tag{5.5}$$

The total flux of wave energy accounting for all frequencies and directions is equal to:

$$F_0 = \frac{\rho g^2}{2}\int_0^{\infty}\int_0^{2\pi} S(\omega,\theta)d\omega\, d\theta . \tag{5.6}$$

Here, $S(\omega,\theta)$ is wind waves' two-dimensional energy spectrum. Often, a frequency spectrum is used instead of the two-dimensional energy spectrum.

$$S(\omega) = \int_0^{2\pi} S(\omega,\theta)\, d\theta . \tag{5.7}$$

This allows for calculating energy flux in this way:

$$F = \frac{\rho g^2}{2}\int_0^{\infty}\frac{1}{\omega}S(\omega)\, d\omega . \tag{5.8}$$

When using the spectral approach, an evaluation of energy resources contained in wind waves wholly depends on the energy spectrum and its adequacy for all stages of wave development. At this point, describing the frequency spectrum of real wind waves is a difficult task. The available spectrum expressions are usually achieved based on an assumed stationarity of the stochastic undulation process. A great number of frequency spectrum expressions are offered that correspond to the relevant stages and conditions of undulation development (the Krylov, Neiman, and Davidan spectra) [8]. This poses a difficulty when choosing a specific type of spectrum that corresponds to certain average conditions of wave development for a given basin over a large period of time (one season or one year).

In [36], I. N. Davidan, L. I. Lopatukhin, V. A. Rozhkov, and other researchers have summarized the existing notions of wave development and produced an expression of a one-parametric energy spectrum. A graphic representation of the results of calculating the energy flux in accordance with this spectrum and based on the average parameters of h and T is shown in Fig. 5.1. In order to make this diagram more convenient to read, it also shows statistical curves that delineate the areas of wind waves and ripples, as well as curves that represent wind speeds corresponding to particular wind wave values.

To determine the behavioral energy characteristics of sea and ocean basins, existing reference material on behavioral climatic wave parameters is used, which has been accumulated based on visual observations made by ship crews during voyages. These data are usually introduced as wave occurrence rate P_{ij} with parameters h_i and ω_j in accordance with the specific time of year for each area observed. The behavior-specific flux of wave energy, with the occurrence rate taken into consideration, will then be estimated as follows:

$$F = \sum_{ij} P_{ij} F_0(h_i,\omega_j) . \tag{5.9}$$

One important aspect for the practical application of reference materials is the cross-identification of visually observed wave parameters with wave parameters of certain statistical occurrence. As follows from the analysis detailed in [8], the USSR Register Reference Book presents behavioral climatic data on wave heights with an occurrence rate of 10%, which is an approximate equivalent of the notion of “significant” undulation.

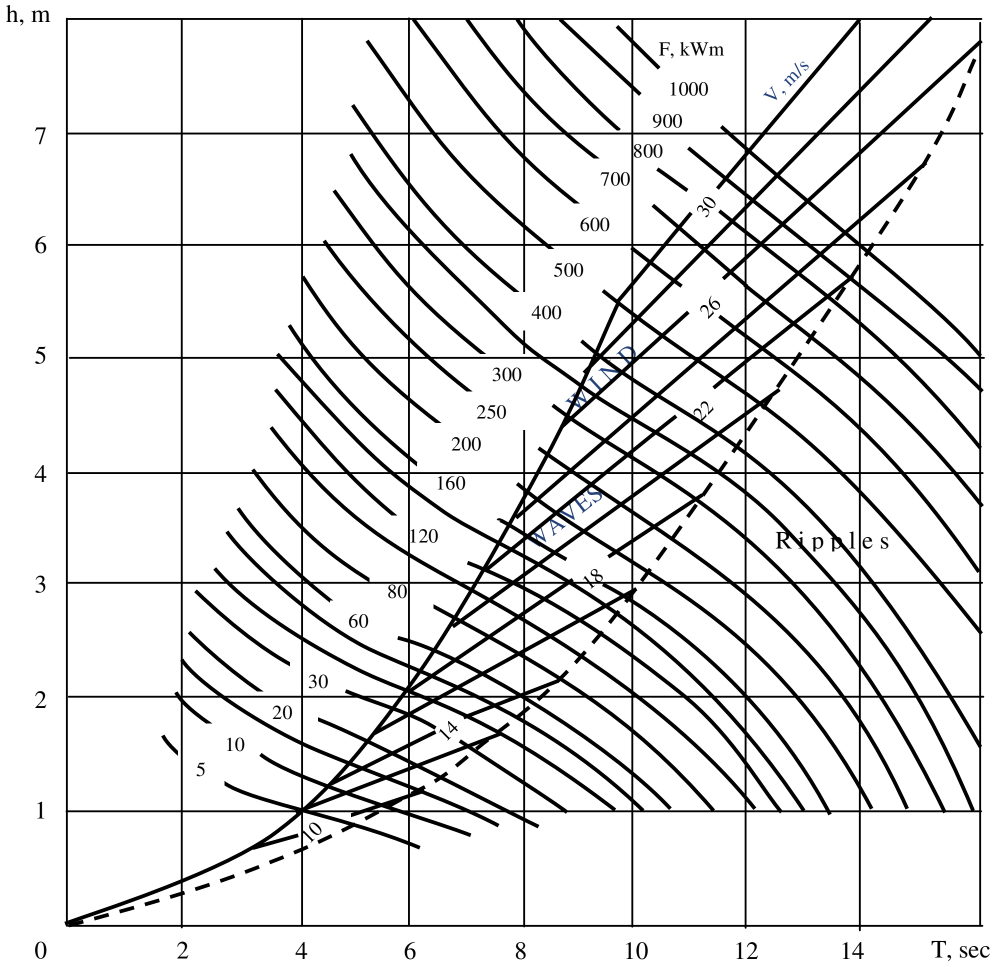

Fig. 5.1. Wave energy flux as estimated by the Davidan spectrum, with statistical characteristics of wind waves depending on wind speeds.

Estimations for the wave energy flux of the North Atlantic Ocean based on observed wave behavior (as calculated by data from [8]) are shown in Table 5.2. This table will also demonstrate an important characteristic of sea undulation, its variability depending on the season. During the winter months, sea surface waves are approximately twice as high as during the summer.

Table 5.2

Wave energy flux in the North Atlantic Ocean, kW/m

Latitudes	Months				Average per year
	XI, I - II	III - V	VI - VIII	IX - XI	
Polar	92	67	46	79	71
Middle	85	81	49	89	76

Moving away from the analysis of methods used to estimate potential wave energy to estimation of wave energy resources for a particular region, that is, the coastal areas of the Murmansk region – the following can be stated: According to data accumulated by Viktor Sichkaryov [8], average yearly values for wave energy flux in the North Atlantic range between 71 kW and 76 kW per 1 meter of wave front edge. This estimation is in agreement with data presented in [26], where, according to materials compiled by international researchers, average annual specific wave energy reaches 70 kW/m on the coast of Great Britain, and 60 kW/m on the western coast of Canada.

The Barents Sea, which washes against the coasts of the Kola Peninsula, the Arkhangelsk region and Novaya Zemlya, borders on the far northeastern part of the Atlantic. According to an estimate by Matushevsky [33], the potential wave energy here reaches from 22 kW/m to 29 kW/m. These figures are close to data presented in [37] characterizing the wave energy potential in the neighboring region, the coast of Norway, where this potential ranges between 25 kW/m and 30 kW/m.

Summarizing the data presented above, a conclusion can be made that the average annual specific wave energy in the Barents Sea can reach between 20 kW/m and 25 kW/m.

Taking into consideration that waves are formed by the force of wind, and that there is a direct correlation (Fig. 5.2) between the seasonal changes in wind speeds on the northern coasts of the Kola Peninsula and sea undulation in the North Atlantic (Curves 1 and 2 in Fig. 5.3), the seasonal variations in wave energy flux of the Barents Sea can therefore be illustrated by Curve 3 in the same Fig. 5.3. In other words, it can be expected that during winter months, the average wave energy potential will reach between 30 kW/m and 32 kW/m, while the summer months will yield an average energy potential of between 15 kW/m and 20 kW/m.

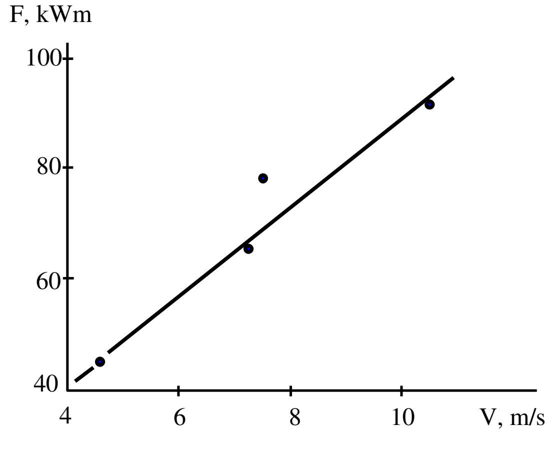

Fig. 5.2. Correlation between wave energy flux F and average monthly wind speeds.

According to [30], the wide water expanse of the Barents Sea and the strong frequent winter winds blowing from November through March are two factors that contribute to the development of powerful ocean waves. During this strong-wind period, waves with a height of 6 m have an occurrence rate of 5% to 8%, and waves with a height over 8 m have an occurrence rate of around 2%. During the summer months, heavy waves are less frequent and in the western and central parts of the sea the occurrence rate does not exceed 1.0% to 1.5% even for waves of 6 meters.

As regards the White Sea, its average annual wave energy potential is considerably lower, only 9 kW/m to 10 kW/m, due to the comparatively small size of the sea and the presence of an ice sheet on the sea surface during winter.

5.3. Undulation's renewable energy

To understand the value of ocean surface waves as a source of renewable energy, an evaluation first has to be done of the total power of the waves and their energy potential in a given basin. In accordance with the Paniker approach [31, 32] detailed above, the area surveyed is divided into slots with Side l_1 and Side l_2. The wave period T helps identify its characteristic length $\lambda = gT^2/2\pi$ and the number of waves in the slot $n = l_1/\lambda$. After this, the total power of all waves within one slot will be expressed by this equation:

$$N = Fnl_2 = Fl_1l_2/\lambda, \qquad (5.10)$$

where F is the energy flux for every wave.

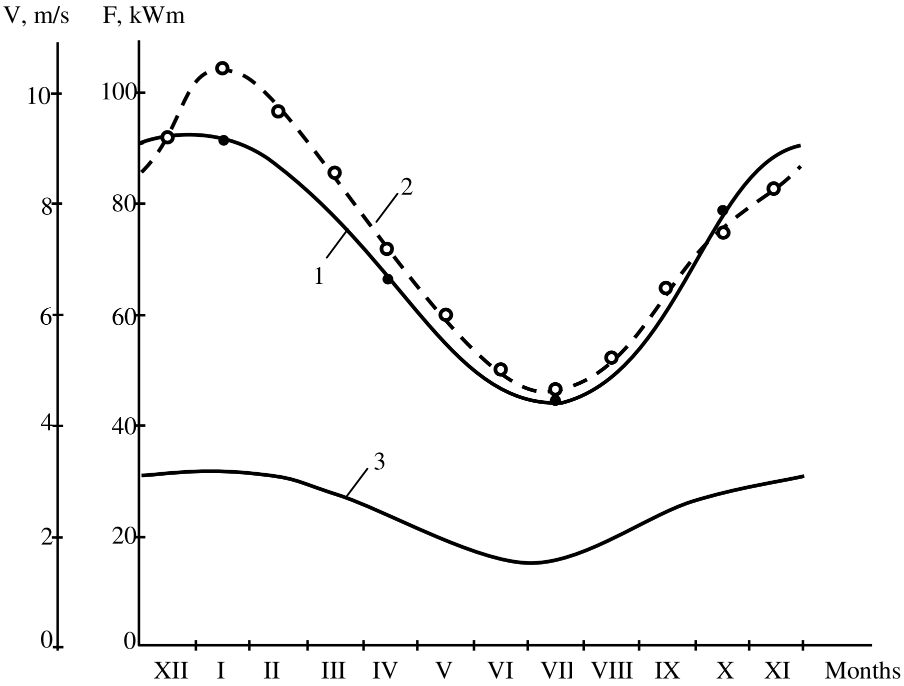

Fig. 5.3 Seasonal variations in wave energy flux in the northern latitudes of the Atlantic ocean (1), average monthly wind speeds on the northern coast of the Kola Peninsula (2), and potential flux of wave energy in the same coastal area (3)

Matushevsky uses a similar approach [33, 34] with the difference that the energy flux of one nominal wave is calculated with consideration given to the probable density of wave heights and periods ψ (h,T) as follows from (5.4).

The methods mentioned above help account for the power of all waves occurring simultaneously within a given basin. This estimated wave power is usually dubbed “full” wave power. If undulation could produce such power, it would be sustained within one period of wave, after which the sea would become calm, and it would take a long time (see Figs. 54 through 5.6) for undulation to be restored under the impact of wind. For purposes of practical application, interest lies with that portion of full capacity that is consistently conveyed to the waves externally and maintains them at a certain observed climatic level. For this power, Sichkaryov introduced a special term: Renewable wave power. Such or similar power can be harvested for a long period of time. Renewable wave power is closely connected with wave-generating factors, such as the distance of wave fetch x, its time t, and wind speed V. More detailed information about these relationships is available in [30].

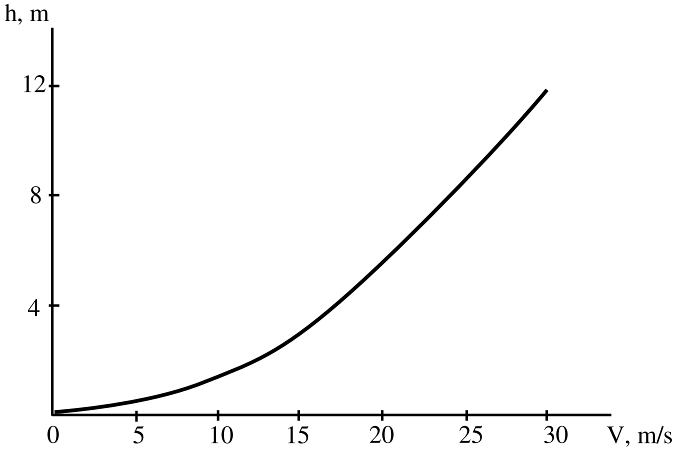

Fig. 5.4 Dependence of average wave height of fully developed undulation on wind speed.

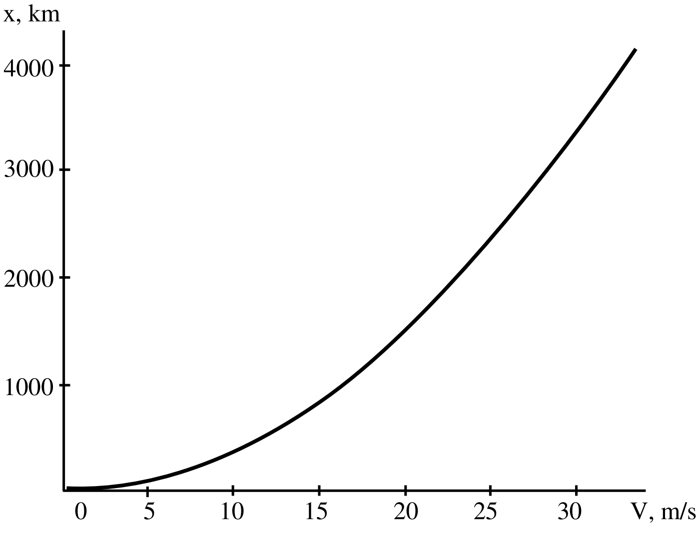

Fig. 5.5 Correlation between the wave fetch distances necessary for the development of advanced undulation and wind speed.

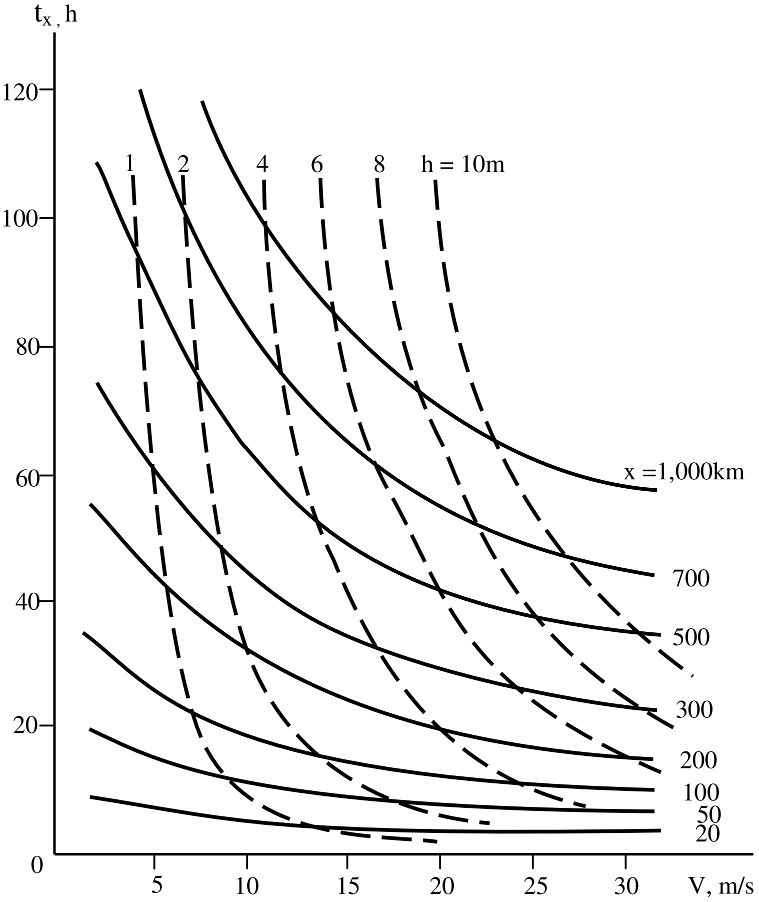

Fig. 5.6 Correlation between the time of undulation development t_x and wind speed V at varying wave fetch distances x. Dotted lines represent wave heights.

An evaluation of the renewable part of undulation power can be performed in the following way: A basin with area S is divided into strips which are perpendicular to the wind direction and whose widths are equal to wave fetch x. The total length of all such strips will be L=S/x. The total renewable wave power in the given basin will then be expressed by the product of energy flux F by the total length of wave fronts L:

$$N_{\mathrm{w}} = FL = F\frac{S}{x} \quad . \tag{5.11}$$

If, for the sake of ultimate clarity, one assumes that the wave fetch is chosen in such a way that the undulation at the end of the strip is fully developed, then in that case, the correlation between x and F will be determined by the following expression:

$$x = 7482 \times F^{0.4} . \tag{5.12}$$

Then the total renewable wave power will be:

$$N_{\mathrm{w}} = 1.34 \cdot 10^{-4} F^{0.6} S \ , \tag{5.13}$$

and annual renewable wave energy in this basin will be:

$$E_{\mathrm{w}} = N_{\mathrm{w}} T_{\mathrm{year}} = 4215\, F^{0.6} S . \tag{5.14}$$

In these equations, wave energy flux F is expressed in watts per minute, N in watts, yearly time T_{year} in seconds, and E in joules.

Renewable wave power and energy values of the Barents and White Seas are summarized in Table 5.3. Data on the Bering Sea and the Sea of Okhotsk are also represented for a comparative analysis [8].

Table 5.3.

Renewable power and annual energy values of certain seas on the Russian territory.

Sea	F, kW/m	S, m^2	N_W, W	E_W, J
White Sea	10	$0.09 \cdot 10^{12}$	$3.03 \cdot 10^{9}$	$9.55 \cdot 10^{16}$
Barents Sea	25	$1.42 \cdot 10^{12}$	$0.83 \cdot 10^{11}$	$2.61 \cdot 10^{18}$
Sea of Okhotsk	29	$1.59 \cdot 10^{12}$	$1.01 \cdot 10^{11}$	$3.19 \cdot 10^{18}$
Bering Sea	45	$2.30 \cdot 10^{12}$	$1.90 \cdot 10^{11}$	$6.00 \cdot 10^{18}$

A comparison between renewable wave power and full wave power can be of certain interest. According to Matushevsky, renewable wave power makes only 0.026% to 0.040% of the full wave power. On the one hand, this would lead to a conclusion that even taking off all of the renewable power will result in an insignificant change in the full power of the undulation, and by extension, in a minor environmental impact of such harvesting. However, on the other hand, this points to the low density of the renewable power of the waves. Calculations show that for the Barents Sea, it only reaches 58.5 kW per one square kilometer of the basin.

5.4. A brief outline of main types of wave energy conversion systems

The design of ocean wave energy converters is based on the utilization of either the speed of the seawater, or the changes in the wave surface angle, or the changes in the hydrostatic or total hydrodynamic pressure of the waves.

Independent of the converter type, all wave energy installations are comprised of three fundamental parts: the working medium, the power converter, or power take-off, and the mooring system. The functions and purposes of each of these components can be described as follows [26]:

The working medium is in immediate contact with the water and performs movements of this or that kind depending on the impact of the waves, or changes the conditions of the wave movement in this way or another. Working mediums used in wave energy converters can be buoys, water wheels or turbines, seawall devices, wharf walls and other structures. The working medium transforms the energy of the water into some other kind of energy, making it more convenient for further conversion.

The power take-off is designed to convert the energy accumulated by the working medium (the mechanical energy of the movement of the working body, of the water level difference in the basins, or of the air or oil pressure) into the kind of energy suitable for transmission over distance, or for immediate use. Many diverse types of hydraulics serve as power converters, like piston-based pumps, toothed gear, chain gear, and tendon drives, hydraulic turbines and water wheels, air turbines, or other known or specially developed devices.

The mooring system keeps the wave energy converter in place. If the wave energy installation is located onshore, then the very structure of the installation serves to secure it in its place. Offshore wave energy converters are fixed in their locations by means of solidcast supports, poles or trestle piers, or chains or cables fastened to the sea bed with the help of bracing structures or anchors. Flexible devices can also be used to attach the installation to the vessel that transports it. Some designs suggest floating wave energy installations that do not need a mooring system and can drift freely, where the accumulated energy is collected from the installations after a substantially prolonged period of time.

Using the information available in [8], the following types of ocean wave energy converters can be noted:

The most popular devices designed to tap ocean wave energy resources are the buoy-type or float-type wave energy converters, or point absorbers. The working medium of these installations – the point absorber – is located on top of the sea surface and moves up and down in accordance with the variations in water levels caused by wind waves. The buoy's vertical movements are used for the alternate compression of gas or liquid in some kind of a container, or they are converted into the rotational movement of the power generator, or utilized in other similar ways. For instance, at an amplitude of eight meters vertical movement and an efficiency rate of 80%, the buoy with a 16 meter diameter developed in Norway can produce up to 4 million kW/h per year [26].

The amplitude of the float's vertical oscillation can be increased significantly – ten- or twelve-fold – through certain elaborations on its design. To raise the amplitude, or the float's resonance with the waves, a vertical cylinder-shaped tube is used, which is partially (depending on the wave and float parameters) filled with seawater, or a plummet of a relevant weight is attached to the float. A large-scale point-absorber model (Fig. 5.7.) studied in Japan had a diameter of 2.2 meters, a height of 22 meters, and a mass of 13.5 tons. It was outfitted with a propeller-type turbine 0.8 meters in diameter. The amplitude of the float's vertical movement reached 8 meters at wave heights ranging between 0.5 meters and 1.5 meters.

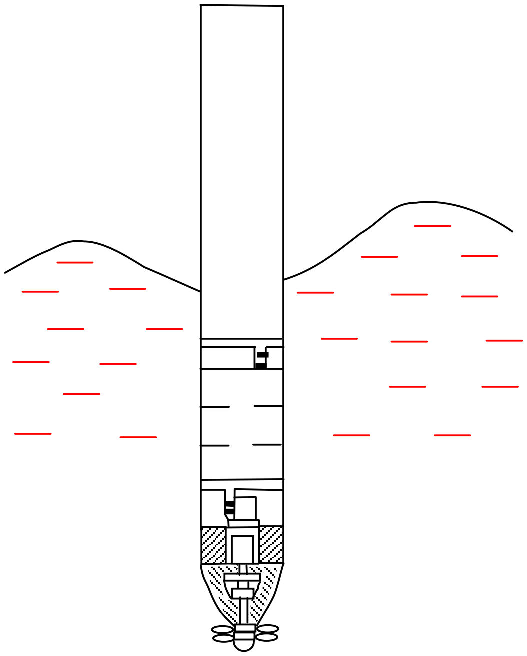

Fig. 5.7 Point absorber.

Another wave energy converter type, dubbed the "oscillating water column," is a housing, or chamber, the lower open part of which is submerged to the lowest water level (wave trough). As the seawater level in the chamber rises and falls, a cycle of air compression and expansion takes place. The movement of air through a system of valves drives the rotating motion of the air turbine, which is located in an aperture on top of the chamber. A diagram illustrating the efficiency of the oscillating water column design is shown in Fig. 5.8. [8]. Symbols H and λ designate wave height and wave length, respectively.

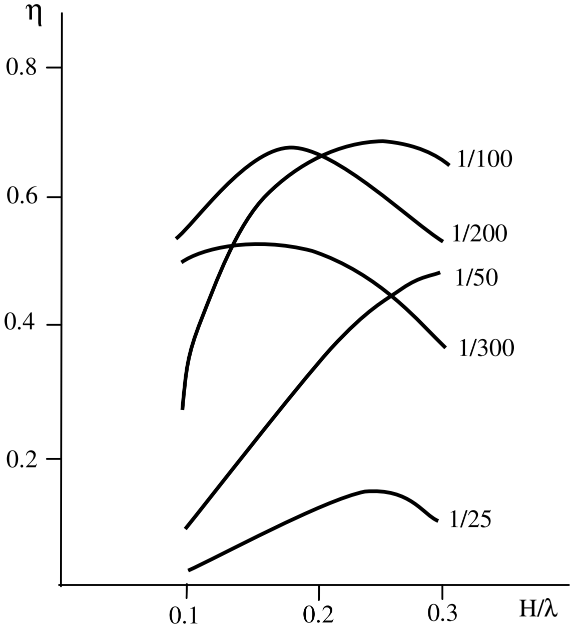

Fig. 5.8. Oscillating water column's efficiency rate.

The most well-known installation of the oscillating water column type was designed by the former Japanese naval commander Yoshio Masuda in 1961, and is dubbed the Masuda Device. The wave energy converter, which comprised several inter-connected oscillating water columns, was built into the hull of a vessel with a deadweight of 500 tons, christened Kaimei. The power-generating equipment of the installation is made up of three air turbines with rotors 1.4 m in diameter and 125kW AC generators. During the testing, maximum power output was observed when the length of the installation, namely the ship, happened to equal the wave length.

Buoys placed on the sea surface do not only move vertically, but make angular oscillations as well, depending on the wave profile. The working body of such installations consists of two or more floats connected between themselves with hinges made of piston pumps or bellows. These converters follow the change in the shape of the sea surface under wind-induced undulation by changing the angular position of the floats relative to each other and thus drive the hydropumps or the bellows.

Cockerell's Raft (Fig. 5.9.), or the wave contouring raft system, suggested by Sir Christopher Cockerell in 1972, is the most famous of this type of installation. This wave energy converter's efficiency is illustrated in Fig. 5.10. [8].

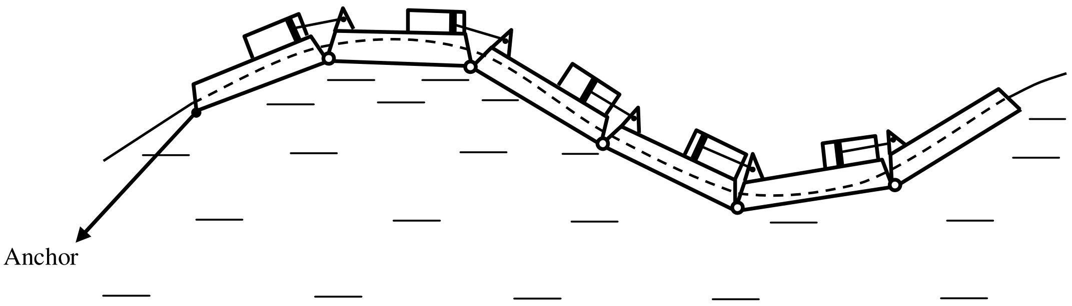

Fig. 5.9. Cockerell's Raft.

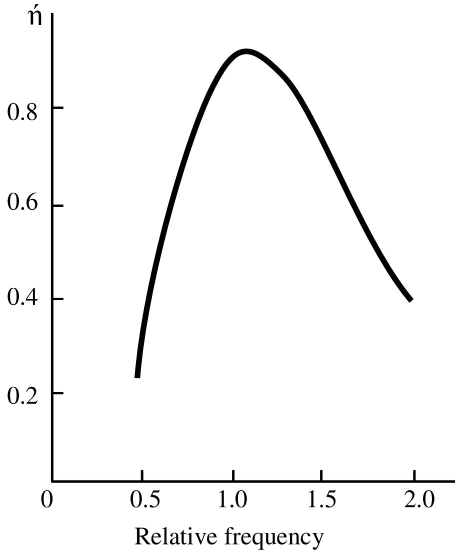

Fig. 5.10. Efficiency of a two-raft system with the tail raft stabilized into a rigid position.

The efficiency of float-based installations increases with the use of cam-shaped buoys, which do not just oscillate with the waves, but also absorb the pressure of the oncoming wave. One of the best known installations of this type is the so-called Salter's Duck, suggested by Professor Stephen Salter. The buoy is a cylinder-shaped asymmetric point absorber propped on a horizontal axis, with its tail end shaped as a circular shaft. The axis stretches along the wave front. When the wave applies its direct force on the cam lobe the latter moves in angular oscillation relative to the axis. The horizontal axis has to be stabilized to prevent linear or rotational displacement. For this purpose, Salter suggested frontal phase stabilization: The axis is made sufficiently long to accommodate several cams so that wave crests arriving in difference phases mutually compensate for the stress on the axis.

The efficiency of this device has been studied by many researchers, who have confirmed the results achieved by Salter (Fig. 5.11.). It has also been demonstrated that a system consisting of three to four working bodies is capable of absorbing almost all the energy of a random wave in the broad frequency bandwidth. Even limiting such a system to only two bodies ensures the ability to collect more than 95% of the energy of a random wave in the wide frequency spectrum. In this case, each of the sections has the highest efficiency in its own frequency spectrum (Fig. 5.12.).

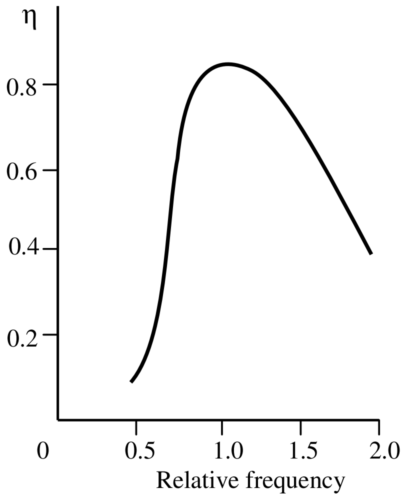

Fig. 5.11. Efficiency of Salter’s Duck with one degree of freedom.

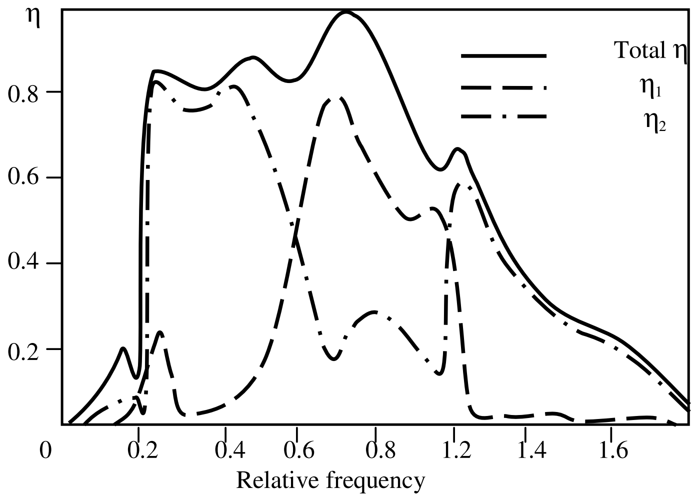

Fig. 5.12 Efficiency of a two-duck system.

Certain types of wave energy converters employ as the basis for their operation the difference between the levels of the wave crest and the wave trough. Wave crests overtopping a dam, for example, or the alternating opening of valves or lock paddles, fill a water basin. The difference created between the water levels in the basin and the sea is used by a waterwheel, a low-head hydraulic turbine, or other devices to generate electric energy or drive other mechanisms. The most popular among wave energy systems of this type is the so-called Russell Rectifier.

To enhance the actual drop between water levels, or water heads, this type of works utilizes the effect of wave climb over a sloping surface. To achieve that, the work area is constructed as a slanted conduit narrowing at the top. When concentrated in a 12 m feed canal, a sea wave with a height of 1.1 m amassed along a wave front of 350 m can result in a standing wave with an amplitude of 17 m. An installation employing an inclined surface with a slope angle of 30° provides for a 2.5 m wave elevation with an average wave height of 1.5 m. One wave energy generating system of this type is currently under development in the U.S. Dubbed Dam-Atoll, this installation is based on a construction element shaped like a portion of a sphere with a diameter of 100 m and a height of up to 30 m. The convex part of this submerged element protrudes over the sea surface. The top of this artificial island is lined with wave-directing ridges, while the center of the top surface accommodates a water-feeding aperture and a water conduit with a diameter of up to 18 m with a hydroturbine.

The horizontal water pressure of the oncoming waves can also be absorbed directly by the various resilient or sliding walls, the movement of which ensures the rotation of the generator shaft or the pressure of the working medium of the piston pump.

Constructions of this type include the oscillating plate wave absorber called the Farley Triplate suggested by F. J. Farley in 1977. Tests conducted on this installation in Great Britain – in lab conditions, with waves of lengths ranging between 1.5 m and 7 m, and during field experiments on a large-scale model with waves reaching 150 m in length – have shown that the design-based efficiency rate of this energy conversion system can be as high as 80% to 90%, or more.

The types of ocean wave energy converters listed above include operating elements that are placed on the water surface and are thus subject to the impact of not only expected climatic conditions, but also extreme storm waves that exceed design estimations. To avoid such impact, the working body of the wave energy converter can be fully submerged below sea level. In such installations, the progressive wave of the pressure, created by the difference of pressures between the wave crest and the wave trough, will be used to compress a series of elastic claddings arranged on the sea bed along the direction of the running wave, or will be applied on a horizontal plate fixed at the sea bottom on a set of supports. The jolts of pressure in the claddings, or over the top of the horizontal plate, will be used to increase pressure in the working medium and move the operating fluid or gas.

An installation called Hose-Pump, which was suggested in Sweden and developed under Great Britain's AquaBuOY project, is capable of absorbing both the vertical and the horizontal components of hydrostatic pressure. Project tests have shown that the installation has a high reaction speed to variations in wave pressure.

In 1976, Bristol University in England developed a wave energy converter called the Bristol Cylinder. This installation is a circular cylinder fully submerged into surface seawater layers parallel to the wave front. The cylinder has a positive buoyancy and is fixed in its submerged state by a system of anchors. Load devices such as hydraulic cylinder rams are installed in the hookups of the anchoring system. Efficiency data on this installation, gathered through experiments, is illustrated in Fig. 5.13 [26].

5.5. Technical resources of ocean surface wave energy of the Barents and White Seas

Evaluating technical resources of ocean surface wave energy requires information on the efficiency rates of various wave energy conversion systems. According to the data presented above, different types of wave energy converters have varying efficiency rates. The best installations working at optimal performance provide a considerably high – 70% to 90% – efficiency rate of wave power take-off. Taking into consideration energy losses incurred by converting wave energy into electric power, the resulting efficiency rate of wave power electric stations ranges between 30% and 80%. These efficiency values are among the highest found in non-conventional energy conversion systems.

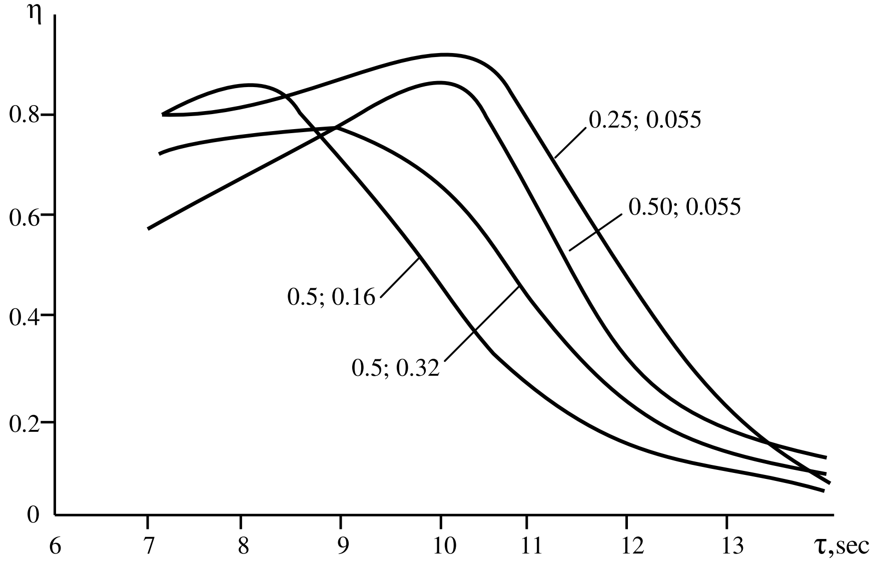

Fig. 5.13 Efficiency rate of the Bristol Cylinder ocean wave energy conversion system, at an optimal viscous damping rate. Cylinder diameter D is 12 m. The figures placed near the curves indicate the relationships of d to D and h to D; d expresses the depth of submersion.

If the efficiency rate of 60% is taken as the basis for calculations of potential energy yield, then the capacity of wave power electric stations placed in the basins of the Barents and White Seas could reach 50 million kW and 1.8 million kW respectively, while total technical resources of wave energy available in these basins are estimated to reach around 450 TWh per year.

Technical wave energy resources of the Murmansk region in the coastal areas of the Kola Peninsula – a strip of shoreline 10 km wide – can be estimated at 1.2 TWh on the coast of the Barents Sea and around 0.4 TWh on the coast of the White Sea. The capacities of wave energy power stations in these areas could reach 230 MW and 100 MW, respectively.

As regards the economic aspect of the application of ocean surface wave energy, it could be noted that the costs of electric power generated by wave energy conversion systems are as yet quite high. According to [8], these costs fluctuate between $0.10 and $0.20 per one kilowatt-hour for a range of diverse wave energy installations, which is still significantly higher than the costs of energy generated by traditional power plants. However, as fossil fuel prices increase and wave energy conversion technologies improve in the future, this difference is expected to shrink.

6. BIOENERGY RESOURCES

6.1. Utilization of biodegradable wastes from livestock and poultry breeding industries

The intensification of agricultural industries has resulted in a significant concentration of livestock and poultry populations on farms and farming complexes – rather than isolated farming estates. As a rule, the traditional approach to livestock management, which includes using the litter system, is not applied universally due to the challenge of preparing the vast amounts of litter materials needed on a large farm. Consequently, litter-free livestock management has become increasingly widespread in the past 20 years. Water – as well as mechanical waste removal devices – is very commonly used to remove manure from livestock houses. The result is the accrual of large quantities of liquid dung and poultry droppings near the farms – so called organic waste.

The biodegradable outputs of livestock management are valuable organic fertilizers, which contain all kinds of nutrients necessary to feed growing plants: nitrogen, phosphorus and potassium, as well as large quantities of minor nutrients. However, animal manures also contain significant quantities of tapeworm eggs, which are capable of remaining viable for prolonged periods of time, weed seeds, and microorganisms – including germs that are pathogenic for human health. Utilization of unprocessed animal waste is extremely inadvisable as it can cause significant adverse effects on the environment.

Today, the following approaches to manure recycling exist and are widely applied:

1. Accumulation and utilization of these wastes on farming lands with maximum retention of their nutritive properties. This approach implies mechanical separation of biodegradable waste slurry into solid and liquid fractions, and their separate application.
2. Construction of manure drainage systems for the irrigation of croplands, or further treatment of the liquid waste fraction until it has been distilled enough to be flushed into open waters. This approach is used on large hog farming complexes, where water - or a flushing system - is used to remove manure from the stalls.
3. Organic waste recycling into organic fertilizers or into biogas; the latter is done in methane tanks (biogas installations) without oxygen (anaerobic digestion).

This third approach to organic waste reprocessing received wide recognition in European countries, the United States and Canada in the early 1970s following an economic crisis and rising prices for oil and oil products. However, the biogas approach was well-known and widespread in use in Southeastern Asia a long time ago. In China alone, biogas installations number around 5 million. These are mostly of the “domestic” or small-reactor type. These installations reprocess not only livestock wastes, but also organic outputs generated on crop and vegetable farms. They do not have preheating or mixing systems.

Russia has lagged significantly behind in developing technologies for the methane fermentation of organic wastes produced by animal and poultry farming. However, already in the 1980s, research began on the optimization of the methane fermentation process, and experimental industrial-scale installations were built. Experience gained by operating pilot methane digestion installations helped calculate optimal fermentation parameters, quantify necessary input components, determine their optimal quality, etc.

Methane digestion takes place in sealed containers at temperatures ranging between 30^0 and 57^0 Celsius (the range from 30^0 to 37^0 Celsius is the mesophilic range, while the range from 50^0 to 57^0 Celsius is the thermophilic range). The optimal moisture content of the source material should be 90% to 92%. The process includes periodical procedures such as: mixing the waste undergoing fermentation, pumping out the generated biogas, piecemeal unloading of the fermented material and loading of the source biomass to be digested.

Within a short period of time (seven to 20 days, depending on the temperature used for the process), this technology yields both biogas and high-quality organic fertilizer. While fermenting inside the methane tank, animal manures undergo disinfection and get cleansed from pathogenic microflora and tapeworms. All weed seeds lose their germinating capacity. During this process, losses of the main nutrients in phosphorus and potassium are insignificant. Part of the albuminous nitrogen is converted into an ammoniacal compound, which is easier for absorption by plants. Some of the organic matter transforms to a gas and some mineralizes, while the level of malodors decreases sharply. Air and water pollution is also prevented.

Application of reprocessed biodegradable wastes, produced by animal farming, on crop and vegetable lands not only facilitates the preservation of a clean environment in the areas immediately surrounding the farms, but also allows for a considerable enhancement of cultivated soils since organic fertilizers are a main source of humus replenishment.

Using organic fertilizers helps increase the yield of agricultural crops by 10% to 20%.

6.2. Evaluating bioenergy resources: Background data on the Murmansk region.

Table 6.1 shows information on the livestock and poultry populations in the Murmansk region. These reference population numbers helped estimate the general figures for the output of animal manure from the region's farms and farming complexes.

Table 6.1

Populations of livestock and poultry in the Murmansk region as of January 1, 2004 г., in thousands of heads[38]

1. Cattle,	8.8
including dairy herd (cows)	4.1
2. Hogs	27.2
3. Poultry	740.8

Volumes of organic waste output depend on the type and age of the animals, their management, type of feed, and other factors. All estimations of animal manures output from farms of the Murmansk region were done in accordance with the "Russian Federal Norms for the Technological Design of Systems for Removal, Recycling, Disinfection, Storage, Preparation and Utilization of Animal Manures."

1 . Cattle farms.

The Murmansk region has only dairy farms. Each farm manages a population of around 400 animals. Manure output averages between 0.04 m^3 and 0.05 m^3 per cow per 24 hours; waste dampness content is 88%. In yearly quantities, waste output comes to 15 m^3 to 18 m^3. One ton of cattle manure slurry with 88% moisture content contains 120 kilograms of dry matter, or 100.8 kilograms of dry organic matter, as ash content of dry cattle slurry averages 16%.

In one year, the following output can be received from all cattle farms in the Murmansk region:

total slurry – 113,000 to 114,000 tons;
dry matter – 13,000 to 17,000 tons;
dry organic matter – 11,000 to 14,000 tons.

2. Pig farms.

Closed-cycle pig farms produce an average of 4.5 kilograms of slurry per animal per 24 hours. Daily slurry output from all pig farms of the Murmansk region is estimated at 122 tons.

In one year, the following output can be received from pig farms in the Murmansk region:

total slurry – 45,000 tons;
dry matter – 5,400 tons;
dry organic matter (15% ash content) – 4,600 tons.

3. Poultry farms.

Most poultry factories in the Murmansk region are egg producers. Daily output of manure from one mature bird is between 180 and 300 grams depending on its weight, age, type of feed, etc. Besides adult populations, poultry farms manage young birds as well, so manure output per one poultry head will average 150 grams per day.

In one year, the following output can be received from all poultry farms in the Murmansk region:

total slurry – 111,000 tons;
dry matter (75 % moisture content) – 28,000 tons;
dry organic matter (17% ash content) – 23,000 tons.

6.3. Energy potential of fuel production with anaerobic livestock and poultry waste recycling

The anaerobic recycling of biodegradable livestock waste is a multi-stage process of decomposition of organic matter. It takes place inside special containers, or digesters, in an oxygen-free environment under the activity of anaerobic microorganisms, and produces methane and carbon dioxide as a result. As was noted above, this process can occur at different temperatures. The higher the temperature is, the faster the decomposition of organic matter. However, temperature levels do not have any impact on the quality of the biogas generated. Besides temperature, the very process of anaerobic fermentation is influenced greatly by: the qualitative composition of the input material, including the content of dry matter, the quantity of the raw material in one load, speed of mixing, and other factors.

The biogas produced as a result of waste fermentation comprises 60% to 80% methane, 20% to 25% 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 kcal/m^3 to 6,000 kcal/m^3 and depends on the percentage of carbon dioxide it contains. After purification, its heat-generating capacity increases by another 1,000 kcal/m^3. One cubic meter of biogas can provide one hour's worth of a two-horsepower engine's run or 1.25 kilowatt-hours' worth of electric power output.

As research conducted both in Russia and internationally shows, one ton of dry organic matter that has undergone anaerobic fermentation can produce:

- from pig manure: 500 m^3 of biogas, or 0.36 tons of fuel equivalent;
- from cattle manure: 450 m^3 of biogas, or 0.321 tons of fuel equivalent;
- from poultry manure: 660 m^3 of biogas, or 0.428 tons of fuel equivalent.

Annually, from all the farming complexes in the Murmansk region it is possible to obtain the following:

- from pig manure: 2.3 million m^3 of biogas, or 1,700 tons of fuel equivalent;
- from cattle manure: 5.6 million m^3 of biogas, or 4,000 tons of fuel equivalent;
- from poultry manure: 15.1 million m^3 of biogas, or 9,800 tons of fuel equivalent.

Taking into consideration that 25% to 50% of the biogas generated – depending on the temperatures used under fermentation – will be spent on compensating for the heat losses and on the preheating of the source material fed into the methane tank, marketable biogas volumes are estimated at 12 million to 17 million m^3 of biogas, or 7,000 to 11,000 tons of fuel equivalent.

6.4. Effects gained from application of anaerobic recycling products

Application of anaerobic fermentation technologies helps solve three major issues.

1. Environmental goals: Disinfection of livestock and poultry farming wastes. According to the results of studies performed by the All-Russian Scientific Research Institute for Veterinary and Environmental Hygiene and Sanitation[1] and the Russian Academy of Agricultural Sciences' Konstantin Skryabin All-Russian Scientific Research Institute of Helminthology[2], within 72 hours the thermophilic process of fermentation successfully disinfects manure from helminth eggs and pathogenic agents that cause a range of infectious diseases, the seeds of weed plants lose their capacity to germinate, and the fetid organic compounds disintegrate, which leads to a decrease in malodor.
2. Increasing food supplies: Fermentation of livestock and poultry waste benefits crop farming by producing high-quality fertilizers for application on crop and vegetable lands. According to data made available by one Vladimir-based research institute, using fermented manures in crop and vegetable farming results in a 10% increase in harvest volumes as compared to the use of non-fermented.
3. Energy needs: Partial replacement of liquid and gas fuels by biogas. The heat-generating capacity of biogas is one cubic meter of biogas equivalent to 0.6 liters of fuel oil.

6. 5. Prospects of application of lumber wastes

Woods growing in Russia's northwestern territories are made up primarily of coniferous forests – pine-trees and firs – which provide the basis for the operation of wood-logging and woodworking industries of the region. Timber is used to produce paper, cardboard, wood pulp, cellulose, and other products.

A considerable portion of the 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. Part of the lumber resources is sold for export, but the majority of it is used to produce sawn timber. Lumber and woodwork wastes are used as fuel for electric power and heat energy output only in very insignificant quantities. A number of various obstacles still hinder development of full-scale application of wood-logging and woodwork wastes. Lumber camps are often located at great distances from industrial centers or other population areas, and no developed infrastructures are available to effectively collect, transport and recycle wood-logging waste.

Yet, interest in the utilization of wood wastes has been growing in recent years. This is not only due to growing prices for traditional kinds of organic fuels (coal, petroleum

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[1] As translated from the original Russian name. The institute has no official English equivalent of its name.

[2] As translated from the original Russian name. The official English equivalent of the institute's name – if there is one – is unavailable.

products and gas) but also stricter legislative regulations for forestry and environmental protection.

The potential bioenergy resources of woodworking wastes in the Murmansk region are relatively small. Total yearly output of timber wastes in the region is 0.75 million m^3 (including 0.3 million m^3 at the tree-felling stage and 0.45 million m^3 during wood processing). In fact, the Murmansk region has at its disposal the least potential lumber waste resources among all of the administrative regions of the Russian Northwest. It has almost five times as little wood waste resources as the Republic of Karelia, and almost 20 times as little as the Republic of Komi and the Arkhangelsk region [39, 40].

In terms of energy potential, estimations show that wood waste resources of the Murmansk region are equivalent to 1.5 TWh. The potential application area for these energy resources in the Murmansk region would be small populated localities whose electric power needs are covered by local diesel-burning power stations and whose heating is supplied by municipal boiler houses. Altogether, the region now numbers around 150 diesel power stations with a combined power capacity of 9 MW, as well as 355 small boiler installations with a combined installed heat capacity of around 5,320 MW [41, 42].

However, the planned development of oil and gas resources on the continental shelf of the Barents Sea makes any prospects of utilizing lumber wastes as fuel rather problematic. Even the initiative undertaken under the framework of the Norwegian program BIPIR has generated no pilot projects aimed at application of wood-logging and woodworking industry wastes to the heating needs of the region’s small consumer groups. In a long-term perspective, as new technologies are introduced based on the use of briquettes and sawdust pellets, as well as burnable fractions of industrial and domestic wastes [43], this area of non-conventional energy could be developed.

CONCLUSION

For many years, the energy supply system of the Murmansk region has developed by means of the consistent exploitation of the region's hydro energy resources, the burning of organic fuels delivered from elsewhere at thermal power plants and boiler houses, and the generation of electric power from nuclear fuel at the Kola Nuclear Power Plant. The policy of further development of the region's energy economy hinges on the construction of the second Kola Nuclear Power Plant and the transportation of natural gas deliveries to the region. At the same time, the Murmansk region has at its disposal a wide array of non-conventional and renewable energy sources – such as energy of the sun, wind, small rivers, tides and sea surface waves, etc. – which under certain conditions can successfully compete with traditional energy sources, or complement the latter, and provide an economic benefit.

The table below shows the results of an assessment of potential and technical resources available in non-traditional renewable energy sources. This evaluation clearly demonstrates that sun energy resources are the region's largest. However, northern conditions present a number of difficulties that will challenge efforts to exploit this source of energy. The main challenge is posed by the minimum occurrence of solar energy, or the lack thereof, during the winter months, when energy needs of the consumers reach their peak. Secondly, because of the intense cyclone activity characteristic to northern latitudes, the number of days in a year with clear and sunny weather is relatively modest. Therefore, only a few small sites, like beacons or buoys, are currently suitable for the practical application of solar energy, where the traditional scheme for supplying energy is too costly.

Table
Resources of non-conventional and renewable energy sources in the Murmansk region, in TWh

Energy sources	Potential resources	Technical resources
Sun	110,000	11,000
Wind	21,000	360
Small river	7	4.4
Tides	11	2.0
Sea waves	3	1.6
Wood wastes	1.5	0.9
Biodegradable livestock and poultry wastes	0.13	0.09

The Kola Peninsula also has significant prospects in tidal energy. It has gained valuable experience operating the Kislaya Bay Tidal Power Plant with a capacity of 400 kW. However, due to the relatively small tidal heights washing against the peninsula's coasts – two to three meters on average – and the limited number of water basins that could be cut off by a dam, tidal power plant projects are only applicable in a few select places in the region. One noteworthy site is Lumbovsky Bay of the White Sea, where the average tidal height is 4.2 m, and the size of the water basin suitable for use by a tidal power plant is between 70 and 90 km^2. It has been estimated that a future Lumbovsky Tidal Power Plant will potentially have a capacity of between 320 MW and 670 MW and a yearly energy output of up to 2 TWh. However, the remote location of this prospective construction site and the necessity of sizable investment funds, as well as a number of other factors, push this project off into a less foreseeable future. Besides, as specialists estimate, it would be more expedient to start exploring this energy source with an experimental industrial-operation model – a Kola Tidal Power Plant with a capacity of 40 MW – in Dolgaya Bay, near the village of Teriberka. This pilot project may serve as an intermediate phase for the development of the Lumbovsky Tidal Plant construction project.

The Kola Peninsula has a coastline more than 1,000 kilometers long. An evaluation of energy resources of ocean surface waves available along the coasts of the Barents and White Seas has shown that these resources are quite substantial. However, due to the severe climate, it is quite problematic to convert, store and transmit surface wave energy into generated power. As of today, there are no obvious premises warranting development of this energy source in the region.

Last, though not necessarily least, in the list of non-conventional and renewable energy sources is bio-energy found in wood waste and the organic waste of the livestock and poultry farming industries. The technical potential of these resources in the Murmansk region is small in comparison to other energy sources – less than 1 TWh a year. Besides, bio-energy resources are dispersed across a multitude of small farms in the region. It is nonetheless obvious that utilizing biodegradable waste resources is of certain interest to small and isolated populated areas and localities where these wastes are generated. Timber and wood waste have been used by mankind for centuries. Biodegradable wastes generated from livestock and poultry farming constitute a "younger" energy source, but various technologies developed in the past decades to efficiently recycle these raw materials have finally reached polar regions as well. In particular, they have been successfully applied in the Kovdor region of Murmansk, where biogas is produced with the help of bio-energy converters, a fuel both valuable and convenient for practical use. Further popularization of the experience accumulated in Kovdor can only be welcomed.

Of all the non-conventional renewable energy sources studied in this report, exploitation of small river hydro energy and wind energy are the most promising for the Murmansk region. Technical hydro energy resources of the region's small rivers are estimated at 4.4 TWh, with an average yearly capacity reaching 516 MW. This evaluation encompasses 35 small and medium-size rivers of the region.

The challenges of harnessing hydro energy of small rivers are not new. In the post-war years, a number of small village hydro energy plants were constructed – running on heads of between 2 m and 6 m and with capacities ranging between 10 kW and 100 kW. In the 1960s, these plants were gradually replaced by diesel installations which were cheaper at that time. Today, because of the rising prices of organic fuels, application of stream flow energy has started to attract growing interest. The significance of fishing for the majority of the region's rivers is a serious obstacle to construction of new hydroelectric power plants. Compromises are needed, such as parallel construction of hydroelectric power plants and fishways, or construction of fish farms to compensate for the damages incurred during construction and operation of the hydropower works.

So far efforts aimed at exploring small river energy have been spinning their wheels. A breakthrough could be achieved by the construction of a few pilot small-scale hydropower plants that could demonstrate beyond a reasonable doubt that stream flow energy application can be efficient and capable of yielding great economic benefit. First-priority sites fulfilling this purpose could be found the following: a small-scale hydropower plant with a capacity of 6 MW near the fish farm on the Pirenga River, which flows into Lake Imandra; a small-scale hydropower plant with a capacity of 1,250 kW on the Chavanga River in the southeastern part of the Kola Peninsula, seven kilometers from a village of the same name; and a small-scale hydropower plant with a capacity of 500 kW in the center of the peninsula, 12 kilometers from the village of Krasnoshchelye on the Elreka River, a tributary of the Ponoi River. The potential output of energy that these plants could generate would be 30% to 50% higher than that of the diesel power stations already in operation in these locations.

The Murmansk region also possesses a promising potential of wind energy, concentrated mostly in the coastal areas of the peninsula. The region's technical wind energy resources are estimated to average 360 TWh, with the combined installed capacity of wind energy converters reaching around 120 million kW. The strongest and most persistent winds can be observed on the northern coast of the peninsula. This is in fact the windiest place in the whole of Russia's European North, and thus, most abundant in the most accessible and economically advantageous energy source. Making use of even 1% to 2% of the estimated wind resources – which comes to 3 TWh to 7 TWh in power output, or 1 million to 2 million kW in energy capacity – can indeed play a very significant role in the region's energy economy.

Several favorable premises warrant the application of wind energy resources on the territory of the Kola Peninsula:

- the high wind potential available across sizable areas of the region;
- the presence of prevailing winds (south and southwest winds), which will allow for the more compact and more cost-efficient arrangement of wind energy converters while installing them in the chosen location;
- the coincidence of winter maximum wind intensity with the maximum demand for electric energy and heating on the part of the consumer;
- the mutually complementary character of seasonal variations in wind energy and hydro energy which will enable them to supplement each other;
- the availability of 17 hydroelectric power plants with a combined capacity of over 1.5 million kW in operation on the Kola Peninsula; equipped with water reservoirs with daily, seasonal and multi-year regulation capable of compensating for uneven supply of energy from the wind energy converters.

Three major wind energy development trends can be identified in this regard:

- autonomous wind energy development, which implies that isolated wind energy converters operate to supply energy to isolated or remote consumer groups;
- system-based wind energy development, where a series of wind energy converters – or wind parks – operate as part of the grid;
- and, application of wind energy converters to cover the heating needs of consumers.

Non-integrated wind energy converters can enhance significantly the logistics of electric power supply for decentralized consumers, such as isolated settlements and villages, weather stations, beacons, border patrol quarters, sites of the Russian Northern Fleet, fishing and hunting camps, etc. Fuel supply for these energy users is challenging as they receive their energy from independent sources, such as diesel power stations, small gas-burning boilers, or primitive stoves. Operating in conjunction with these traditional heating sources, wind energy converters can replace between 30% and 50% - or as much as 70%, in the windiest areas – of the hard-to-obtain organic fuels.

System-based wind energy – or application of wind energy resources as part of the grid – is advisable primarily in locations where there is a high wind potential, usable roads to deliver large wind energy converter installations, and an access to the grid. It is preferable that such an area is located near hydroelectric power plants already in operation, or under construction. One site that fulfills all these requirements is the area encompassing the Serebryanka and Teriberka Hydropower Plants. It is a 40 square kilometer site, at the top of which are located the Teriberka and Dalniye Zelentsy settlements, the Serebryanka-1 Hydroelectric Power Plant and the 81st kilometer of the Murmansk-Tumanny highway (the Teriberka Exit). There are substantial prospects for the development of large-scale wind energy resources in this area.

Outside Russia, system-based wind energy has already developed to a self-standing, profitable sector of the energy economy, which makes considerable contributions to energy production in Germany, Denmark, Spain and other countries. In Russia, however, system-integrated wind energy is still in its infancy due to the financial and economic hardships of the past 15 years. At the same time, Russia has at its disposal the necessary scientific and production capabilities and has already developed the first experimental wind energy converters designed to the latest scientific and technological standards. Wind energy converters are already in operation near the northern city of Vorkuta, in the southern republic of Kalmykia, in the western enclave of Kaliningrad, and other parts of the country.

On the Kola Peninsula, one pilot wind energy converter model has been installed in cooperation with Norway. The 250 kW windmill near Murmansk is used to supply energy to the hotel Ogni Murmanska (Murmansk Lights). The next step in the region's development of wind energy could be the construction of a wind park with a capacity of between 6,000 and 20,000 kW near the settlement of Teriberka on the coast of the Barents Sea. These efforts are the first steps towards development of system-based wind energy on the Kola Peninsula.

Using wind energy converters to supply heat implies participation of wind power installations in heating small towns and villages located in windy areas that are included in the centralized electric power supply, but experience difficulties in obtaining a stable supply of heating due to rising prices for organic fuel deliveries, namely, fuel oil. The favorable premises for the application of wind energy for heating purposes are the following:

- the heating season on the Kola Peninsula lasts for nine months, while wind speeds are noticeably higher during winter months than they are in the summer; therefore, the seasonal peak in heat energy demand on the part of the consumer coincides with that of the potential energy output from wind energy converters;
- using wind energy converters in these areas will allow transforming wind from a climatic factor prompting increased heat losses into a full-fledged energy source, which will provide for a steady flow of energy usable for heating purposes exactly during the windiest periods of the year;
- application of wind energy through wind energy converters will greatly facilitate saving on costly fuels delivered to the Kola Peninsula from locations as far away as 1,500 to 2,000 kilometers;
- using wind energy converters for heating purposes does not necessitate complying with the stern requirements normally applied to the quality of the wind-produced energy; this will allow making the wind energy converter design as simple as possible, rendering it both more cost-efficient and reliable;
- using wind for heating purposes enables control over the main disadvantage of wind energy: its variability across prolonged periods of time; seconds or minutes of lapses in the wind energy converter's capacity can be smoothed over by the accumulating capability of the heating supply system, while longer fluctuations, lasting from ten minutes to several hours, will be compensated for by the accumulating capacities of the buildings covered by the heating supply; during very long periods of stillness, special auxiliary heat accumulating systems or heating sources running on organic fuels can be switched on as a backup;

On the whole, the Kola Peninsula has a vast potential of non-conventional and renewable energy sources at its disposal. It is introducing these energy sources into the region's economy that presents the main scientific and technological challenge today. But finding a solution to this challenge will both help supply cost-efficient energy to a whole range of consumer groups and greatly reduce the region's current energy dependence.

CITED LITERATURE[1]

1. Энергетическая стратегия России на период до 2020 года. – М.: ГУ ИЭСМинэнерго России. 2001. – 544с.
   Russia's Energy Strategy from 2000 til 2020. – Moscow, The Russian Ministry of Energy. 2001. – 544 pages.
2. 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.
   P. P. Bezrukikh, G. A. Borisov, V. I. Vissarionov etal. Energy Resources and the Efficiency of Using Renewable Energy Sources in Russia. – St. Petersburg, Nauka. 2002. – 314 pages.
3. Минин В.А., Дмитриев Г.С. Перспективы развития нетрадиционной энергетики Мурманской области / Природопользование в Евро-Арктическом регионе: опыт XX века и перспективы. – Апатиты: Изд-во Кольского научного центра РАН. 2002.-С.134-139.
   V. A. Minin, G. S. Dmitriyev. Prospects of Development of Non-conventional Energy sources in the Murmansk region / Use of Natural Resources in the European Arctic Region: 20th Century's Experience and Future Prospects. – Apatity, Kola Scientific Center of the Russian Academy of Sciences. 2002. – Pp. 134-139.
4. Минин В.А., Якунина Т.И., Коробко И.Л. Перспективы использования солнечной энергии в Мурманской области / Проблемы энергообеспечения Мурманской области. –Апатиты: Изд-во Кольского научного центра РАН. 1992.-С.73-81.
   V. A. Minin, T. I. Yakunina, I. L. Korobko. Prospects of Application of Solar Energy in the Murmansk Region / Energy Supply Problems in the Murmansk Region. – Apatity, Kola Scientific Center of the Russian Academy of Sciences. 1992. – Pp. 73-81.
5. Зубарев В.В., Минин В.А. Степанов И.Р. Использование энергии ветра в районах Севера. Л.: Наука, 1989. – 208с.
   V. V. Zubarev. V. A. Minin, I. R. Stepanov. Application of Wind Energy in the Arctic. – Leningrad, Nauka. 1989. – 208 pages.
6. Минин В.А., Дмитриев Г.С. Перспективы развития ветроэнергетики на Кольском полуострове. – Апатиты, 1998. – 97с.
   V. A. Minin, G. S. Dmitriyev. Prospects of Development of Wind Energy on the Kola Peninsula. – Apatity. 1998. – 97 pages.
7. Приливные электростанции. Под ред. Бернштейна Л.Б. –М.: Энергиздат,1987.-296с.
   Tidal Power Plants. Edited by L. B. Bernstein. – Moscow, Energizdat. 1987. – 296 pages.
8. Сичкарев В.И., Акуличев В.А. Волновые энергетические станции в океане. -М.: Наука, 1989.-132с.
   V. I. Sichkaryov, V. A. Akulichev. Ocean-based Wave Energy Conversion Systems. – Moscow, Nauka. 1989. – 132 pages.
9. Дьяков А.Ф., Морозкина М.В. Проблемы использования энергии волн. –М.: Энергоатомиздат, 1993.-176с.
   A. F. Dyakov, M. V. Morozkina. Problems of Application of Wave Energy. – Moscow, Energoatomizdat. 1993. – 176 pages.
10. Справочник по климату СССР. Вып. 2. Ч.1. Солнечная радиация, радиационный баланс и солнечное сияние. – Л.: Гидрометеоиздат, 1966. – 62с.
    USSR Climate Reference Book. Second Issue, Part 1. Solar Radiation, Radiation Balance and Sunshine. – Leningrad, Gidrometeoizdat.1966. – 62 pages.

---

[1] Original Russian titles and names of the authors are rendered in English as they appear in the Russian text. As required by the Russian tradition, only initials were available for the Russian names.

11. Тепловой баланс // Труды ГГО, вып. 179. – Л.: Гидрометеоиздат. 1965. – 200с.
    Heat Balance / Works of the Chief Geophysical Observatory, Issue No. 179. – Leningrad, Gidrometeoizdat.1965. – 200 pages.
12. Даффи Д.А., Бекман У.А. Тепловые процессы с использованием солнечной энергии / Пер. с англ. д.т.н. Ю.Н. Малевского.-М.: Мир,1977.-420с.
    John A. Duffie, William A. Beckman. Solar Engineering of Thermal Processes (Translated into Russian by Yu. N. Malevsky, Doctor of Engineering. – Moscow. Mir, 1977. – 420 pages.
13. Минин В.А., Степанов И.Р. Ветроэнергетический кадастр европейского Севера СССР. // Изв. АН СССР. Энергетика и транспорт, №1, 1983. – С.106-114.
    V. A. Minin, I. R. Stepanov. 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.
14. Рекомендации по определению климатических характеристик ветроэнергетических ресурсов. – Л.: Гидрометеоиздат, 1989. – 80с.
    Recommendations on How to Determine Climatic Parameters of Wind Energy Resources. – Leningrad. Gidrometeoizdat, 1989. – 80 pages.
15. Справочник по климату СССР. Ветер. Мурманская область. Вып.2, часть 3. –Л.: Гидрометеоиздат, 1966. –120с.
    USSR Climate Reference Book. Wind. Murmansk Region. Second Issue, Part 3. – Leningrad. Gidrometeoizdat, 1966. – 120 pages.
16. Первоочередные площадки для ветропарков на Кольском полуострове. Минин В.А., Дмитриев Г.С., Никифорова Г.В. и др. – Апатиты: Изд-во Кольского научного центра РАН, 2004. – 24с.
    V. A. Minin, G. S. Dmitriyev, G. V. Nikiforova etal. First-priority Wind Park Sites on the Kola Peninsula. – Apatity. Kola Scientific Center of the Russian Academy of Sciences, 2004. – 24 pages.
17. Windenergie 2002. – Osnabrueck, Deutschland Bundesverband WindEnergie Service GmbH. 2002. – 264 pages.
18. Концепция использования ветровой энергии в России. Под ред. Безруких П.П. – М.: Книга – Пента, 2005. – 128с.
    A Concept of Application of Wind Energy in Russia. Edited by P. P. Bezrukikh. – Moscow. Kniga – Penta, 2005. – 128 pages.
19. Renewable Energy. Power for Sustainable Future. Edited by Godfrey Boyle. Oxford University Press - The Open University, 1996. - 479 pages.
20. Оценка запасов и эффективности использования энергии ветра и малых рек в районах Европейского Севера России: Отчет о НИР /Институт физико-технических проблем энергетики Севера (ИФТПЭС); Руководитель В.А. Минин, отв. исполнитель Г.С. Дмитриев, 2-91-2309, №ГР 01920015356, Инв. № 02960003984. -Апатиты, 1995. - 213 с.
    An Evaluation of Wind and Small River Energy Resources and Efficiency of their Use in the Regions of the Russian European North: Report on a Scientific Research Study / Institute for Physical and Technological Problems of Energy in Northern Areas[2]. V. A. Minin, G. S. Dmitriyev. – Apatity, 1995. – 213 pages.
21. Малая гидроэнергетика. Под ред. Л.П. Михайлова. М.: Энергоатомиздат, 1989. - 180 с.
    Small Hydro Energy. Edited by L. P. Mikhailov. – Moscow. Energoatomizdat, 1989. – 180 pages.

---

[2] The name of the institute is rendered into English as the official equivalent preferred by the institute. See Chapter 3: Small River Energy.

22. Схема гидроэнергетического использования малых и средних рек Кольского полуострова. Этап II, часть II, общая пояснительная записка, АО «Ленгидропроект», Санкт-Петербург, 1994. - 342 с.
    A Project of Application of Hydro Energy of Small and Medium-size Rivers of the Kola Peninsula. Stage II, Part II. A General Commentary. – St. Petersburg. Lengidroproyekt, 1994. – 342 pages.
23. Схема гидротехнического использования малых и средних рек Кольского полуострова. Этап 1, Пиренгская ГЭС на р. Пиренга, АО «Ленгидропроект». - Санкт-Петербург, 1993. – 107с.
    A Project of Application of Hydro Energy of Small and Medium-size Rivers of the Kola Peninsula. Stage I, The Pirenga Hydroelectric Power Plant on the River Pirenga. – St. Petersburg. Lengidroproyekt, 1993. – 107 pages.
24. Перспективы энергоснабжения изолированных потребителей Севера с использованием энергии ветра и малых рек. Отчет о НИР (промежуточный) / Институт физико-технических проблем энергетики Севера (ИФТПЭС), Руководитель В.А. Минин, отв. исполнитель И.Р.Степанов, 2-91-2309, №ГР 01920015356, Апатиты, 1993. - 107 с.
    Prospects of Electric Energy Supply of Isolated Energy Consumers of Northern Territories through the use of Wind and Small River Energy. An Intermediate Report on a Scientific Research Study. / Institute for Physical and Technological Problems of Energy in Northern Areas[3]. V. A. Minin, I. R. Stepanov. – Apatity, 1993. – 107 pages.
25. Ляхницкий В.Е. Синий уголь. -М.: Изд-во АН СССР, 1926. –107с.
    V. E. Lyakhnitsky. Blue Coal. – Moscow. The USSR Academy of Sciences, 1926. – 107 pages.
26. Волшаник В.В., Зубарев В.В., Франкфурт М.О. Использование энергии ветра, океанских волн и течений. – М.:ВИНИТИ, 1983. – 100с. (Итоги науки и техники. Сер. Нетрадиционные и возобновляемые источники энергии; т.1).
    V. V. Volshanik, V. V. Zubarev, M. O. Frankfurt. Application of Wind, Ocean Wave and Stream Flow Energy Sources. – Moscow. The Russian Institute for Scientific and Technological Information, 1983. (Science and Technology and Their Results. In the series: Non-conventional and Renewable Energy Sources, Vol. 1). – 100 pages.
27. Indian wave plant is commissioned // Int/ Water Power and Dam Construction. 1991. 43, No. 12. P.20.
28. Wave Power Becomes a Reality // S. Atr. Mech. Eng., 1991. 41, No. 4. Pp.122-123.
29. Proof Test for Wave Power Generation //Techno Jap.- 1990. 23, No. 6. P.6.
30. Давидан Л., Лопатухин Л.И. На встречу со штормами. –Л.: Гидрометеоиздат, 1982. –136с.
    L. Davidan, L. I. Lopatukhin. Facing the Storm. – Leningrad. Gidrometeoizdat, 1982. – 136 pages.
31. Paniker N.N. Energy from Ocean Surface Waves: Ocean Energy Resource // Energy tech. Conf., Houston (Tex.). 1977. N.Y.: 1977. – Pp.43-67.
32. Paniker N.N. Power Resource Estimate of Surface Waves // Ocean Energ. 1976. Vol.3, No. 6. – Pp. 429-439.
33. Матушевский Г.В. Оценка энергозапасов ветрового волнения в морях СССР. – М.: 1982. – 9с. Деп. в ИЦ ВНИИГМИ – МЦд. 1982. N 145 ГМ-д 82.
    G. V. Matushevsky. An Evaluation of Resources of Wave-induced Undulation in the Seas of the USSR. – Moscow, 1982. – 9 pages.
34. Волшаник В.В., Матушевский Г.В. Энергия морских ветровых волн и принципы ее преобразования // Гидротехническое строительство, 1985, №4. –С.41-45.

---

[3] See Footnote 2.

G. V. Matushevsky, V. V. Volshanik. Energy of the Sea Wind Waves and Principles of its Conversion // Hydroworks Construction, 1985. No. 4. – Pp. 41-45.

35. Матушевский Г.В. Новый тип режимной функции распределения параметров волн // Метрология и гидрология, 1977, №3. –С.66-72.
    G. V. Matushevsky. New Type of Climatic Function of Wave Parameter Distribution // Meteorology and hydrology, 1977. No. 3. – Pp. 66-72.
36. Ветер и волны в океанах и морях: Справочные данные. Под ред. И.Н. Давидана. –Л.: Транспорт, 1974.-360с.
    Wind and Waves in Oceans and Seas: Reference Material. Edited by I. N. Davidan. – Leningrad. Transport, 1974. – 360 pages.
37. Васильев Ю.С., Хрисанов Н.И. Экология использования возобновляющихся энергоисточников. –Л.: Изд-во Ленингр. ун-та. 1991.-343с.
    Yu. S. Vasiliyev, N. I. Khrisanov. Environmental Aspects of Application of Renewable Energy Sources. – Leningrad. The Leningrad State University, 1991. – 343 pages.
38. Мурманская область в 2004 г. Статистический ежегодник. – Мурманск: Мурманскстат, 2005.-205с .
    The Murmansk Region in 2004. A Statistical Annual Report. – Murmansk. Murmanskstat, 2005. – 205 pages.
39. Твайдел Дж., Уэйр А. Возобновляемые источники энергии. М.: Энергоатомиздат, 1990.
    J. W. Twidel, A. D. Weir. Renewable Energy Sources. – Moscow. Energoatomizdat, 1990.
40. Борисов Г.А., Сидоренко Г.И. Энергетика Карелии. Современное состояние, ресурсы и перспективы развития. С.-Пб.: Наука, 1999.- 303с.
    G. A. Borisov, G. I. Sidorenko. Energy in Karelia. Current Matters, Resources and Development Prospects. – St. Petersburg. Nauka, 1999. – 303 pages.
41. The Bio-fuel Potential from Forest and Wood Industry in the Regions of Northwest Russia/ Volume1, Oslo, 1999, BIPIR Program . - 24 pages.
42. Market Analysis of the Biofuel Conversion Potential for Northwest Russia. Ole Veiby, Inger-Anne Blindheim, IET, Norway,1999.- 44 pages.
43. Энергия биомассы // Энергия будущего. Научно-аналитический журнал, июнь 2006. - М.: С.65-66.
    Biomass Energy // Energy of the Future, a Scientific Analytical Magazine, June 2006. – Moscow. – Pp. 65-66.

BELLONA'S POSITION

This position paper provides arguments for development of renewable energy sources on the Kola Peninsula, summarizes the scientific findings of the Kola Science Centre study of alternative energy potential in the region, and makes recommendations that outline a plan of action for implementation of renewable energy on the Kola Peninsula.

Introduction

For many years renewable energy sources, which include solar, wind, hydro, tidal, wave and bioenergy, have been disregarded as serious energy alternatives. Today, the largest share of the world's energy needs is still covered by oil (38%), followed by coal (26%), gas (23%), renewables (7%) and nuclear energy (6%) (International Energy Outlook 2007, EIA). Climate change and global warming, diminishing reserves of organic fuel, as well as the risks and negative consequences associated with nuclear energy make the development of renewable energy sources an imperative for the 21st century. Recent reports from the UN Panel on Climate Change provide overwhelming evidence of the negative environmental consequences of climate change and human-induced CO_2 emissions from coal, oil and gas. In addition, the Stern Review on the Economics of Climate Change Report estimates the economic costs to governments of catastrophes from global warming to be 5-20 % of their GNP, exceeding that of either of the two World Wars.

Summary

One of the regions in Russia where a transition to clean energy sources is most urgent is the Kola Peninsula where the Kola Nuclear Power Plant poses an environmental threat for both sides of the border. In order to identify prospects for implementing clean energy, Bellona commissioned the Kola Science Centre of the Russian Academy of Sciences to conduct a study of renewable energy sources on the Kola Peninsula in 2006. The report "Prospects for Development of Non-conventional and Renewable Sources of Energy on the Kola Peninsula" by V.A. Minin and G.S. Dmitriev shows the region possesses an enormous potential for renewables. In particular, the region has one of the greatest wind energy resources in Europe, estimated at 360 billion kWh annually. Using all the renewable energy resources available in the region is more than sufficient to meet the current electrical power demands of the region, or match the power capabilities of the most outdated nuclear reactors, thus permitting their retirement.

Annual energy consumption in the Murmansk region is approximately 16 billion kWh (16 TWh). According to the Murmansk Center for Energy Efficiency, nuclear power provides for approximately 37% of the region's energy requirements, hydro-electric stations 57% and thermal power plants 6%. Other official figures used by the government give the following estimates: 50-60% nuclear, 42 % hydro and 19% thermal. With the exception of large hydro energy, other types of renewables are undeveloped in the region despite their enormous potential. In recent years, the region has had an energy surplus, but an energy deficit will result when the KNPP reactors are decommissioned, unless an alternative is found. Earlier this year proposals for construction of a new KNPP-2 were discussed and subsequently rejected as too expensive. But a second plant is still being contemplated. In addition, the current reorganisation of the nuclear industry in Russia which entails plans for its privatisation, placing nuclear sites and materials in private hands, is certain to increase safety and security risks. Bellona recommends renewable energy sources as the best alternative to nuclear power on the Kola Peninsula, and strongly urges their development for the benefit of the environment and the economy in Northwest Russia.

Obstacles to renewable energy

In Russia there are several obstacles to the development of renewable energy. First, there is a traditional reliance on, and lobbying for, fossil fuels and atomic power to meet energy requirements. Fossil fuels account for approximately 63% of Russia's electricity generation, followed by hydropower (21%) and nuclear energy (16%). (www.eia.doe.gov) Consideration of renewables is also impeded by Russia’s fossil fuel fixation, and the connection between export of these resources and Russia’s economic and political status. Approximately 78% of Russia’s exports are based on oil and gas. Second, there exists no legislation that specifically addresses the development of renewable energy. The Russian Federation energy policy “Energy Strategy of Russia until 2020” of August 28, 2003 focuses on fossil fuels and nuclear energy and devotes only 3 of its 118 pages to discussing renewable sources of energy. A draft law “On Renewable Sources of Energy” has been discussed for several years, but as of January 2007 is not yet adopted by the state Duma. Third, there are no economic measures such as taxation, subsidies, or quotas that act as an incentive for RES and influence market behaviour. Fourth, until recently the low costs of fuel and the high costs of implementing renewable energy alternatives made their development economically unfeasible. However, rising fuel prices in Russia and technological progress in alternative energy the past decade have decreased costs of their exploitation making the time ripe for renewable energy to be given the attention it deserves. Lastly, peoples perceptions and limited access to information. Notions of nuclear energy as a good renewable energy substitute for oil and gas, and insufficient knowledge about the benefits of using renewable energy have hindered their consideration. Most people are unaware that a solar collector can warm water for the same price as an electric heater (Chistaya Energiya, 2 /2005).

Advantages of renewable energy for the Kola Peninsula

There are numerous reasons for utilising renewable energy sources – accessibility, sustainability, reliability, profitability and ecological purity.

In contrast to diminishing reserves of organic fossil fuels, renewable energy sources are virtually unlimited, easily accessible and sustainable, and do not deplete natural resources. Despite large deposits of oil, gas and coal, Russia’s supply of organic fossil fuels is limited. At the current rate of production, oil and gas are expected to be depleted this century. (Chistaya Energiya 1/2005). Northwest Russia possesses enormous potential for renewable energy sources, especially wind and small river hydro energy. Renewable energy can enable preserving reserves of organic fuels for future generations and help meet the increasing demands for energy in connection with the revival in industrial development in the region.

Renewable energy can enable regional energy security, ensure a stable, reliable energy supply to remote areas, and protect connected customers from cut-offs. In decentralised settlements, located in the eastern portion of the Kola Peninsula, energy is based to a significant degree on fuel imported to the region. Developing renewables where they are available locally will enable diversification of the energy supply. At the present time traditional fuel costs are high, as are tariffs on electricity and heating. Fortunately, the areas experiencing the most difficulty with fuel supply are the same areas that possess the highest potential for renewable energy sources. Renewable energy can ensure a sustainable heating and electric supply to remote settlements with decentralised energy supply relieving them from unreliable fuel supply, unstable fuel prices and high costs associated with fuel transport over long distances. Renewable energy can also be beneficial for connected customers. Winter 2006 caused an energy deficit and electrical power shortages in Northwest Russia and other regions. Renewable energy can protect consumers that are dependent on centralised energy supply, and experiencing cut-offs, by guaranteeing a minimum supply of energy during periods of high demand.

Renewable energy is a profitable sector providing the basis for new employment opportunities and financial income. Developing renewable energy in Northwest Russia can be a means of generating jobs, income and tax revenue in the region. Expanding the industrial base, or utilising the existing one, for production of renewable equipment and parts such as wind converters can boost the local economy through the creation of new workplaces. In addition, producing installations locally will decrease their prime cost by economising on expenses otherwise incurred in connection with their transportation and import. Markets also exist for green equipment and green technology abroad. Denmark, for example, generates revenue by exporting wind turbines, one of its most important products.

In comparison with nuclear energy, renewable forms of energy are non-hazardous to human health; they are risk-free, ecologically clean, producing no waste, requiring no processing and are non-polluting to the local environment. Local environmental safety and health are another important reason to prioritise development of renewable energy sources, rather than nuclear energy, in Northwest Russia. In 2006, the Kola Peninsula was nominated among the top 25 most polluted places on earth in the Blacksmith Institute report “The World’s Worst Polluted Places”. The most pressing issue on the Kola Peninsula is the condition of the two oldest reactors at the Kola Nuclear Power Plant (KNPP) which exceeded their service life in 2003 and 2004. These reactors should be decommissioned and replaced by a renewable energy source. These reactors are over 30 years old and have lower safety standards than western reactors. According to a safety analysis made by the International Atomic Energy Agency in 1991, the chance of a reactor meltdown is 25% in the course of 23 years (The Arctic Nuclear Challenge, 2001). Nuclear energy entails considerable risks – danger of nuclear accidents, leakages from radioactive waste storage and spent nuclear fuel assemblies, transportation, reprocessing, nuclear weapon proliferation and security issues – none of which are a factor with non-traditional renewable energy.

In comparison with fossil fuels which make harmful emissions to air and ocean, causing climate change and chronic impact on the marine ecosystem, renewable energy sources emit no CO_2 and do not entail the same degree of risks and consequences. Last year, the Russian Federal Agency on Hydrometeorology and Monitoring of the Environment published a report documenting that general warming in Russia the last 100 years is greater than the global average and showing an increased occurrence of extreme acts of nature (Doklad ob Ocobennoctyax Klimata ha Territoriy Rossiskoy Federatsiy za 2006 god). Many of the negative consequences of climate change have detrimental impacts especially for the regions of the north. For northern latitudes the expected consequences of global warming are flooding of islands, erosion and loss of coastline, reduction of biological diversity and extinction of some polar species, collapsing infrastructure, houses and roads in permafrost areas, damage to pipelines, and more extreme, unpredictable weather. Despite the perception often held in Russia that climate change is a positive thing (enabling better access to petroleum resources, greater crop yields and an opening of the northern sea route once the North Pole becomes ice-free) long-term consequences outweigh any short-term benefits. Thawing permafrost, reduced by 7% the last 100 years, is causing the release of large quantities of methane trapped in the frost. There is a potential threat of viruses escaping as well. Developing renewable energy is the means to reducing CO_2 emissions, the key to stopping global warming and preventing the undesirable and negative consequences of climate change. A 1MW windmill can reduce annual CO_2 emissions by 2000 tons if it substitutes a fossil fuel power plant (Wind Energy in Russia, G. Dimitriev, 2001).

Development of renewable energy sources will generate support, rather than opposition, at the local and regional level. Another reason to develop renewable energy solutions is political legitimacy. Neither the local population on the Kola Peninsula, nor the neighbouring Nordic countries (with the exception of Finland) want the risks associated with another nuclear power plant. Results of public hearings in December 2006 to discuss the region's energy policy showed that over 89% of Murmansk citizens attending were opposed to building a new KNPP-2 and 93% were in favour of prioritising wind energy development. A nationwide survey conducted in October revealed only 19% of Russians support atomic energy, a figure comparable to the EU. According to the European Commission, 80% of EU citizens support solar energy while 20% support atomic energy. Internationally, a host of industrialised countries are making plans to implement renewable energy on a large scale. In January 2007, the EU Commission presented an energy package proposing to increase the share of renewable energy to 20% of electricity production by 2020, while Russia plans to increase its share of renewables to 1% by 2010.

Potential for renewable energy on the Kola Peninsula

In 2006 the Kola Science Centre studied the potential of sun, wind, hydro, tidal, wave and bioenergy resources on the Kola Peninsula as alternatives to coal, oil, gas and atomic energy. The report identifies specific geographical areas most prosperous for development of renewable energy, and shows that Russia possesses experience, technologies and industrial capacity in most sectors to lay the foundation for development of renewables on a large scale.

Solar energy

Solar resources are the most abundant of alternative energy sources. However, given the characteristically cloudy conditions on the Kola Peninsula, direct radiation is reduced by 60-70%. Solar radiation data for the region is comparable to that for Sweden. The biggest obstacle to developing this energy source is the absence of solar radiation in the winter, when the demand for energy is highest. Seasonally, there is great monthly variation in sunshine, from zero hours in December to 200-300 hours in June and July when the most intensive solar radiation is observed. Fortunately, solar and wind energy resources peak in opposite seasons making it possible for these two resources to complement one another when used jointly. Scandinavian experience shows application of solar energy can be effective for the entire heat supply system. The challenge is to store solar energy in sufficiently large quantities during the summer months. Reservoirs serving as heat accumulators can be either above ground or underground as in Sweden. The main elements of a simple system are a solar collector, an accumulator for storing energy until it is needed to meet heating requirements of the consumer, and a reserve energy source for use when the sun is absent for prolonged periods of time. An advanced circuit can include an auxiliary energy source such as a wind installation.

The most promising candidates for solar energy are remote isolated consumers with expensive heating costs and difficult fuel supply and southern locations with a high technical potential. In recent years, solar energy was used in a successful Norwegian-Russian project to gradually replace decaying, radioactive strontium batteries in lighthouses along the northern coast of the Kola Peninsula with solar cells. According to the Kola Science Centre's data, radiation in the vicinity of Umba (a remote settlement, pop. 6,500) is similar to that from Ingelstad, Sweden where a solar heating station successfully warms 52 houses. This makes Umba a promising site for a solar project. In the northern latitudes, solar energy potential is inferior and should be considered as a complement to hydro or wind power, the latter of which peaks in winter. In terms of economic feasibility, the high costs of solar panels the past decade (approximately USD $4-5,000 per solar cell unit on the international market, compared with USD$1-2,000 per unit for a wind power installation) served as a barrier to serious consideration of this energy source. However, developments in solar energy, particularly in Norway, are expected to increase effectiveness and push prices down below the current 20-30 cents per kWh. Therefore, solar power projects will be economically feasible in the near future.

Wind energy

The opportunities for large-scale development of a wind energy system in the Murmansk region are just as large as they are in Denmark, Germany, Spain or the United States where wind energy is already a source of revenue. Russia possesses the necessary scientific and industrial capabilities, as well as experience from pilot wind electrical stations in Vorkuta, Kalmyka and Kaliningrad. Wind resources on the Kola Peninsula, while not as large as solar, are enormous and estimated at 360 billion kWh. The greatest wind speed is observed in the coastal regions of the Barents Sea. Along the northern coast of the Kola Peninsula, which is the windiest place in the European part of Northern Russia, it reaches 7-9 meters per second. This average annual wind speed is actually higher than in coastal areas in Denmark, Germany and the Netherlands where wind energy predominates and is profitable. The variation in average annual wind speed is only 5-8%, which is low in comparison with the 15-20% variation for river flow in the region. Maximum wind speeds occur in the winter and coincide with the seasonal peak in heat and energy consumption. This winter wind maximum is in a counter phase to the annual river flow creating an advantageous opportunity for wind energy and hydro power to successfully complement one another when used jointly. During the summer when wind speed is reduced, the maximum wind speed occurs during the daytime when an increased consumption of energy on the part of consumers is usually observed, creating another favourable condition for efficient use of wind energy.

The high wind potential on the Kola Peninsula, the correspondence between winter maximum wind intensity and maximum energy consumption, and the presence of 17 hydroelectric stations with reservoirs create unique conditions for utilizing wind energy on a large scale. The region is also especially favourable for multi-turbine windparks due to the presence of prevailing winds which have the greatest energy concentration and allow a compact, and less expensive, location of wind installations with minimal interference and energy loss. Along the northern shore, south-western winds predominate approximately 50-60% of the year. Particularly prosperous areas for construction of multiple windparks are Dalniye Zelentsy and Teriberka located near the Serebryansky and Teribersky hydro-electric stations, which are connected to the Kola energy system and capable of facilitating large-scale use of wind energy in the region. A system that links windparks to hydroelectric stations will produce the greatest economical effectiveness.

There are also several favourable conditions for utilising wind energy to supply electricity or heat to small isolated settlements, meteorological stations, lighthouses, frontier posts and Northern Fleet establishments, located in windy areas. These dispersed consumers receive electrical energy from autonomous diesel electric stations, rather than from the Kola energy system. They pay high costs for diesel supply due to poor transport arteries; expenses are 30-70% higher along the coast and 150-200% higher in inaccessible inland areas. Wind energy can enable economising of expensive diesel fuel which in the most extreme cases is transported a distance of up to 1500-2000 kilometres. In the windiest areas, wind electric converters can supplant up to 60-70% of fossil fuel. During periods of prolonged lulls in wind, special accumulating units or auxiliary heating systems can be switched on.

In selecting appropriate sites for location of windparks, it is necessary to consider areas with high wind potential, infrastructure (roads) and an entrance to the energy system (Grid) or a high-power sub-station, location of base personell and installation facilities. From a practical point of view, wide open spaces are preferred to hills because this simplifies construction of underground paths and erection of the wind converters.

Profitability of wind power is an important issue. Experience from other European countries, particularly Denmark, show that wind power is economically competitive with other types of energy. Currently the cost for construction of a new windmill is $800-$1000 per kilowatt, but this price is expected to decrease to $600-$700 dollars in the next 10 years. The private pilot windmill at the Murmansk hotel “Ogni Murmanska”, including transport, construction of the foundation and erection cost about 4 million rubles, or $750 per kilowatt. With depreciation equal to 7%, operation costs are 3 cents/kWh which is less that the hotel would pay to buy energy from the Grid.

The energy of small rivers

On the Kola Peninsula, the economically feasible hydro resources are already exploited on large and medium-size rivers by 17 hydropower stations which produce 6 billion kWh (6 TW) and provide 42% of the total energy production in the Murmansk region. Ecological and financial limitations make construction of hydro-electric stations on the remaining undeveloped large rivers problematic. “Kolenergo” is working on improving utilisation of the existing hydro-electric stations, but small rivers remain undeveloped. The technical potential of small hydro resources is approximately 4.4 billion kWh, one-third of which is economically feasible to exploit. A confluence of several factors make development of small hydro power advantageous - periodic fuel crises, increases in tariffs on electrical energy, restrictions on construction of large complexes due to their negative ecological consequences, and progress in automation and remote control by hydro-generators. Small hydro-electric stations are defined as stations with an installed capacity under 20-30 megawatts. In the Russian north, the majority of small hydro-electric stations do not exceed 3-5 megawatts. China is the leader in the construction of small and micro hydro-electric stations with over 100,000 plants in operation and produces small turbines based on Russian technology. Two basic trends observed in the use of small hydro-electric stations in industrialised countries, namely the use of dams and water reservoirs created for water supply and the use of small channels and traditional lay-outs, are virtually non-existent in Russia at the present time.

Excluding from consideration the rivers which are significant for the fishing economy of the Kola Peninsula such as the Nota, Varzina, majority of the Umba, Varzyga and Strelna, leaves many prospective rivers for small hydro power. The following rivers have promising sites for small system integrated hydro-electric stations: Pirenga (1 site), Bolshoy Olenka (2), Ura (2), Zapadnaya Litsa (1), Titovka (1), Tumcha (3), Umba (1). Kolenergo and TGK-1 are planning to utilise all these rivers as part of their development. Development of small hydro power plants on the Pirenga and the Tumcha are probably the most feasible and effective.

Small hydro power can provide an inexpensive, independent source of electrical and thermal power to remote areas with de-centralised heating supply, where diesel electric stations are the primary source of electric power and the cost of electrical energy is largely dependent on the cost of diesel. The Murmansk region has previous experience from the 1950s in using small hydro power for the benefit of isolated consumers. At the present time 80-100 settlements exist which are not encompassed by the centralised electric power supply. Their energy requirements vary from 5-10 to 500-800 kilowatts. Three isolated villages are prime candidates for small hydro power: Krasnoschele, Chavanga and Chapoma, as well as the military border settlement Svetly. Fuel supply to these areas is extremely difficult due to the absence of roadways. Small hydro power can be used as a supplement to diesel electric stations which can cover electric demands during periods of little water and act as a reserve for emergencies. The Ponoy tributary on the Yelreka River, the Chavanga River and the Lotta River are the best candidates for pilot small hydro electric stations that can demonstrate the advantages and efficiency of small hydro power for decentralised consumers.

Tidal energy

Tidal electric power stations are also a source of ecologically clean energy which do not pollute habitat with harmful wastes (unavoidable during operation of thermal electric power stations) and do not require any kind of flooding (unavoidable during construction of large hydro electric power stations on level rivers). Tidal energy is unchangeable throughout the month and is independent of annual and yearly water content, despite intervals in the 24-hour cycle and irregularities during the lunar month. These qualities make it a rather powerful source of energy which can be combined with river hydro electric stations containing water reservoirs. The area of the tidal basin and the tidal height are the most important indicators of theoretical potential. Along the coast of the Kola Peninsula, the relatively small size of the tidal range (2-3 metres) and the limitations of an aquatory allowing a cut-off from the dam, make construction of some possible tidal electric stations economically unprofitable.

There are several promising sites for development of tidal power plants (TPP). The Mezen TPP, currently under development at the Abramov-Michaelovsky Cape where the tide reaches 10 metres has the greatest technical potential. This project requires construction of a pumped storage power station on the Ribachy Cape of the Kola Peninsula, which could guarantee an additional 3 million kilowatts of electrical power to the central north-west provided a high-voltage connection exists to the Mezen station. The expected total annual output for Mezen TPP is 50 billion kWh. Another site is a remote area at the Lumbovsky gulf where the average size of the tide is 4.2 metres and the aquatory is 70-90 km^2. A third site, the Kola TPP, is a pilot project under development in the Dolga Bay and will provide a prototype design for the Mezen TPP. Lastly, there is the Kislaya Bay TPP. Constructed as a pilot project in the 1960s to provide scientific and technical experience necessary for larger, powerful tidal plants like Mezin, it’s operation is now terminated. A ship-building factory in Severodvinsk, Archangelsk region, is currently preparing a prototype working wheel for the Mezin TPP which will be tested at Kislaya Bay.

Economic and technical calculations show that it is most economically advantageous to utilise medium- and large-size TPP, combined with water reservoirs and pumped storage power plants, or hydroelectric stations which transform cyclical unevenness into dependable, guaranteed energy. Additional costs for construction of a regulating reservoir and for transmission lines connecting the hydroelectric station with the TPP are compensated for by the exchange of a portion of energy from the thermal station to the tidal. Russian and foreign research conclude the importance of preliminary small pilot tidal electric stations for experimenting with hydraulic turbine equipment when constructing tidal electric power stations with unique output capacities like that of Mezen.

Wave energy

Wave energy possesses a higher energy density than wind and solar energy. Two merits of ocean waves along the Kola Peninsula are their ability to accumulate wind energy over a significant distance and their availability to a large group of consumers along 1000 km of coastline. The disadvantages of wave energy are its periodic instability, dependence on ice conditions, and difficulties of conversion and transmission to the consumer. The possibilities of exploiting wave energy have been explored for over 200 years. However, the practical utilisation of wave energy is very complex necessitating: reception and conversion of energy; a strong reinforcing system capable of withstanding a large load, especially in extreme conditions; evaluation of parameters and behaviour of windy seas; and study of the impacts of a wave installation on the environment. Great Britain, Scotland, and Japan are among the countries that have created and tested a model for wave energy.

An important peculiarity of ocean waves in the northern zone of the Atlantic Ocean is their seasonal irregularity. During the winter the waves are approximately twice as high as during the summer. The Barents Sea is estimated to have an average annual wave energy potential of 22-29 kWh per meter, which is close to data on wind potential in the neighbouring coastal region of Norway. As far as the White Sea is concerned, the average annual potential of wave energy is considerably lower, 9-10 kWh per meter, due to the comparatively small size of the sea and the presence of ice cover in winter.

Wave energy has one of the highest efficiency rates in non-traditional energy. The total net efficiency of wave electric stations in converting energy to electricity is 30-80%. If one calculates wave energy in the Barents and the White Seas using a 60% efficiency rate as a basis then total technical resources of approximately 450 billion kWh (450 TW) per year is estimated. Along the coast of the Kola Peninsula the technical resources of wave energy for a 10 kilometre strip consist of 1.2 billion kWh for the Barents Sea coast and 0.4 billion kWh hours for the White Sea coast. The expected capacities of wave power plants in these locations are 230 MW and 100 MW. Today the cost of wave energy today is approximately 10-20 cents per kWh. This makes wave energy less expensive than solar, but more expensive than wind, and much more expensive than energy produced by conventional power plants.

Bioenergy resources

In comparison with other types of renewable energy on the Kola Peninsula, bioenergy resources are relatively small. In the Murmansk oblast, the potential for bio resources from agricultural waste is approximately 1 billion kWh annually. Processing agricultural waste by the application of anaerobic fermentation provides a solution to three problems: ecological – disinfection of animal wastes and removal of disease-causing substances, food supply – production of high-quality organic fertiliser which increases agricultural productivity by at least 10%, and energy – a partial replacement of liquid and gas fuel by biogas. Russia has conducted research on optimisation of technical methane fertilization of organic animal and bird waste, and began construction of experimental pilot-industrial installations in the 1980's.

Biogas can be produced from the anaerobic treatment of organic wastes. In its purified form biogas is compressed into cylinders and used for operating cars and tractors, or burned for heating. One cubic meter biogas equals 0.6 litres mazut/black fuel oil and is sufficient to power a motor with a 2-horse power capacity for 1 hour or yield 1.25 kWh electricity. Annually, the Murmansk oblast can produce: 2.3 million cubic meters biogas or 1,700 tons fuel oil equivalent from pig manure; 5.6 million cubic meters biogas or 4,000 tons fuel oil equivalent from cattle manure; and 15.1 million cubic meters biogas or 9,800 tons fuel oil equivalent from poultry manure. The marketable yield of biogas is estimated at 12-17 million cubic meters biogas or 7,000-11,000 tons fuel oil equivalent.

In the Murmansk region waste from the forest and wood-processing industry is used in an insignificant volume as fuel for electricity and heating. A main obstacle to utilising timber waste is undeveloped infrastructure. Murmansk possesses the least forest residues of all regions in Northwest Russia and its potential for bio resources from lumber waste is estimated at only 1.5 billion kWh. Therefore, small population points which receive electricity from local diesel electric stations and heat from community boilers are a potential sector for utilisation of lumber waste. There are 150 diesel electric stations and 355 small boilers in the Murmansk oblast, but no pilot projects to use bio wood waste. Introduction of technology for briquettes and pellets from sawdust, and combustible distillates from industry and domestic waste could contribute to the development of bioenergy as a resource.

Implementation of renewable energy

The research conducted by the Kola Science Centre found enormous natural resources on the Kola Peninsula that can benefit both centralised and de-centralised consumers. Technical resources for wind alone are estimated at 360 TWh, which is approximately 20 times the region's current electricity consumption of 16 TWh. Moreover, the research indicates that the potential energy capacity from joint application of wind and hydro resources is more than adequate to replace the energy generated by the 2 oldest nuclear reactors. These two reactors contribute approximately 20-30% of the region's total electrical energy. In terms of economic feasibility, it is only fair to consider the 5.5 billion US dollars price tag for the proposed, and recently scratched, KNPP 2 and contemplate what 134 billion rubles could do for development of renewable energy on the Kola Peninsula. Bellona advocates developing non-traditional renewable energy sources, as well as energy efficiency measures and clean production methods to reduce the threats posed by nuclear energy and the negative environmental impacts caused by CO_2 emissions from fossil fuels. In order to make real headway in implementing renewables however, it is imperative to create a framework for their development. At the present time the legal, economic and socio-political basis for developing renewables on the Kola Peninsula is absent.

Legislation

Governmental regulation is necessary in order to ensure successful development of renewable energy. A legal and regulatory framework is needed that stimulates growth in renewables and establishes priorities. European countries, for example, have had success with policies that specify concrete targets for renewable energy and allocate resources to its technologies. The EU has committed to increasing renewable energy to 20% of the energy balance by the year 2020, and Sweden has set an ambitious goal to be independent of fossil fuels by then. The countries with some of the highest percentages of renewables in their energy mix, Sweden (46%), Finland (30%), and Denmark (25%) (figures from 2004 according to the European Commission) have supportive governmental policies. In Russia, lack of a clear governmental policy for development of alternative energy sources and lack of government investment are two major hindrances to development of clean energy. For many years there has been a discussion in the Ministry of Energy of a draft federal law "On renewable sources of energy", but no action has been taken to adopt it. In addition, a draft law has been elaborated by the founders of the wind company "Vetro Energo" to regulate small businesses producing clean energy. They defined major obstacles to clean energy alternatives in Russia as limitations on capital investment during company creation, the taxation system, and connection to the GRID (Ekologiya u Prava, 1(22)/2006). The EU-Russian Technology Centre has also identified specific institutional and economic barriers and recommended specific measures to combat them. (Renewable energy sources potential in the Russian Federation and available technologies, 2004). A summary of Russian legislation related to renewable energy is provided in Appendix 1. Bellona recommends creating a regional programme for developing renewables on the Kola Peninsula that contains supportive policies and specific sector targets.

Economic mechanisms

Successful development of renewable energy requires establishment of economic measures that influence market behaviour and make the sector competitive in comparison with traditional energy sources. Experience shows that when economies of scale increase, the costs of implementing renewables decrease and it becomes more profitable. Renewable energy is already economically lucrative in Denmark, Germany, Spain and the US. A number of economic mechanisms are in use such as taxes on fossil fuels that reflect environmental costs, subsidies and tax-exemptions for clean energy production and technology, feed-in tariffs or quotas for power companies that require a percentage of power be produced by renewable energy, and incentives. European countries provide many examples of success. Denmark, which has chosen to focus on wind energy, has a tax on polluting electricity. The German government has chosen to decommission its nuclear power plants in favour of wind and solar energy. By subsidising its solar industry Germany has created a demand for solar panels and thousands of new jobs. Consider that the country is now a global leader in solar cell installations in spite of the fact that it does not have the most optimal solar resources. Sweden made bioenergy profitable by taxing oil and electricity in the 1990s and today bioenergy from district heating warms half of Swedish households. It is also noteworthy that Sweden finances windmill projects through a system of green electricity certificates, whereby power producers are required to buy certificates from producers of renewable electricity who receive certificates based on how much they produce. There are numerous European models that can be used as guidelines when developing economic measures that increase demands for renewables and make it an economically viable industry in Russia. Bellona advocates in particular the development of a market for green certificates as one of the best means of stimulating development of renewable energy sources.

Participation of industry and civil society

Cooperation and involvement of industry, the scientific community, NGOs and authorities is just as important as governmental regulation of, and economic incentives for, renewable energy. Strategic alliances and networking should be encouraged to provide for information exchange, technology transfer, project consultancy, and training personnel. NGOs can function as a link between local communities, scientists, industry and authorities. They can play a vital role in increasing public awareness and participation. In particular, NGO’s can spread knowledge about renewable energy and its advantages, organise debates and keep the public informed about developments. In order to harness NGO support it is necessary to provide access to information. Industry also plays a major role by developing technologies and commercialising them. It can transform environmental initiatives into competitive businesses. In order to achieve the best cost-efficient and effective technologies and production, it is imperative to remove obstacles that hinder competition within industries or import of renewable energy technology and equipment. Stopping discriminatory practices that restrict an equitable access to the GRID is equally important. There are a number of consulting companies in Scandinavia with experience from the Russian market that can give project assistance and be potential partners or investors for renewable energy projects in Northwest Russia: ECON, Energy Saving International AS (ENSI), Kan Energi AS, Norsk Energi, Ramboll Group and Varanger Kraft AS. Assistance in delivery and installation of systems in Russia can be obtained through the Center for Renewable Energy at www.energy-center.ru. In addition, there are valuable networks working to promote renewable industries, such as the Russian Association of Wind Industry and the European Wind Energy Association. For information on renewable energy projects and project partners in Europe visit the European Commission energy website at www.ec.europa.eu/energy/res/index_en.htm and select FP6 Demonstration projects.

Renewable energy projects

Pilot projects for renewable energy should be initiated at prospective sites identified by the Kola Science as having the best potential for solar, wind, small hydro and tidal energy. Pilot projects are a means to test technology, identify problems, find solutions, demonstrate economic profitability, and increase public awareness. Once these issues are settled pilots can be followed by large-scale projects. As all energy sources have consequences for the environment, environmental impact assessment should be mandatory prior to building on any site in order to keep negative consequences to a minimum. The World Energy Council has produced a

"Renewable Energy Projects Handbook" with guidelines on selecting projects using evaluation criteria. Finally, experience from the Kola Peninsula should be exported to other regions in Russia.

In addition, potential sites could also be identified for exploitation of wave and bioenergy resources in the future. Wave energy has one of the highest efficiency rates of renewable energy and with 1000 kilometres of coastline a suitable site most certainly exists. The value of bioenergy, despite its small technical potential in comparison with other renewable energy on the Kola Peninsula, should not be underestimated. Agricultural waste can be utilised for isolated consumers; domestic waste can be used in city district-heating systems. Barriers and opportunities for bioenergy development in Northwest Russia have been studied by the Barents Energy Working Group Task Force on Bioenergy (Final Report 04/30, 2004).

Financing

Adequate financing and investment are prerequisites for success in renewable energy development and implementation. In countries where large-scale application of renewables is successful, governmental authorities are actively engaged and the industry has grown thanks to heavy subsidising. It is also possible to elicit funds from foreign stakeholders. There are a number of international institutions that provide financial assistance to clean energy and energy-efficiency projects in Russia. A few of the most prominent are the EU-Russia Technology Centre, the Global Environmental Facility (GEF), the International Finance Corporation (IFC), the Nordic Environment Finance Corporation (NEFCO), The Norwegian Barents Secretariat and The Renewable Energy and Energy Efficiency Partnership (REEP). Before initiating pilot projects on the Kola Peninsula it might be wise to apply to one of these institutions for seed money or more substantial funding. Removing investment barriers is another important mechanism. Businesses interested in making investments can contact the Multilateral Investment Guarantee Agency (MIGA) which promotes direct foreign investment by insuring investors against political and non-commercial risks.

Another financial instrument is Joint Implementation (JI) under the Kyoto Protocol, which Russia ratified in 2005. Projects that reduce greenhouse gas emissions such as fuel switching from coal-to-biomass, energy efficiency, or renewable energy may qualify for JI provided the eligibility criteria are met. Under JI an investing country buys carbon credits to meet its Kyoto targets, by making capital investment in emission-reducing projects in a host country which then reaps economic and ecological benefits. Russia has a great potential to host JI projects based on cost efficient GHG reduction, large potential for energy efficiency, and lack of renewable energy intiatives and support mechanisms. As of January 2007, 31 emission-reducing projects were proposed for Russia, but only one of these is located on the Kola Peninsula (www.cdmpipeline.org/ji-project.htm). Several parties are working to identify potential carbon emission reduction projects in Russia that meet JI criteria, including the Core Carbon Group (previously the Russian Carbon Fund), Norsk Energi and ECON. The latter two consulting companies are also training local experts in project design and documentation as part of a programme funded by The Nordic Council of Ministers and the Barents Secretariat. There are no limits on Russia's sale of JI credits, but Moscow requires a Memorandum of Understanding with investor countries prior to approval. Until recently foreign investments were delayed by the Russian government's failure to establish a domestic framework for hosting projects. However on May 28, 2007 Prime Minister M. Fradkov signed a governmental decree containing the Statute on project adoption and review procedures for Joint Implementation projects. http://info.rusrec.ru/en/news/1241

Information exchange

Access to information about renewable energy is needed on the part of the public, environmental groups, and the industry. Information is essential for building local support, attracting potential investors, finding external partners. The mandate of regional offices like the Murmansk Oblast Energy Efficiency Center (MOEEC) should be strengthened. The work of these information centres could be expanded to include renewable energy as well. Development of renewable energy will produce a need for information dissemination on the laws, regulations, standards, subsidies, taxes, incentives, benefits, and new developments governing renewables. Alternatively, a web site can inform and promote renewable energy to the public, industry, and officials. Renewable companies can obtain news updates on their industry, and promote their services to others by registering their company at www.renewableenergyaccess.com a website with global listings.

Renewable energy as a regional effort

In the absence of a cohesive federal policy it is up to regional authorities, scientists, industry, ecologists and society to take a bold initiative and push for development of renewable energy. We see examples of this type of engagement on the US west coast where regional authorities in Washington and California launched environmental initiatives on their own to reduce local and global emissions. The mayor of Seattle, Washington for example committed his state to the Kyoto Protocol, and convinced 401 other mayors to do the same thing, despite the US federal government’s refusal to sign the accord (Dagens Nжringsliv 17/18 februar 2007). California implemented the strictest state environmental programme in the US requiring that 20% of energy comes from renewable sources by 2010, and proposing CO_2 reductions of 25% by 2020, and 80% by 2050. California’s solar program, which provides subsidies to businesses that install solar panels, is enticing large industries to join the green movement. (Dagens Nжringsliv 11/04/07) In Sweden, Volvo decided to be a CO_2 - neutral company and bought its own windmills to supply its factory with energy. (Aftenposten 02/02/2007) In December 2006, the governor of Murmansk agreed to support environmental groups’ demand for a 20% share of wind energy in the energy balance by 2020. More recently, a Working Group on Renewable Energy in the Murmansk Oblast was established in March 2007, by the Oblast Committee for Nature Protection. Bellona welcomes these initiatives as promising first steps towards renewable energy on the Kola Peninsula, and advocates developing a plan of action that fully exploits the enormous potential for renewable energy in the region.

Conclusion

Renewable energy enables production of electricity and heating without emissions and without hazardous waste. Many prerequisites exist for development of renewable energy on the Kola Peninsula: tremendous natural resources, a scientific-technological basis, a host of advantages – sustainability, accessibility, reliability, profitability, and ecological purity. Renewable energy can benefit both centralised and de-centralised users, and are in sufficient quantity to meet both current and future energy demands. There is really no reason not to pursue an aggressive exploitation of renewables on a large scale. Today the decision to exploit fossil fuels and nuclear power, or develop renewable energy sources is really a question of political will.

Bellona recommends development of renewable energy as an instrument for decommissioning the oldest reactors of the KNPP while providing safe, clean, reliable energy that provides for regional economic growth. Prompt government action is necessary to remove legislative, economic and socio-political barriers to renewable energy. In summary, Bellona advocates the following measures for implementation of renewable energy sources on the Kola Peninsula.

- Establish government legislation with concrete targets for renewables and its organisation

- Create economic mechanisms that prioritise and stimulate renewables and their technology

- Involve industry, the scientific community and NGOs in strategic alliances for cooperation

- Initiate pilot projects in geographical areas with high technical potential identified by KSC

- Secure funding from government and financial institutions and attract private investors

- Create an office that informs and promotes renewable energy, its laws and standards

Nordic neighbours can also participate in development of renewable energy, and economic growth, in Northwest Russia by making environmentally responsible financial investments in projects that are mutually beneficial, by creating forums for exchange of technology and know-how, by establishing a market for green certificates that support production of clean energy, and by refusing to import energy produced by nuclear reactors.

The analysis conducted by the Kola Science Centre provides a scientific foundation, and an impetus, for making a transition to renewable energy. Moreover, the findings present an opportunity for many actors. For the Kola Peninsula, development of renewables can produce regional economic growth, energy security and environmental benefits. For industry, on both sides of the border, renewable energy can become a new sector for business development, technology transfer, cooperation and competition. For the Norwegian government, development of renewable energy on the Kola Peninsula should be seen as an arena for closer bi-lateral cooperation on measures that will ultimately reduce the nuclear threat and security risks in the High North. This is indeed an excellent opportunity to put the ambitions of the Soria Moria Declaration into practice.

"*……….The risks of shipping accidents, the challenges from increased petroleum activity, the consequences of climate change, and the danger of radioactive pollution shall be met offensively through our own increased preparedness and closer international cooperation on measures that reduce the dangers."*

[Soria Moria Declaration]

Lastly, Bellona hopes that the current fixation with oil and gas revenues, on both sides of the border, will not blind authorities to the value of renewable energy as a mechanism with which to meet the challenges of climate change we face today.

Appendix 1: Russian Legislation in the Sphere of Renewable Energy

By Olga Krivonos

The 1992 UN Declaration on the Environment and Development proclaimed that the right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations. This means that energy policies of the future will not be able to bypass the need to conserve energy and increase the use of renewable energy sources.

For the past ten years, fundamental changes in the overall approach to renewable energy have not occurred in Russia. In 1995 legislative acts were passed and decrees were made at the executive and legislative levels of the Russian Federation, which stipulated that certain measures be taken regarding energy conservation in Russia. A year later, a federal law “On Energy Conservation” introduced the concept of renewable energy and its utilization in the economic turnover, however the necessary conditions for utilizing renewable energy sources were not formalized in the law. Discussions over a new law on the use of renewable sources of energy continued in 1998, when a bill was introduced in the National Duma “On national policy in the sphere of non-traditional renewable sources of energy.” One of the provisions in the bill stated that no less than three percent of national investments in the Russian energy industry should go to financing the development of renewable energy. By 2003, the bill passed all three readings in the National Duma, but was rejected by the President and subsequently discarded.

That same year, the Russian government confirmed its Energy Strategy for the Period up to 2020, which nominally acknowledges the necessity of developing and using renewable energy in order to facilitate the policy of energy conservation, as well as the reduction of harmful emissions from energy stations in cities with a complicated environmental situation. In the strategy itself, there is a provision that mentions the necessity of passing a new law concerning the development and utilization of renewable energy sources.

Presently, in accordance with the task of RAO “EES Rossii” a bill has been drawn up regarding government assistance in the development and utilization of renewable energy. It proposes the introduction of a system of “green” certificates based on model of the international Renewable Energy Certificate System (RECS). The bill is yet to be introduced in the National Duma for review.

The Energy Strategy Proposal for the Period up to 2030 has been formulated, which contains a provision concerning the use of renewable energy sources copied from the Energy Strategy for 2020. A member of the Energy Committee of the National Duma, V.B. Ivanov, feels that the new Russian energy strategy should contain concrete tasks and strategies, and not just a desire for renewables.

Representatives from the scientific community, likewise, cannot be ignored on the issue of renewable energy. Two scientists from the Kola Science Center, V.A. Minin and G.S. Dmitriev, have put forth their own vision for a future law on renewable energy, based on the experience of other countries in this realm: tax benefits, guarantee of tax stability and the right to free access to centralized energy supply networks for all small enterprises developing and using energy derived from renewable energy sources.

The prospects for developing renewable energy in Russia are closely linked with the passage of a new law that could become an indicator of the country's transition to a new stage in its attitude toward energy resources - that is, one based on the principle of environmental protection. Today, however, the future of renewable energy sources in Russia is still unpredictable.