FEASIBILITY STUDY ON PREREQUISITES AND SPECIFICS OF FLOATING WIND FARMS DEPLOYMENT IN THE BULGARIAN OPEN SHELF

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ABSTRACT

Following the EC directives and corresponding National regulations under approval, the possibilities for deployment of marine energy conversion farms have been considered, with a focus on the floating wind generators as one of the most promising applications and advantages. The specifics of local climate, hydrology and geography along the Bulgarian Black Sea coast have been analyzed, based on long-term surveys, and three potential areas of deployment were recommended, keeping in mind restrictions imposed by the Natura 2000 network of nature protection areas as well as extensive marine traffic and comparatively high urbanization of coastline. Various floating wind generator solutions have been compared from the view point of design, construction, installation, operation and maintenance. The WindFloat semi-submersible design that has already been employed in many European projects is recommended as a favorable design. An assessment of the impact on the local economy as well as on the local communities has been made and optimal capacity of the wind energy park is proposed.

Keywords: wind energy, floating wind solution, Bulgarian Black Sea coast

INTRODUCTION

The world ocean covers about 70% of Earth surface and appears as an immense source of natural energy. At present, solar and wind energy extraction technologies are most promising, at least in land applications. First steps in marine wind energy utilization have been done in shallow coastal waters, but perspectives lay in expanding activity to deep waters distant from shore, to cope with urban and short sea transport expansion. Offshore solutions grant access to vast offshore wind resources, which are typically stronger and more consistent than onshore winds. Moreover, floating wind farms have the advantage of being scalable, allowing for larger installations in the future as technology and industry experience advances.

The European Commission (EC) has been a strong advocate for offshore wind energy, recognizing its potential to contribute to the European Union's renewable energy targets

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and de-carbonization goals [1]. The EC has issued directives and regulations to support the development of offshore wind, including floating wind farms. These directives focus on streamlining permitting processes, promoting cross-border cooperation, and establishing clear frameworks for offshore wind development. Europe's Green Deal sets itself the ambitious goal of making Europe the first carbon-neutral continent by 2050. Energy from offshore renewable sources, including energy from floating wind farms, has the potential to become the core of the European energy system.

Offshore wind energy has immense potential, particularly in regions with favorable coastal wind resources. Offshore wind farms can be deployed in shallow waters close to shore as well as in deeper waters using floating platforms. The global technical potential for offshore wind is vast, estimated at over 29,000 GW by the International Renewable Energy Agency [6]. Europe, in particular, has been at the forefront of offshore wind development, with significant potential in the North Sea, Baltic Sea, and Atlantic Ocean, but also Black Sea – the World Bank's 2021 report shows that there is huge technical potential in Southeast Europe, with a staggering 166 GW of floating marine energy in the Black Sea alone [5].

The EU has committed to reducing greenhouse gas emissions by 55% by 2030 compared to 1990, with wind farm capacity expected to reach 453 GW, corresponding to 374 GW of those installed on land and 79 GW operating in EU maritime spaces. The original RePowerEU action plan [2] calls for renewable energy to reach 45% of the total, with the total installed wind capacity reaching 27% onshore and 32% offshore respectively.

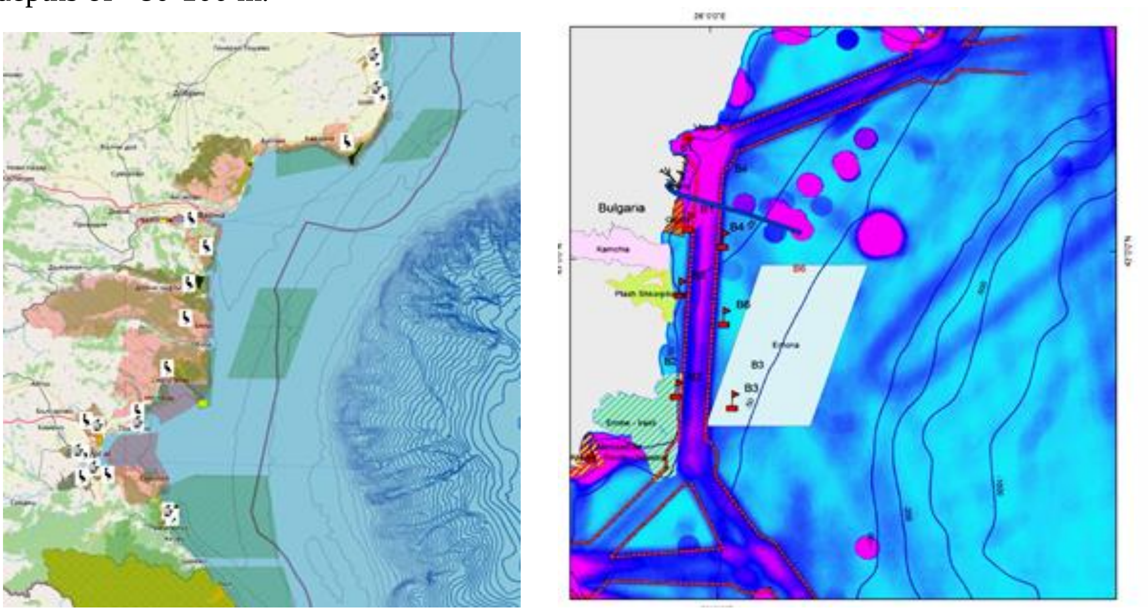
It's important to note that while wind energy has vast potential, the actual deployment and utilization depend on various factors, including policy frameworks, investment incentives, grid infrastructure, and social acceptance. Key element of development strategy obviously is the selection of conversion technology and most proper location of deployment. Further in this paper, those aspects are considered for the specific conditions of Bulgarian Black Sea coast.

1. EXISTING WIND POTENTIAL OVER WESTERN BLACK SEA SHELF

1.1 Location

This study initiates the idea of deploying a wind generator park in the open Black Sea area at the end of the Bulgarian shelf, where better expressed dynamic characteristics of the environment (uniformity of flow, wind speed and persistence) are expected. According to estimates in [3], the wind potential of the region at a height of 50 m exceeds 400 W/m^2 per year, which according to [4] provides a good operating mode for the turbines.

To determine the favorable areas for a wind park allocation, the Bulgarian shelf zone is divided into three parts: Northern (east of the cape Kaliakra – it borders immediately on the North-West shelf, which is the most extensive shallow-water part of the Black Sea, with intense wind effects especially during the cold season), Central (opposite of cape Emine) and Southern one. The cities of Varna and Burgas can be used as logistics centers for the wind farms, respectively. To evaluate the features of the wind field, generalized results obtained during climate averaging of synoptic maps, data from measurements, remote observations and numerical calculations (including reanalysis) were used. In addition to the characteristics of the circulation conditions, which are leading in the selection of the type of wind generators and the anchoring system, it is also necessary to take into account the restrictions imposed by "Natura 2000" zones [7] and the ship traffic organization system [8] (Fig. 1). Obviously, for all three mentioned parts, the possibilities for building wind farms are outlined at the end of the shelf at depths of ~80-100 m.



a) *b)*

Fig. 1. “Nature 2000”restricted zones (a)’, Intensive traffic zones with Emine restricted zone (b)

1.2 Atmosphere Circulation and Wind Conditions

According to the regime characteristics of the wind over the Black Sea [9], the cyclonic type of circulation prevails, contributing to the strengthening of the meridional exchange in the atmosphere and significant spatio-temporal variability. In winter, under the influence of the Siberian anticyclone, conditions arise for the appearance of sustained NE winds with a speed of 7-8 m/s, often reaching storm force. As the Asian anticyclone weakens, the impact of Mediterranean cyclones increases, causing unstable weather, often with very strong SW winds. In the summer, with an intense transformation of the air masses, the water area of the sea falls under the influence of the Azores maximum and monsoon effects with prevailing weak (2-5 m/s) NW winds, anticyclonic vorticity prevails over the Western Black Sea, NE storm winds rarely occur. The comparative analysis of the results of the various studies shows as a common feature that the western part of the basin is distinguished by the highest average wind speeds. Against this background, the character of the wind regime of the individual parts of the Bulgarian coast and the adjacent shallow shelf is significantly influenced by the orography - the data from the meteorological observations objectively present its features. The total duration, Σ_τ [hours], of wind action with a speed between 2 and 14 m/s significantly exceeds (by 300-400 hours) the corresponding values in the flat parts of the country; the maximum total duration is observed in autumn and winter. And the character of Σ_τ for Kaliakra and Emine - the two promontories jutting far into the sea, is similar to that of the high mountain regions of Bulgaria. The differences in the wind regime between the capes (Kaliakra) and the bay coasts (Varna) are shown in Tabl. 1.

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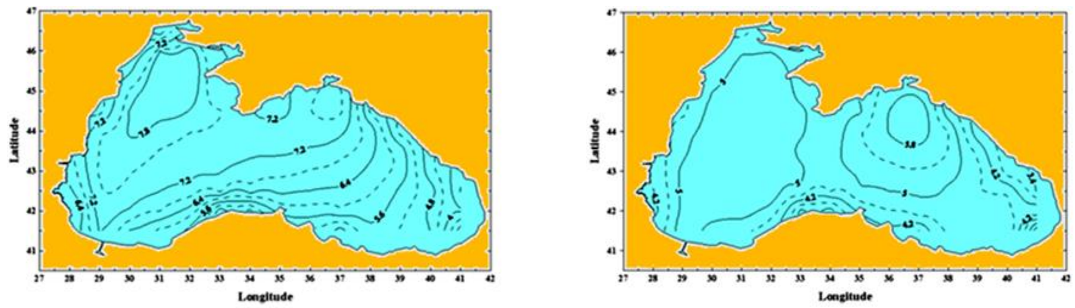
Throughout the year, the wind regime in the Western part is distinguished by higher average speeds not only than the rest of the water areas, but also that of the coast (Fig. 2). During the cold season in the open sea, the speed is in the range of 7-8 m/s, N winds predominate. During the warm season, the number of cases with NE, E, SE and S winds increases; less often, W and SW winds are observed [10].

Table 1. Seasonal climate assessments for weather stations Varna (Vn) and Kaliakra (Kal): total (A) and average continuous (B) duration (hours) of wind occurrence with different speeds (m/s) and number of cases with continuous action (C)

Station	≥ 2 m/s				≥ 14 m/s				≥ 20 m/s				Characte-ristic
	Win	*Spr*	*Sum*	*Aut*	*Win*	*Spr*	*Sum*	*Aut*	*Win*	*Spr*	*Sum*	*Aut*	
Kal	1912	1697	1680	1860	401	217	151	269	148	69	37	77	**A**
Vn	1308	1252	1186	1316	69	32	14	31	16	5	3	4	
Kal	18.1	11.1	9.2	13.6	10.2	8.6	6.4	7.4	9.2	8.2	6.0	6.6	**B**
Vn	12.8	10.3	8.5	10.9	5.0	3.7	2.9	3.8	4.2	3.1	2.4	3.1	
Kal	105	153	182	137	39	25	24	36	16	8	6	12	**C**
Vn	102	122	140	14	9	5	8	4	2	1	1		



Winter season *Summer season*

Fig. 2. Monthly average climatological wind speeds over the Black Sea [m/s] [10]

1.3 Wind Waves and Current

The wave and current intensity over considered offshore zones have twofold influence on wind farm location selection. From one side, they prescribe convertor design conditions; on the other side they reveal possibility for hybrid utilization of carried energy thus increasing total effectiveness of conversion process.

Along the western Black Sea coast, the wave height usually increases from North to South (except the large bays of Varna and Burgas). In a strong storm, the significant wave height reaches 6 m, with single waves of 7-8 m, the wave period varies from 9 to 11 s, the wave length reaches 40 - 60 m. The central and southern regions of Western Black Sea shelf have the highest potential of average annual wave energy – 37.3 and 43.9 MWh/m, respectively [11].

The general movement of the surface sea water layers follows a cyclonic scheme with the main dynamic feature known as Main Black Sea current (MBSC) – frontal current with stream character, average width of about 70-100 km and average speed of 40-60 cm/s. The MBSC stream is generally located at the edge of the shelf and over the continental slope, and due to hydrodynamic instability it experiences wave-like oscillations from its mean position. Due to significant seasonal variability of the dynamics, the stability of the MBSC is greater in winter and the currents are most intense, occasionally reaching up to 1.5 m/s [9].

FLOATING WIND SOLUTION

The general requirements defined by the European Commission [1], with which energy extraction facilities must comply in order to be licensed to operate in European waters, are:

- To not interfere with navigation;
- To not affect negatively the value of coastal real estates;
- To not affect negatively marine flora and fauna;
- To have a low maintenance cost;
- To guarantee reliable operation;
- To guarantee minimum operating period of 10 – 20 years;
- To sustain the value of the facility over the period of operation.

The effectiveness of a wind power plant is determined generally by construction costs as well as wind energy capacity of the region. It is common opinion, that land based installations are cheaper. In the same time, they are located over potentially agriculture areas, weather conditions are changeable and the coefficient of flow uniformity is small due to natural landscape obstacles. Offshore units are expected to be more expensive in building and installation, but more effective in operation, due to higher flow uniformity, large wind fetch distances and thus higher energy content in the wind flow [12].

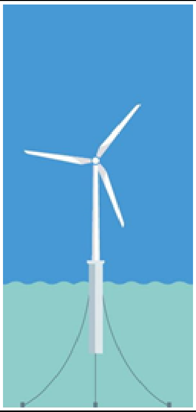
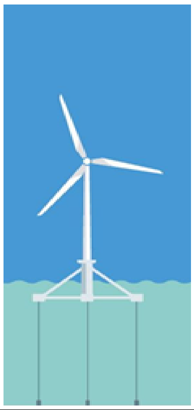
Two basic concepts are in common use. More popular at present is “fixed” concept – the tower buried into the seabed in order to ensure stable fixation, which however is harmful for the marine ecosystem. Floating wind farms are an emerging technology that holds great potential for harnessing wind energy in deeper offshore areas where fixed-bottom wind farms are not feasible. “Floating” concept presumes utilization of the whole experience and standards already mastered in ocean engineering, installation and de-commissioning is easy and no significant interaction with the surroundings takes place. Besides, floating structures can be moored at deeper zones out of visibility from the shore, which serves to the urban aesthetics [12].

2.1 Technology

The technology behind floating wind farms is still evolving, but several floating platform designs have been developed and deployed in pilot projects and small-scale commercial installations. These platforms, such as tension-leg platforms (TLPs), semi-submersibles, barges or spar buoys, utilize various types of floaters and mooring systems to provide stability and enable the turbines to operate in rough offshore conditions. A short juxtaposition of variants is outlined in Table 2. It can be concluded, that the four variants are competitive. Judging from the preference use in deep waters and advanced technology, the choice is tending to semi-submersible floaters that have already been employed in many European projects, some of them already operating [14].

Besides floater’s technology, other important issues emerge, such as logistics of wind farm service (including use of Offshore Wind Service Vessels), power transmission and grid access, as well as decommission operations, having in mind, that service life of considered units cover about 20 years.

Table 2. Comparison of various floating wind solutions [12]-[17]

Type	**Spar**	**Semi-sub**	**TLP**	**Barge**
Description	*The turbines are mounted on long cylindrical platforms that extend below the water surface*	*The turbines are mounted on platforms that partially submerge in the water*	*The turbines are mounted on platforms tethered to the seabed using tensioned mooring lines*	*The turbines are mounted on towed flat-bottomed vessels - barges or ring pontoons*
Image				
Stability & Reliability	**	***	****	***
Deep Water Deployment	***	****	****	***
Environmental Impact & Concerns	***	***	*	**
Flexibility & Adaptability	**	***	*	***
Engineering Complexity	***	**	*	**
Costs	**	***	*	***
Maintenance & Accessibility	*Offshore Wind Support Vessels*			
Power Transfer	*Cable or battery*			

2.2 Effectiveness

Since offshore wind technology is still evolving, the key points highlighting its effectiveness consider general terms of interaction with environment, like access to stronger winds (increase of resource availability), coastal community friendly (reduced visual impact, low noise, less ecological impact), compatibility to existing solutions and enhanced productivity. Reported overall efficiency amounts to 40-45% with a tendency of further increase with maturity of the technology. Cost reduction of about 48-50% is expected [17] in the process of transition from prototypes to commercial realization.

2.3 Legislation

Floating wind legislation varies from country to country and is still evolving in many regions. The leaders of offshore wind development, such as UK, Japan, USA and Norway, had established a legal framework to support its growth, along with financial support measures. The European Commission has proposed a regulatory framework known as the Offshore Renewable Energy Strategy, which aims to facilitate the growth of floating wind and other offshore renewable technologies. This strategy includes guidelines for permitting, grid connection, environmental assessments, and support mechanisms.

In the course of this, a bill on Marine Renewable Energy has been submitted to the Bulgarian Parliament and is expected to enter in force soon. This law regulates public relations related to the production of electrical energy from wind power plants in the maritime spaces of the Republic of Bulgaria. The law also regulates the preliminary studies for establishing the feasibility of offshore wind farms, their construction, operation and decommission.

3. PERSPECTIVES AND CONCLUSION

While floating wind farms are still in the early stages of development, they offer significant potential for expanding offshore wind energy generation in deep waters. With ongoing advancements and cost reductions, floating wind farms are likely to become increasingly effective and contribute to the global transition towards renewable energy sources. The analysis shows slight preference toward semi-submersible floaters.

Several installations and ongoing projects have been reported worldwide, i.e. Viana Do Castelo (Portugal), Aberdeen (Scotland), Erebus (Wales), Ulsan (Korea), Leucate (France), etc., the unit power varying between 5 and 20 MW and the total power delivery between 20 and 100 GW.

Currently, two projects have been declared for the installation of offshore wind turbines along the Bulgarian Black Sea coast. One of them [18], was initiated by the Romanian Energy Policy Group (EPG) and envisages the joint construction of an "energy island" on the border of the sea zones of Bulgaria and Romania, with the prospect of joining other Black Sea wind farms (Azerbaijan, Georgia). Production is expected to reach 3 GW by 2030. The second project BLOW [19], launched by the European engineering company Eolink, brings together 16 European partners to pioneer the installation of a 5MW floating wind turbine in the Black Sea off the Bulgarian coast by 2025.

The proximity of the site suggested by above projects to the interstate boundary lines on the Black Sea west coast is geographically justified, and the macro and mesoscale climate assessments of the wind field in Paragraph 1 above indicate that all three considered areas of the open Western shelf have suitable characteristics for the construction of a wind turbine floating park. However, from a logistical point of view, preference should be given to the Central region, which is convenient to maintain from both Varna and Burgas, while allowing to mitigate the impact of the harsher and unfavorable phenomena characteristic of the Northern region.

Eventual “hybrid” utilization of the three major sources of marine energy – wind, waves and current – is promising perspective for supposed increase in conversion effectiveness. This would be subject of further investigations and considerations.

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