Complex analysis of renewable energy resources in coastal regions: approaches and research

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Abstract

The task of the complex analysis of renewable energy sources (solar, wind and wave) of coastal regions is put in the work. The urgency of the task is connected with the high concentration of these resources and the presence of energy consumers in regions remote from centralized energy supply (the case of the northern and Far Eastern seas of Russia) and in recreational zones (southern regions of the Russian Federation). The coast and water areas of the Black, Baltic and Barents Seas have been chosen as a research region. Open databases NASA SSE, NASA POWER which allow to determine the arrival of solar radiation on differently oriented surfaces are used to estimate solar energy resources. To calculate the parameters of wind waves in the Black Sea and Barents Sea the spectral wave model of the third generation SWAN and WaveWatch 3-model were used. Resource databases have been created and maps of the potential distribution of solar and wave energy have been constructed.

Keywords: renewable energy sources, databases, modeling.

1 Introduction

The wave energy of the ocean occupies a special place among other renewable energy sources (RES). This is due, on the one hand, to the enormous natural (gross) potential and significant efficiency of devices that convert wave energy into useful energy sources (up to 90%), on the other hand, by a small number of realized projects and installed wave power facilities in the world. The latter factor is related both to problems of a technical nature (lack of technical solutions that make it possible to achieve profitability of projects), and the lack of niche consumers of energy from wave installations. The latter factor plays a special role in Russia: the country has a huge length of the coastline. However, the coast of the Arctic and Pacific oceans is among the least populated areas, where power supply problems are traditionally solved with the help of diesel generators and local fuels. The coast of the southern seas of Russia (Black, Azov, Caspian) is characterized by high population density, but it is covered by centralized energy supply, which also limits the use of renewable energy sources in these regions. At the same time, even under these conditions, it is possible to identify some prospective consumers of renewable energy.

In this case a complex analysis of renewable energy resources for the coastal zones is urgent. Experimental measurements of the physical and geographical characteristics that determine the potential of these renewable energy sources are complex, therefore methods of mathematical modeling, remote sensing of the Earth and the Ocean and reanalysis are widely used in this field. These methods and data sources allow calculations and estimates to be made on spatial grids with sufficient resolution for practical purposes. The paper presents approaches to assessing renewable energy resources for coastal regions using the example of solar and wave energy.

2 Assessment of the solar energy potential

In accordance with the tasks, two data sets on incoming solar radiation (daily sums of total solar radiation and direct normal radiation) were collected on the basis of the open NASA SSE and NASA POWER databases [1, 2]. As the study regions, the water area and the coast of the Black, Barents and Baltic Seas were considered. The boundaries of the territories covered by the data sets are shown in Table 1.

TABLE 1 Borders of research regions

Region of research	The boundaries of data sets about incoming solar radiation
Black Sea	46 ° N 32 ° E – 46 ° N 42 ° E 46 ° N 32 ° E – 46 ° N 42 ° E
Barents Sea	71 ° N 31 ° E – 71 ° N 64 ° E 64 ° N 31 ° E – 64 ° N 64 ° E
Baltic Sea	60 ° N 25 ° E – 60 ° N 32 ° E 54 ° N 20 ° E – 54 ° N 32 ° E

The structure of the data sets is presented in Table 2. They include solar radiation on the receiving surfaces of different orientations and different periods, during which the averaging of the characteristics of solar radiation is carried out. In a large territory of Russia, due to climatic conditions, solar installations are effective only when used in the summer, or in the warm six months. Therefore, the following values of solar radiation are included in the data sets: the average value for each month of the year, the average value for the year, the summer period, and for the warm six months. Spatial resolution of the database is (1x1)°.

TABLE 2 Structure of the data sets. φ is the latitude of the site, the optimal orientation is the angle at which the receiving surface receives the maximum amount of solar radiation for a given averaging period, the warm half year is April-September, the cold half year is October-March

Characteristic	**Orientation of the receiving surface (the angle relative to the horizontal, °)**	**The averaging period**
The total solar radiation, (kWh/m²/day)	0, 90, φ, φ+15, φ-15, optimal orientation	Month, year, summer, warm half year
Direct normal radiation (kWh/m²/day)	Surface oriented normal to the solar radiation	Month, year, summer, warm half year, cold half year

Figure 1 illustrates the cartographic implementation of the data sets on solar energy resources for the research region (the Barents Sea).

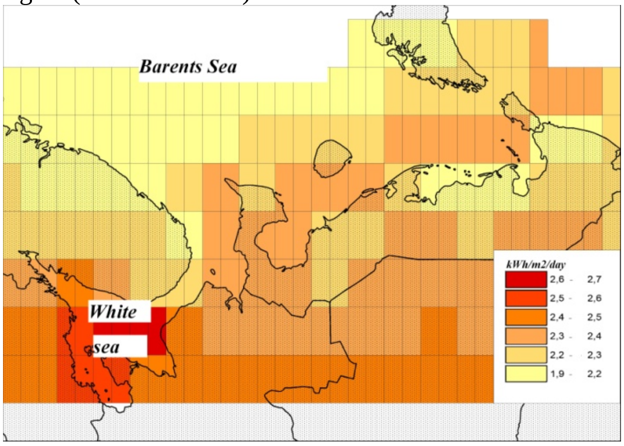

FIGURE 1 Annual averaged insolation incident on a horizontal surface (kWh/m²/day)

3 Assessment of the wave energy potential

To calculate the parameters of wind waves in the Black Sea, the spectral wave model of the third generation SWAN (Simulating Waves Nearshore [3, 4]) have been used. To model the waves in the Barents Sea, the WaveWatch 3-model was used, since this model allows us to specify the boundaries of the sea ice spreading. The configuration of the model WaveWatch3 was chosen almost the same as in the SWAN model, so that the results of the wave reproduction were the same [5].

As the input wind data, the high-resolution reanalysis NCEP Climate Forecast System Reanalysis (1979-2010) were used. The spatial resolution of the reanalysis is ~ 0.3 °, the time step is 1 hour.

The calculations were carried out on a special irregular triangulation grid, which allows reproducing high-resolution wave parameters in selected coastal regions with a small total number of nodes. For the open part of the Black Sea, the space step was 12 km, and for the coastal zone up to 200 m. The total number of grid nodes is 31565. For the Barents Sea the space step is from 50 km to 500 m respectively. As a result of the calculations, the values of the wave energy flux (W/m) were obtained for each node of the grid for each of the seas with a time step of 3 hours. For the Black Sea a series was obtained from 1979 to 2010, for the Barents Sea – from 1979 to 1997.

Based on the simulation data, the annual and monthly average wave energy supplies (the fraction of the whole series of data when the wave energy exceeds a predetermined value) were calculated. The average long-term distribution of the wave energy supply (more than 1 kW/m) for the Barents Sea is shown in Fig. 2. In the open part of the Black Sea energy in only 30% of cases exceeds the value of 1 kW/m, then for the Barents Sea this value exceeds 80%. In both seas the wave energy decreases from west to east, which is due to the general western transport in the atmosphere and the trajectories of the cyclones. The average energy for the Barents Sea is an order of magnitude greater than for the Black Sea.

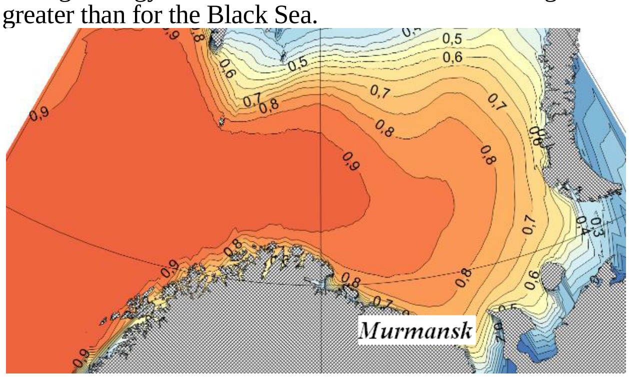

FIGURE 2 Distribution of the wave energy supply (more than 1 kW/m) for the Barents Sea

Also on the basis of the calculations carried out, the maps of the wave energy supply were constructed for values of 2, 5, 10 kW/m. Of some interest is the average energy supply for different seasons of the year. For example, in January for the Black Sea wave energy supply is 2 times greater than for the summer months. In the Barents Sea seasonal differences are much less pronounced and the wave energy supply is more constant in time.

4 Conclusions

The obtained results can be used to determine the water areas most promising for the location of wave power plants, as well as coastal areas that have a high solar energy potential. Numerical modeling of the wind wave fields of the Black, Baltic and Barents seas is carried out using the spectral wave models SWAN and WaveWatch3. Calculations were made on irregular and rectangular computational grids of high spatial resolution. As the driving force the wind from NCEP/CFSR reanalysis was set. Comparison of the results of calculations with the data on the heights of wind waves from moored buoys has shown that the use of the new generation of NCEP / CFSR reanalysis significantly improves the quality of the reproduced wind wave fields in comparison with the results obtained using NCEP / NCAR reanalysis. Based on the simulation data, the annual and monthly average wave energy supplies were calculated.

Acknowledgments

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