# ASSESSMENT OF THE OFFSHORE WIND POWER POTENTIAL OF THE BLACK AND AZOV SEA

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DOI: 10.5281/zenodo.7495099

**Abstract:** Based on the Global Wind Atlas an assessment of the wind resources of the Black and Azov seas was completed. The distribution of wind power density in the Black and Azov Seas is defined, as well as to identify areas with the most favorable conditions for the placement of offshore wind turbines. Most of the Black and Azov Seas are characterized by significant wind resources (value of wind power density > 400 W/m$^2$). The total area of sites with favorable conditions for the placement of offshore wind turbines is about 98500 km$^2$.

**Key words:** offshore wind turbines, wind power density, Black Sea, Azov Sea, Global Wind Atlas

## 1. INTRODUCTION

Today, the renewable energy sector in Europe belongs to the established sectors of the economy and special attention is directed to the development of such areas of the Blue Economy as offshore wind energy.

Currently, technologies for the use of offshore wind energy have become the main direction in the development of wind energy. Due to the lower water surface roughness compared to the earth's surface, the wind speed over the sea is usually 20% higher than under the same conditions over the surrounding lands. This contributes to the production of much more energy from offshore wind farms than onshore. An offshore wind turbine has a higher power factor than its onshore analogue. In addition, because the wind speed over the sea surface is relatively homogeneous with less pulsation and turbulence, it simplifies the control systems of offshore wind turbines (OWT) and reduces the wear of their blades (EEA, 2009).

As of June 2020, there are twenty offshore wind farms in the Baltic Sea – nine owned by Denmark, five by Germany, four by Sweden and two by Finland. The total capacity of these wind farms is about 2 GW. Expected capacity from offshore wind farms installed in the Baltic Sea is estimated at approximately 9 GW by 2030 (Nghiem and Pineda, 2017).

Record increase in offshore wind power capacity in the world by 5 GW was set in 2020, as a result, the global operational capacity of offshore wind energy was approximately 33 GW, which allows to maintain the growth rate, despite the problems caused by COVID-19. Fifteen new power plants were commissioned in 2020, this means that there are now more than 160 offshore wind farms operating around the world. The UK remains the largest offshore wind energy market in the world with around 10 GW of installed offshore wind power capacity. In second place is Germany with about 8 GW and in third place in the world is China, with an installed offshore wind power capacity about 7 GW (WBG, 2021).

Offshore wind power growth is projected to accelerate in the coming years, reaching around 200 GW by 2030.

The assessment of the offshore wind power potential of the Black and Azov Seas is of considerable interest, in terms of, that the development of offshore wind energy could provide additional capacity to the energy system of Ukraine and other countries of the Black Sea region, and strengthen the transition of their national energy complexes to renewable energy sources, which will help reduce carbon dioxide emissions into the atmosphere and help to counteract climate change on the planet.

The aim of this study is to determine the distribution of wind power density in the Black and Azov Seas, as well as to identify areas with the most favorable conditions for the placement of OWT.

## 2. REVIEW OF STUDIES OF WIND CONDITIONS

A wide range of research is devoted to the study of the wind over the Black and Azov Seas (Repetin and Belokopytov, 2008, 2009; Mel'nikov *et al.*, 2018), since data on the wind regime are of extreme importance for regional oceanography. The wind directly affects the circulation and mixing of waters, heat and water balance.

Standard regular wind observations at coast stations show, that the southeastern coast of the Black Sea and the southern coast of Crimea are characterized by light winds (mean annual wind speed < 3 m/s). Gentle winds are observed in the western and northwestern parts of the Black Sea, as well as near the Kerch Strait (mean annual wind speed > 4 m/s, and at some stations > 5 m/s) (Repetin and Belokopytov, 2009).

The results of observations at the North-Western Black Sea coastal meteorological stations show, that the long-term average wind speed is in the range from 4.0 m/s (Chornomorsk) to 5.5 m/s (Odessa). The highest wind speeds are observed over open areas of the sea – 6.7 m/s (Snake Island), and 7.4 m/s (Sulina) (Hydrometeorology, 1991).

Analysis of wind characteristics over the open sea (Efimov *et al.*, 2000, 2012), obtained using data from ship observations, global reanalysis of atmospheric fields (ERA-40, NCEP/NCAR, JRA), regional reanalysis with high spatial resolution (Efimov *et al.*, 2012), mean SLP fields (Belokopytov *et al.*, 1998), as well as NASA satellite scatterometer data (Kara *et al.*, 2005) showed, that the obtained estimates of the spatial distribution of wind speed over the Black Sea have common features: the western part of the sea has the highest values, the zone of weak winds is typical for the southeastern part of the sea. The local wind speed maximum is situated in the northeastern part of the sea south of the Kerch Strait.

The mean annual wind speed over the Azov Sea is 4.5-5.5 m/s near the coast, and 7.5 m/s in the central part of the sea. The mean seasonal wind speed in winter is greater than in summer. Wind speed in December in the central part of the sea is 8.3 m/s, on the coastal stations is 6-7 m/s (Il'in *et al.*, 2009).

The study of the long-term changes of wind speed over the Black Sea showed that there is a clear trend towards a decrease in the second half of the 20th century (Belokopytov, 2017). At the same time, according to (Il'in *et al.*, 2012) after 2000, wind intensification is noted in the western part of the sea. At some stations, the decrease in wind speed reaches 20-50% relative to climatic norms.

## 3. MATERIAL AND METHODS

The main characteristic that determines the wind energy potential of the territory is the wind speed. According to the recommendations of the Voeikov main geophysical observatory (Goskomgidromet, 1991), a 10-year series of observations is sufficient to obtain stable values of the mean wind speed. The initial requirement for the deployment site of autonomous wind turbines and wind power plants is the presence of a high wind energy potential. In the first approximation, it can be characterized by the value of the mean annual wind speed ≥ 5 m/s at 10 m height (Gidrometeoizdat, 1989). An additional requirement for the site of placement of wind turbines is the absence or slight recurrence of hurricane winds ($V$ > 32.7 m/s) and a small number of storm periods ($V$ > 20,8 m/s). It should also be borne in mind that not always large values of the mean annual speed are a guarantee of high electricity generation from wind turbines. The winds of the mountain passes are unfavorable for wind energy due to the high frequency of storms.

Potential wind energy resources are the total energy of the movement of air masses moving over a given territory during the year. The most accurate assessment of potential wind resources can be obtained using the wind power density, which is the energy characteristic of the wind, depending on the frequency of wind speeds and the nature of the underlying surface in a particular site. Wind speed is a random function of time. More precisely, its description can be obtained using the Weibull distribution for flat terrain conditions (Kobysheva, 2008):

$$f(u)=\frac{\gamma}{\beta}\left(\frac{v}{\beta}\right)^{\gamma-1}\exp\left[-\left(\frac{v}{\beta}\right)^{\gamma}\right] \tag{1}$$

where *f(u)* is the frequency of occurrence of wind speed u, β – scaling factor (m/s), γ – the shape factor, which describes the shape of the distribution.

The wind power density can be estimated using the formula (Kobysheva, 2008):

$$N_E=\frac{1}{2}\rho\beta^3\Gamma\left(\frac{3}{\gamma}+1\right) \tag{2}$$

where *Ne* – wind power density, ρ – air density (1.226 kg/m$^3$), $\Gamma\left(\frac{3}{\gamma}+1\right)$ – gamma function.

The assessment of the wind energy potential of area is carried out using the criteria given in Table 1, which allow to allocate seven classes for the values of wind power density (*Ne*). The area suitable for accommodation of large-scale wind plants must have a wind energy class of 4 or higher (Tong, 2010).

**Table 1.** Classes of wind power density (Tong, 2010)

| Wind power class | | 50 m height | |
|---|---|---|---|
| | | Wind power density, W/m² | Mean wind speed, m/s |
| **1** | Poor | < 200 | < 5.6 |
| **2** | Marginal | 200-300 | 5.6 - 6.4 |
| **3** | Fair | 300-400 | 6.4 - 7.0 |
| **4** | Good | 400-500 | 7.0 - 7.5 |
| **5** | Excellent | 500-600 | 7.5 - 8.0 |
| **6** | Outstanding | 600-800 | 8.0 - 8.8 |
| **7** | Superb | >800 | > 8.8 |

This approach to estimating wind resources has been considered in a number of studies (Tong, 2010; Goldaev and Radjuk, 2015; El Hadri *et al.*, 2019), has shown good results and has been used to plan the location of wind turbines.

### 3.1. PRINCIPLES OF DESIGN AND PLACEMENT OF OWT

Planning an offshore wind farm requires the following information. Firstly, these are the wind characteristics in the sea. Additional data include water depth, currents, seafloor, sediment transport and wave action which cause mechanical and structural stresses on potential turbine configurations. Other factors include salinity, glaciation and the geotechnical characteristics of the seabed.

Based on the methodology described in the report «Going Global: Expanding Offshore Wind to Emerging Markets» (WBG, 2022), to accommodate OWT are suitable water areas that meet these conditions (WBG, 2019):

1. Annual mean wind speed greater than 7 m/s at 100 m height (6.3 m/s at 50 m height), for the current performance characteristics of OWT;
2. Water depth of less than 50 m – for fixed offshore wind farms;
3. Water depth between 50 to 1000 m – for floating wind farms;
4. Less than 200 km from shore;
5. Any isolated regions < 10 km$^2$ were excluded;
6. Constant turbine planting densities of 3 MW per km$^2$ for wind speeds between 7-8 m/s and 4 MW per km$^2$ for wind speeds greater than 8 m/s.

Sea ice is part of the marine conditions, which in particular must be included in the design process for the support constructions of OWT. Sea ice is an important but under-researched source of loading on all types of OWT structures. The complex ice mechanics, which is influenced by many factors, introduces a serious uncertainty in the assessment of ice loads on the support structures. For example, floating and pack ice on the water surface and atmospheric icing induce the wind turbine to excessive vibrations, ice drift and hitting against the foundation might trigger structural vibrations or even damage it by exciting the tower, while structures icing will excite flapwise the blades but the main effect is felt on the tower (Popko, 2020). From these considerations, it is clear that in cold climates on the high seas, ice formation should be considered as a major factor in site analysis. Ice prevention systems on blades, accurate sealing, load mitigation systems for sea ice, cold weather packages, and diagnostic tools integrated to account for ice loads effects will be a sensible part of the investment and operating costs. Accurate tools for ice risk assessing are thus necessary and the impact on current design ascertained.

### 3.2. BATHYMETRY OF THE BLACK AND AZOV SEAS

In the structure of the bottom of the Black Sea stand out: shelf, continental slope and deep basin. The shelf is a direct continuation of the land, which is under the waters of the sea. The shelf has the greatest width (more than 200 km) and a significant area in the northwestern part of the Black Sea (NW Black Sea). In the NW Black Sea, most of the shelf water area has depths of up to 50 m (approximately along the line of Cape Tarkhankut – Cape Kaliakra), a significant part is located up to the 100 m isobath (approximately along the line of Cape Khersones – Cape Kaliakra), and beyond the 100-meter depth (off the coast of Romania and Bulgaria beyond the 150-meter depth) there is a concentration of the isobaths, that is, a rapid increase in depth with distance from the nearest coast. The northwestern shelf (defined within the limits from Cape Khersones to Cape Kaliakra) occupies 16 % of the Black Sea water area (68 390 km$^2$) and everything 0.7 % water volume (3 555 km$^3$). The maximum width of the shelf reaches 220 km. Near the Caucasian and Anatolian coasts, the shelf is represented by a narrow intermittent strip 2.2-15 km wide at depths of less than 100 m. The central part of the Black Sea is occupied by a deep-sea basin with depths of 2000-2200 m. The greatest depth is 2258 m (Ivanov and Belokopytov, 2011).

The depth of the Azov Sea is on average 7 m (Il'in *et al.*, 2009), reaching in the central part 13-14 m (Shnjukov *et al.*, 1974).

### 3.3. Data Source

The assessment of the wind energy potential was made on the basis of wind data placed on the website of the Global Wind Atlas (GWA, 2022a). This application (Global Wind Atlas) is specially designed to help identify areas with strong winds, suitable for wind turbines. As input data in the atlas were used ERA5 reanalysis data for 2008-2017 of the European Centre for Medium-Range Weather Forecasts (ECMWF) with spatial resolution 30 km. Then, using the mesoscale WRF model, had been performing downscaling of the reanalysis data, as a result, information on wind speed becomes available with a spatial resolution of 3 km. At the next stage, wind speed data is processed using a microscale modeling system (DTU Wind Energy). As a result of the simulation process, the user obtains the characteristics of the local wind climate with a grid spacing of 250 m at five heights: 10 m, 50 m, 100 m, 150 m and 200 m above the earth's surface (GWA, 2022b). The Global Wind Atlas presents wind speed characteristics (mean annual value, indices of interannual, seasonal and daily wind speed variability), mean annual wind power density *Ne*, and it is also possible to plot the dependence of the output power of the wind turbine generator (according to the specified user characteristics) from wind speed.

## 4. RESULTS

According to the Global Wind Atlas, the value of *Ne* at 50 m height changes from 70-200 W/m$^2$ in the southeastern part of the Black Sea to 1048 W/m$^2$ in the Tsemesskaya Bay. In general, the spatial distribution *Ne* over the Black Sea shows an increase from the southeast, where the annual mean wind speed at 50 m height is about 5 m/s, to the northwest, where the wind speed is about 7 m/s.

Based on the value *Ne* and the above requirements for location OWT, favorable conditions for the placement of large OWT have the following sites (Fig. 1, Table 2):

*Plot 1*. Shelf of the NW Black Sea. This plot is located north of the line connecting Cape Tarkhankut and Cape Kaliakra, and has a depth of less than 100 m. The entire area of the shelf is occupied by an alluvial plain, which has a very slight incline and a flat plain abrasion accumulative relief (Mel'nik and Mitin, 1982). The most leveled and gently sloping part of shallow water is the 30-40 m depth zone adjacent to the coast (more than 1/3 of the entire shelf area). Based on these characteristics, we can conclude that this zone has favorable conditions for the placement of large OWT with fixed foundation.

*Plot 2*. The site of Kalamitsky Bay, is bounded in the north by Cape Tarkhankut, in the south by the 1000 m isobath, in the west by Cape Khersones. This site has of fourth wind power class. Most of the water area, located within the outer shelf of the Western Crimea, has depths of 50-150 m, in coastal areas (Kalamitsky Bay) depths are from 0 to 50 m (Myslivec *et al.*, 2019). Both floating and fixed OWT can be placed on this site.

*Plot 3*. Located near the southern tip of the Crimean peninsula between Cape Sarych and Cape Ai-Todor. This site has of fifth wind power class. Most of the water area has depths of more than 50 m (the width of the shelf here is 30-40 km, and the width of the area with depths up to 50 m does not exceed 1.5 km). In this site, on the shelf, traces of tectonic activity appear in the form of fault lines, fracturing on the bench and block displacements (Ignatov, 2010).Based on the above conditions, this water area may be suitable for accommodating floating OWT.

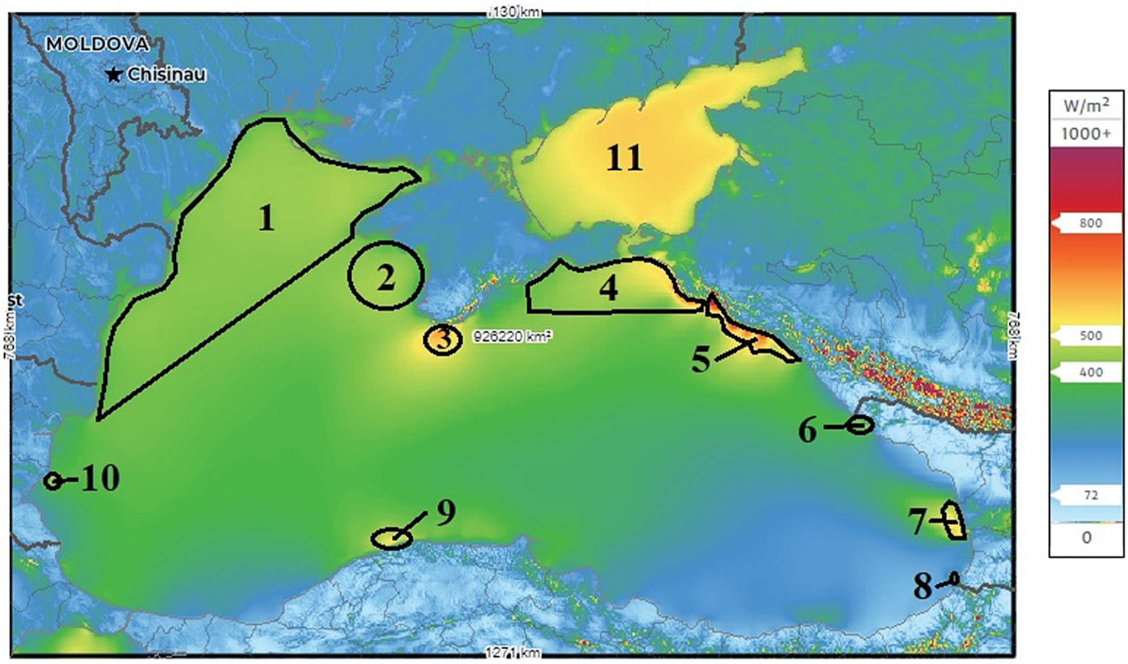

**Fig. 1.** Annual mean *Ne* (W/m$^2$) at 50 m height for 2008-2017 and schematic arrangement of sites with *Ne* > 400 W/m$^2$ and depths up to 1000 m

**Table 2.** Wind characteristics of sites with $Ne > 400$ W/m²

| Plot number | $\overline{V_{an}}$, m/s | $Ne_{100\%}$, W/m² | $Ne_{10\%}$, W/m² | Wind power class | S, km² | Depth H, m |
|---|---|---|---|---|---|---|
| **1** | 7.0-7.2 | 422 | 445 | 4 | 45000 | < 50 |
| **2** | 6.7-6.7 | 421 | 452 | 4 | 6600 | < 1000 |
| **3** | 7.0-7.2 | 555 | 619 | 5 - 6 | 1340 | < 1000 |
| **4** | 7.0-7.4 | 460 | 585 | 4 - 5 | 9000 | < 1000 |
| **5** | 6.9-7.6 | 588 | 818 | 5 - 7 | 1650 | < 1000 |
| **6** | 5.9-6.1 | 420 | 440 | 4 | 39 | 200-800 |
| **7** | 5.8-6.2 | 474 | 540 | 4 - 5 | 1080 | < 1000 |
| **8** | 5.0-5.4 | 414 | 450 | 4 | 20 | < 1000 |
| **9** | 6.4-6.8 | 460 | 520 | 4 - 5 | 715 | < 1000 |
| **10** | 6.5-6.7 | 420 | 455 | 4 | 95 | 15-50 |
| **11** | 7.6-7.7 | 530 | 568 | 5 | 33000 | < 14 |

**Notes:** $\overline{V_{an}}$ – annual mean wind speed at 50 m height;
$Ne_{100\%}$ – the mean annual wind power density over the territory at 50 m height for 100 % of the area of the selected site;
$Ne_{10\%}$ – the mean annual wind power density over the territory at 50 m height for 10 % of the area of the selected site with the highest wind rates

*Plot 4*. Shelf between Cape Meganom and Cape Myskhako (Kerch Shelf of the Black Sea). Most of the water area has the fourth wind power class, near the coast of the Caucasus there is an increase in the average annual wind speeds, and *Ne* values reach 700 W/m² and more, which corresponds to the characteristics of the sixth wind class. The continental shelf in this site has the shape of a semicircle, protruding to the south, with the largest width of about 50-60 km. The angle of inclination of the continental slope is 1-3°, the development of landslide processes is noted on the slope (Muratov, 1973). About half of the site (northern part) has depths of 10-50 m, making it suitable for fixed OWT. The southern half is characterized by depths of more than 50 m, which makes it possible to place floating OWT.

*Plot 5*. Coastal strip along the Black Sea coast of the Caucasus from Cape Myskhako to Cape Kadosh. The site has the largest reserves of wind resources with wind classes from the fifth to the highest eighth power class. Value of *Ne* in some parts of the Tsemesskaya Bay it reaches 1030 W/m². The site has a length of about 120 km. The width of the strip with depths up to 50 m is from 3 to 6 km, with depths up to 1000 m is from 8 to 24 km. It should be noted that between Anapa and Sukhumi i.e. along the coast of the Caucasus, the shelf is weakly expressed. In the coastal zone, the bottom slope rapidly increases, and a continental slope begins at a distance of 400-500 m.

*Plot 6*. The site along the Caucasian coast between Cape Konstantinovsky and Cape Pitsunda is about 20 km long and has a small area. This site corresponds to the fourth wind power class. Depth is from 200 to 800 m. In this area, the spurs of the Greater Caucasus (Gagra Range) come closest to the sea, which leads to a sharp increase in depth. The shape of the coast here forms a small curve, in the waters of which there is an underwater trough, about 5 km wide, about 9 km long and with a maximum depth of about 380-400 m. The internal relief (closed contour) of the trough is 120 m, it is separated from the continental slope by a bridge at a depth of about 260 m (Klimchuk, 2018). This site is suitable mainly for the placement of floating OWT.

*Plot 7*. The site is located off the coast of Georgia between Cape Anaklia and port of Poti has wind power class 4 and 5. This area has depths of up to 700 m and is predominantly located above the zone of the continental slope, the relief of which is undergoing major complications (Arhangel'skij and Strahov, 1939). The bottom is streaked with numerous underwater canyons 150-200 m wide at the edge of the ledge of the continental slope, up to 300-500 m in the middle zone, and 1-1.5 km at the foot (Klimchuk, 2018). This site is suitable mainly for the placement of floating OWT.

*Plot 8*. The site off the coast of Georgia near the city of Batumi has a wind power class of 4. Its length along the coast is about 8 km. The width of the shelf in this place does not exceed 5 km. According to its characteristics, the bottom in this site has similar conditions to *Plot 7*. This site is suitable mainly for the placement of floating OWT.

*Plot 9*. The site is off the coast of Turkey between Cape Kerempe and the city of Cide. This site is a strip up to 10 km wide (limited to depths of up to 1000 m) and about 80 km long, and has a wind power class 4. The width of the shelf here is 3-4 km and it is mainly represented by a stepped abrasion and abrasion-accumulative sea plain, complicated by ridges, buttes, ledges and ravines (Klimchuk, 2018). This site is suitable mainly for the placement of floating OWT.

*Plot 10*. The site off the coast of Bulgaria near Cape Emine has a wind power class of 4. This water area has depths from 15 to 50 m and is located in the zone of the Bulgarian shelf, in the inner part of which there are alongshore swells, hydro dunes and erosion troughs. Moving away from the coast, the bottom is a weakly dissected rampart-shaped hilly underwater accumulative plain, separated from the inner part by underwater hollows, well-defined at a depth of 17 to 40 m (Klimchuk, 2018). Shallow depths in this site make it suitable for fixed OWT.

*Plot 11*. The water area of the Azov Sea has the fifth wind power class. The bottom of the sea is a shallow plain with a leveled relief, the maximum depth of which in the central part does not exceed 15 m. In the western part of the sea, in the area of sea banks, and in the east between the Elenina Bank and the Zhelezinskaya Bank, the flat surface of the sea bottom is disturbed by small local uplifts, which rise relative to the surrounding areas by 3-4 m. This site is suitable for placing both floating and fixed OWT.

## 5. DISCUSSIONS

It should be noted that for *Plot 1* (water area of NW Black Sea), *Plot 4* (Kerch Shelf of the Black Sea) and *Plot 11* (water area of the Azov Sea) from December to March, ice formation is characteristic. Moreover, if in NW Black Sea the appearance of ice in open areas of the sea does not occur every year (Hydrometeorology, 1991; Il'in *et al.*, 2012), then for the Azov Sea, ice formation occurs annually, even in the mildest winters (Il'in *et al.*, 2009). The first appearance of ice occurs in December – early January. First of all, ice forms in bays and estuaries. The annual formation of fast ice is observed only in estuaries and bays. Complete freezing of open areas of NW Black Sea (Odessa, Tendra Spit, Karkinitsky Bay) only occurs in very severe winters. The beginning of breaking or the first shift of fast ice is usually observed in February – early March. The final cleansing of the sea is observed in March (Il'in *et al.*, 2012). The thickness of the ice cover in moderate winters in the NW Black Sea can reach 5-10 cm, in severe winters – 30-45 cm (smooth ice). In the Azov Sea, by the beginning of January, the average ice thickness in the Taganrog Bay reaches approximately 20-25 cm, and in the south of the sea (Kerch, Mysovoe) – 12-14 cm. The ice cover reaches its greatest thickness in late February – March and is approximately 40-50 cm in the Taganrog Bay and 20-25 cm in the southern part of the sea. In severe winters, the thickness of even landfast ice can reach 70-80 cm in the Taganrog Bay and 40-60 cm in the southern part of the sea (Kerch, Mysovoe, Temryuk) (Il'in *et al.*, 2009). Thus, it should be noted that the factor of ice formation must be taken into account at the planning stage of OWT in these areas.

Additional load on support structures of OWT creates wind waves. So, for the west and northwest coast of NW Black Sea the average annual frequency of storm waves is 3.19 % (Chornomorsk), 3.21 % (seaport „Pivdenny") and 4.47 % (Odessa port). For open sea areas of NW Black Sea the most representative are the results of observations at the wave measurement station Chersonesos lighthouse, where storm waves accounts for 22.89 % (Il'in *et al.*, 2012). For the NE Black Sea, the frequency of storm waves ranges from 4/47 % (Zavetnoe) to 9.75 % (Anapa). During the year, an increase in storm activity is observed in the winter months. In the coastal areas of the Azov Sea weak waves prevail, in 89-95 % of cases the height of visually observed waves at all coastal points does not exceed 0.7 m (Il'in *et al.*, 2009).

For modern wind turbines cut-out wind speed is 22-25 m/s. Hurricane winds can cause damage to wind turbines and their repeatability must be taken into account. Despite the fact that hurricane winds (wind speed over 25 m/s) are observed at most coastal meteorological stations of the Black Sea, their repeatability is only 0.08-0.09 %. At the stations of the Kerch Peninsula, hurricane winds are observed for 2-5 days for a period of 45-60 years, in Anapa up to 16 days for 45 years. Most often, such winds are observed in Novorossiysk, where their repeatability is 1.5 %, which is more than 50 days for 45 years (Repetin and Belokopytov, 2009).

Although offshore wind power has grown dramatically over the past few decades, there is still a lot of uncertainty surrounding how the construction and operation of these wind farms affects marine animals and the marine environment (Tethys, 2022).

So, in the Northern Black Sea region there are unique natural ecosystems, three vast deltas of major European rivers – the Danube, the Dniester and the Dnieper, with mouth estuaries near the latter two, on the territory of which 187 species of birds nest (Shhegolev *et al.*, 2017). Of these, the absolute majority – 164 species (87.7 %), are migratory, and only local populations of 23-29 bird species (12 %) are clearly sedentary, still flying in certain situations over short distances (250-500 km). The Northern Black Sea region can be conditionally considered as a certain segment of the ecotone (border) land zone with a total area of 80 000 km$^2$, 100 km wide, adjacent to the Black Sea (plus coastal marine area of the shelf 30 km wide). Vital for 235 bird species, seasonal transit migratory flights take place almost all year round in the region.

Despite the fact that the main direction of flight of migratory birds is 95 % along the coastline of the Black Sea, located in this area from northeast to southwest, some species of birds (white-fronted geese, common cranes, passerines) cross directly water area of the Black Sea.

At the same time, summer migrations of duck birds and waders are observed along the coast in a westerly direction in the northwestern part of the Azov Sea. Part of the birds, flying along the northern coast of the Azov Sea (15-30 %), follow to the southeast and fly along the Arabat Spit to the Caucasus.

Along the Black Sea coast of the Caucasus, there is the most massive migratory flow of birds of prey in Europe, which can be traced in the area of the city of Batumi and the lower reaches of the Chorokh River, in Georgia and Turkey (the village of Borchka) near the southeastern shores of the Black Sea.

In addition to assessing the impact of OWT on the routes of migratory birds, it is necessary to take into account what impact it will have on the inhabitants of the sea. These issues are still under study and it is necessary to focus further research on assessing the impact of the OWT operation on the Black Sea marine ecosystems before planning their deployment.

## 6. CONCLUSIONS

Thus, according to the Global Wind Atlas, most of the Black and Azov Seas are characterized by significant wind resources (*Ne* > 400 W/m$^2$). The total area of sites with the fourth wind power class and above, as well as depths up to 1000 m, is about 98500 km$^2$.

On the north-western shelf of the Black Sea, as well as throughout the entire water area of the Azov Sea, there are significant areas with depths of less than 50 m and a distance from the coast of not more than 200 km, suitable for placing both floating and fixed OWT.

Significant water areas with high wind power classes in the northwestern and northeastern parts of the Black Sea, as well as the Azov Sea, allow the installation of offshore wind farms capable of generating energy on an industrial scale. Installation and connection of the OWT to the hybrid energy complex can partially compensate for the uneven supply of energy resources and improve the reliability of energy supply to consumers in coastal regions of Bulgaria, Georgia and Turkey.

## ACKNOWLEDGMENTS

This study is supported by 'Developing Optimal and Open Research Support for the Black Sea (DOORS)' project. The authors would like thank of the European Research Executive Agency for providing financial support of this research under Grant 101000518.

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