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Algeria's Offshore Wind Potential: Spatial Identification and Energy Assessment in the Eastern Exclusive Economic Zone.

Chalal Yahia [#1], Mezouar Khoudir [#1], Iglesias Gregorio [*2]

[#1] *Laboratoire des écosystèmes marin et littoraux, National Higher School of Marine Science and Coastal Development, University, Algeria*

[1]yahia.chalal@enssmal.edu.dz

[1]khoudir.mezouar@enssmal.edu.dz

[*2] *MaREI, Environmental Research Institute & School of Engineering & Architecture, University College Cork, College Road, Cork T12 K8AF, Ireland*

[2]gregorio.iglesias@ucc.ie

***Abstract*— Offshore wind energy is increasingly recognized as a strategic pillar of the global transition toward carbon neutrality. This study assesses the offshore wind potential of Algeria by examining the eastern sector of its Exclusive Economic Zone (EEZ). A multi-criteria spatial analysis delineated approximately 740 km² of suitable areas for offshore wind development, of which 95% is favourable for floating wind technology due to water depths ranging from 50 m to 1000 m. Within this region, two priority zones were identified based on environmental, technical, and spatial constraints. Energy production simulations, conducted using the 10 MW Vestas reference turbine, indicate capacity factors exceeding 38% in the most exposed floating-wind areas, where mean wind speeds average ~7 m/s. Applying an optimized array layout (Li et al., 2024), the theoretical deployment density reaches 3.54 MW/km². The total theoretical energy output for the entire suitable area is estimated at 2.61 GWh per hour, of which 2.47 GWh/h is attributable to floating wind installations. Average capacity factors were 36.4% for floating and 30.6% for fixed-bottom turbines located near the El-Taref province. These findings highlight the eastern Algerian EEZ as a highly promising region for offshore wind development. The results provide essential guidance for marine spatial planning and underscore the potential role of offshore wind in diversifying and decarbonizing Algeria's future energy mix.**

***Keywords*— Offshore Wind; Floating Wind Turbines; Algerian EEZ; Marine Spatial Planning; Wind Assessment**

I. INTRODUCTION

Fossil-fuel extraction and combustion generate substantial greenhouse gases and air pollutants, driving global warming and environmental degradation [1]. Expanding renewable energy is therefore essential, with each 1% increase in its share reducing CO_2 emissions by 0.28–0.40% and simultaneously lowering CH_4 and $PM_{2.5}$, producing significant health and environmental benefits [2]. Integrated solar, wind, and storage systems further enhance grid resilience to climate-induced stresses [3], while wind energy offers major emissions reductions with minimal water use, provided ecological constraints are considered [4]. Offshore wind has become a key pillar of global decarbonisation, with a technical potential of 71,000 GW and rapidly growing deployment exceeding 75 GW worldwide [5], [6], supported by major expansions in Europe, China, and Northeast Asia [7] and by advances in large turbines and floating technologies [8].

Within this global context, the Mediterranean remains underdeveloped yet highly suitable for floating offshore wind due to its deep bathymetry [9]. Recent studies estimate a regional potential of ~782 GW with competitive LCOE values, though ecological and regulatory constraints require robust spatial planning [9], [10]. In North Africa and particularly in Algeria, the sector is still at an early stage, despite site-level studies indicating favourable coastal and inland wind regimes [9] [14] [16]. However, no spatially explicit offshore-wind assessment covering the Algerian EEZ currently exists, leaving a major gap for planning and investment. This study addresses that gap by delivering the first comprehensive evaluation of offshore wind potential in Algeria's eastern EEZ through integrated ERA5 wind analysis, bathymetry, maritime use constraints, wave

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climate, and port infrastructure, thereby identifying optimal zones and providing essential evidence for future marine spatial planning and feasibility studies.

II. STUDY AREA

The study area is located within the eastern sector of the Algerian Exclusive Economic Zone (EEZ), as delineated in Fig. 1. It extends from the maritime frontage of Béjaïa Province in the central-northeastern portion of the country to the eastern national border with Tunisia, adjacent to El Tarf Province. This region, highlighted in magenta, encompasses the offshore domain situated between approximately 4°E and 8.5°E longitude and forms the portion of the Algerian EEZ where wind resource intensity, bathymetric configuration, and maritime spatial constraints collectively indicate the strongest potential for offshore wind energy development.

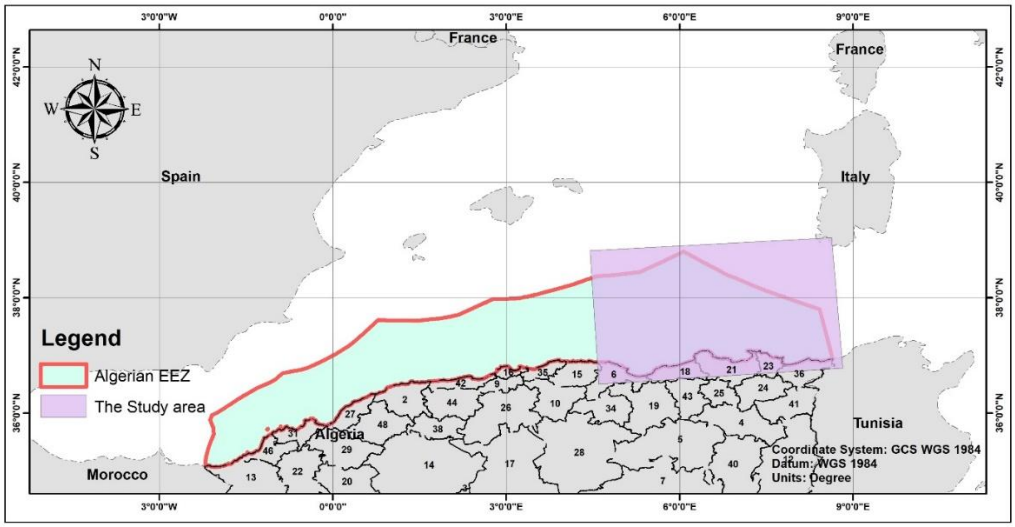

Fig. 1 Geographical situation of the studied area (the eastern algerian EEZ)

III. MATERIALS AND METHODS

The methodological framework follows a multi-stage sequence integrating geospatial analysis, technical screening, and decision-support evaluation. ERA5 wind fields [17], bathymetry, MPAs, and maritime-use datasets are first assembled, pre-processed, and harmonized to a common spatial resolution. A GIS-based technical filter then applies exclusion thresholds for wind speed, water depth, and coastal buffers to delineate preliminary viable zones for offshore wind development. Energy modelling using a representative 10 MW turbine estimates capacity factors, array spacing, and operational losses for both fixed and floating technologies, producing suitability maps and energy indicators that support marine spatial planning and provide a replicable assessment framework for Algeria.

High-potential zones are identified through a multi-criteria evaluation that integrates geographical, technical, environmental, and techno-economic parameters. Wind resource thresholds typically exceed 7 m/s at hub height for commercial offshore projects, though in Algeria’s narrow continental-shelf context, preliminary screening accepts $\geqslant$5 m/s for fixed-bottom and $\geqslant$6–7 m/s for floating systems. Depth constraints restrict fixed foundations to <50 m and floating systems to 50–1,000 m. Additional spatial constraints include distance-from-shore limits of 20–200 km and mandatory exclusion of ecologically sensitive areas such as MPAs [18]. The analysis remains confined to the Algerian EEZ and incorporates competing maritime uses including shipping, fisheries, and military zones. Techno-economic considerations, especially port suitability, marine logistics, and wave climate; shape project feasibility and O&M accessibility, with less energetic seas favoring maintenance. Finally, isolated patches smaller than 12 km² are removed to ensure realistic farm-scale deployment [19]. This integrated filtering approach enables the identification of spatially coherent, feasible offshore wind development zones.

Recent studies have highlighted the critical role of turbine spacing in maximizing offshore wind farm power output. Optimal configurations, involving a longitudinal spacing of 7D and an inter-farm spacing of 15D, combined with a yaw angle of 30° and a yaw rate of 0.0122 rad/s, can increase average power output by

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approximately 2.86 MW compared to standard layouts [20]. The V164-10.0 MW turbine from MHI Vestas, widely deployed in projects such as the floating EFGL pilot in the Gulf of Lion, was selected due to its high efficiency. For this study on Algerian eastern waters, the V164-10.0 MW was evaluated using the 7D × 15D optimal layout [20], with the V164 achieving a theoretical maximum of 3.54 MW/km².

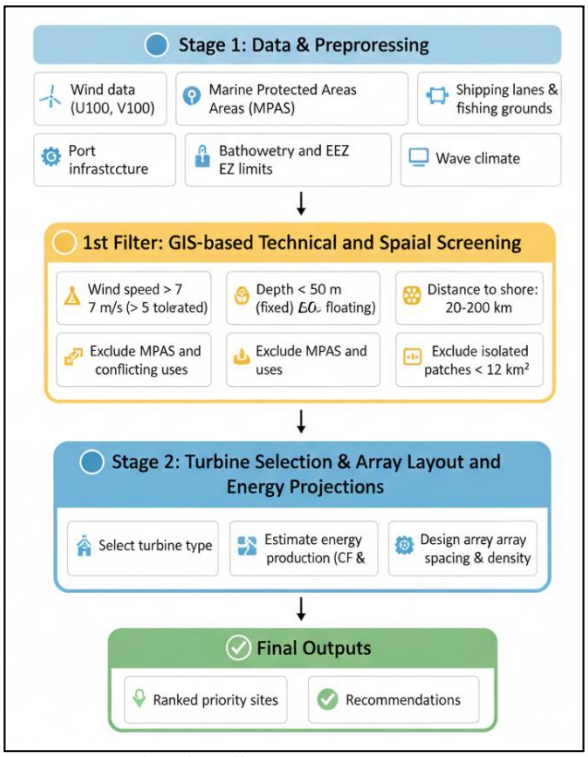

Fig. 2 Methodological Workflow for Offshore Wind Energy Site Selection and Assessment

IV. RESULTS AND DISCUSSION

1. Wind Climate

Analysis of long-term reanalysis data over 85 years, indicates that the eastern sector of the Algerian EEZ, particularly the offshore area adjacent to El Tarf Province, exhibits enhanced wind resources. The 7 $m \cdot s^{-1}$ isoline, which represents a critical threshold for achieving high energy yields, extends up to approximately 65 km from the coastline. This delineates a significant offshore corridor with high wind potential. However, the distribution of this favourable wind is not continuous along the broader Annaba–Skikda coastline, suggesting spatial heterogeneity in wind availability that must be considered in site selection for wind energy projects.

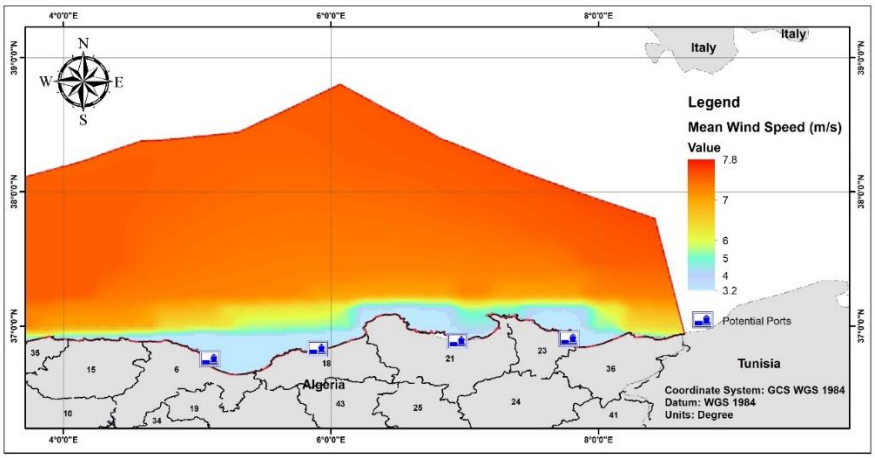

Fig. 3 Mean Wind Speed over the eastern algerian EEZ from 1940 to 2024

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2. Bathymetry

The bathymetric profile of the eastern EEZ, extending from Béjaïa to Annaba, presents the most unfavourable conditions for offshore wind development within the Algerian eastern maritime domain. The continental shelf in this sector is narrow, with widths ranging from 40 to 50 km near Skikda and El-Traf bays, and water depths that are shallower than those observed in the steeper central and western sectors. Such geomorphological characteristics are conducive to both fixed-bottom and floating wind turbine installations. In contrast, the deeper waters of the central EEZ are predominantly suitable for floating platforms, highlighting the spatial variability of technological options dictated by bathymetric constraints.

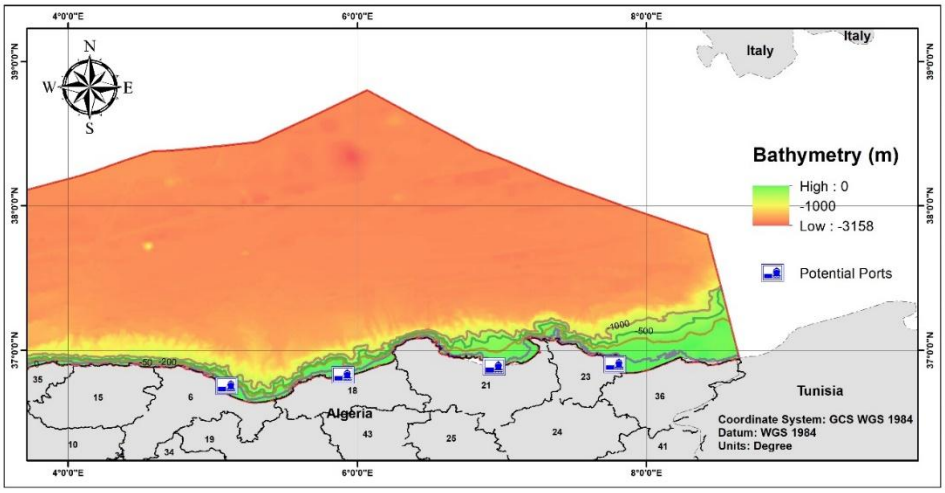

Fig. 4 Bathymetry over the eastern EEZ from Gebco dataset and National marine charts dizitalisation

4. Integrated Interpretation of Suitable Offshore Wind Zones

Following the multi-criteria filtering sequence defined in the methodological framework, covering wind resource thresholds, bathymetric suitability, exclusion of navigation corridors, distance-to-shore limits, and port accessibility requirements four technically viable zones were delineated within the eastern Algerian EEZ for offshore wind development. These areas display distinct environmental and operational conditions, informing their relevance for specific technological solutions and project scales.

The first zone is the only nearshore area compatible with fixed-bottom foundations. Located about 2 km offshore and covering 39.37 km², it achieves a capacity factor of 30.61%, reflecting the moderate southern Mediterranean wind regime. Its proximity to shore offers logistical advantages, including shorter export cables and easier installation and maintenance. However, its limited spatial extent constrains effective capacity to 42.66 MW after turbine-spacing constraints, making it most appropriate for pilot projects, demonstration sites, or port-integrated developments near Annaba or Skikda.

The second zone, situated 26 km offshore, is suitable for floating wind technology and spans 90.7 km². It exhibits a slightly higher capacity factor of 31.38% and benefits from favorable bathymetry, reduced maritime-use conflicts, and manageable operational distances. Although its theoretical capacity reaches 321 MW, effective deployment is estimated at 100.75 MW. This zone represents a balanced option, combining moderate resource quality with technical feasibility and logistical accessibility, and is well suited for intermediate-scale floating offshore wind development in Algeria.

The third zone, located 29 km offshore, is among the most promising sites for large-scale floating offshore wind development. Spanning 244.94 km², it exhibits a high-capacity factor of 39.19%; one of the highest in the Algerian EEZ, resulting in a superior annual energy yield per turbine (34354 MWh). Although its theoretical capacity of 867 MW decreases to about 340 MW after applying realistic spacing and engineering constraints, it remains suitable for commercial-scale deployment. Its offshore distance allows standard O&M strategies, and its location outside major navigation corridors minimizes maritime conflicts.

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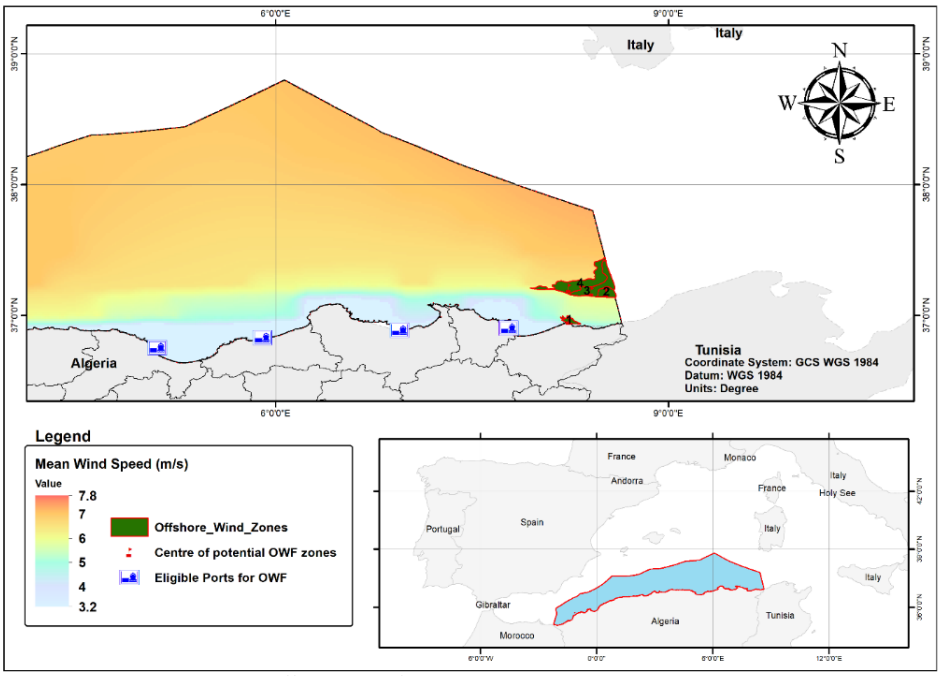

Fig. 5 Potential offshore wind firm zones on the eastern algerian EEZ.

The fourth zone is the largest and potentially most productive area identified, covering 363.2 km². It maintains a strong capacity factor of 38.73% and achieves the highest theoretical capacity (1 285 MW), with an effective deployable capacity of 497.91 MW. Favorable wind conditions, high per-turbine energy output (33 950 MWh), limited navigation interference, and a moderate wave climate position this zone as the primary candidate for utility-scale floating offshore wind and a cornerstone of Algeria's long-term offshore renewable energy strategy.

Table 1: Key techno-economic and geographical parameters for four potential development zones.

Zone	Installation Type	Distance to Shore (km)	Area (km²)	Capacity Factor (%)	Annual Energy per Turbine (MWh/yr)	Theoretical Installed Capacity in Optimal Array (MW)	Effective Installed Capacity under Real Conditions (MW)
1	**Fixed**	2	39.37	30.61	26832.39	139.37	42.66
2	**Floating**	26	90.7	31.38	27508.16	321.08	100.75
3	**Floating**	29	244.94	39.19	34353.67	867.09	339.78
4	**Floating**	29	363.2	38.73	33950.04	1285.73	497.91

The zone benefits from robust wind resources, high annual energy production per turbine (33 950 MWh), natural separation from major maritime corridors, and a relatively moderate wave climate favourable for installation and long-term operation. These characteristics make it the primary candidate for utility-scale floating offshore wind development and position it as a strategic element in Algeria's long-term offshore renewable energy planning.

V. CONCLUSIONS

This study delivers the first spatially explicit and technically integrated assessment of offshore wind potential in the eastern Algerian EEZ. Using 85 years of ERA5 wind data alongside bathymetry, wave climate, maritime traffic, and port-accessibility constraints, it establishes a comprehensive framework for identifying viable offshore wind zones. The results confirm that offshore wind, especially floating technology suited to deep waters is feasible and strategically promising for Algeria.

The multi-criteria filtering methodology delineated about 740 km² of viable areas, with 95% suitable for floating foundations. Four priority zones were identified: a small nearshore fixed-bottom site ideal for pilot projects, and three offshore floating-wind areas (26–29 km from shore) with significantly stronger wind

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resources, reaching capacity factors above 38%. These zones benefit from favorable wind corridors near Annaba and El-Tarf, moderate wave conditions, and proximity to major ports, while avoiding substantial ecological and maritime use conflicts. Collectively, they represent strong candidates for utility-scale development.

Overall, the findings highlight the eastern Algerian EEZ as a promising frontier for floating offshore wind in the Mediterranean. Beyond resource quantification, the study offers a replicable methodological framework supporting marine spatial planning, energy diversification, and early investment decisions.

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