Renewable Energy Production in the Mediterranean: Exploring the Potential for Offshore Wind Development

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Abstract. This study presents an overview of the current state of the Maritime Spatial Planning among the Mediterranean countries, explores the previous studies on evaluating the offshore wind potential of the Mediterranean region along with the criteria for suitable site selection. Based on a review of the current state of offshore renewable energy, the potential locations offshore wind will be explored for the Mediterranean coastline case study area. The research concludes with a set of critical considerations related to the need for proper synergies establishment among different stakeholders and for cultivating social acceptance and community engagement. The analysis aims to support decision-makers evaluating the potential of the Mediterranean coastal area in supporting the energy transition goal.

1. Introduction

In order to meet rising energy demands and combat climate change, offshore renewable energy (including wind, solar, wave, and hybrid systems) has become a key focus area, supporting global sustainability goals and the UN SDGs [1, 2]. Furthermore, the European Union has set the target of net zero greenhouse gas emissions by 2050 [3] and an EU strategy is established by The European Commission on offshore renewable energy (COM(2020)741) [4] proposing an offshore wind installed capacity of 60 GW and 300 GW by 2030 and 2050, respectively. Aiming to address the growing energy demand while mitigating climate change and shifting the energy paradigm in favor of renewables, several studies examine optimal site selection for sustainable energy generation.

1.2. Background on research methodologies

In what concerns research methodologies, site selection for offshore renewable energy systems has been extensively studied using methodologies such as Multi-Criteria Decision-Making (MCDM), Geographic Information Systems (GIS), and fuzzy logic. MCDM techniques—such as AHP, TOPSIS, and hybrid approaches—evaluate technical, economic, social, and environmental criteria [5]. Fuzzy logic is particularly effective in handling uncertainty in offshore data [6]. The integration of GIS and MCDM represents a state-of-the-art approach, providing spatial analysis and visualization capabilities. Several studies employed GIS-MCDM techniques to assess criteria like wind resources, environmental impacts, and infrastructure. For instance, Liu et al. [7] combined GIS and MCDM for optimal site selection while using rough-fuzzy theory to deal with the uncertainty in decision-making. Salvador et al. [8] used Bayesian methods for site selection in Tasmania. However, some studies ([9], [10]) note the complexity and lack of transparency in these models, which can hinder real-world application.

Recent research includes integrating Life Cycle Assessment (LCA), cost-benefit analysis, and meta-heuristic algorithms to better address economic and environmental sustainability [5]. Lo et al. [11] advanced the methodology further with a grey-based MCDM model, enhancing robustness in the face of uncertainty.

According to the literature, selection criteria are grouped into six main domains; environmental factors – Wind speed, wave height, and solar irradiance are vital; different studies underscore their role in energy output stability; economic factors – Construction and operational costs, carbon footprint, and GDP impact are key considerations [6]; geographical and/or technical suitability - Sea depth and seabed type are critical; [12] utilized GIS and SMCDA for assessing geographical viability; and Social and regulatory aspects – Impacts on communities, tourism, and fisheries are crucial; Yanez-Rosales et al. [13] applied LCoE and social impact assessment in island contexts like the Canary Islands.

1.3 Maritime Spatial Planning on the Mediterranean Region

The first step in assessing renewable energy resources in the seas can start with Maritime Spatial Planning (MSP), which aids in making informed and coordinated decisions about how to use marine resources sustainably. In the Mediterranean, there is a significant contrast in the maturity of MSP policies between EU and non-EU countries. In this section, we provide a brief overview of the current state of the MSP in some of the Mediterranean countries.

The EU framework for MSP is established by Directive 2014/89/EU, which mandates the consideration of economic, social, and environmental aspects (Art. 5), relevant maritime activities such as renewable energy production (Art. 8), and cross-border cooperation (Art. 11). It also emphasizes public participation (Art. 9) and is supported by the European Maritime Spatial Planning Platform.

Spain transposed the directive in 2017, requiring MSPs for five maritime regions under Law 41/2010. These plans, known as POEM, underwent public consultation and were finalized in February 2023 [14]. They are subject to periodic review.

Portugal adopted the directive via Decree-law nº139/2015 [15], updating prior legislation. Its MSP (PSOEM) was approved by Resolution RCM no. 203-A/2019 [16]. A working group formed in 2022 proposed areas for offshore renewables, leading to the 2025 approval of the Action Plan for Marine Renewable Energy (PAER) via RCM no. 19/2025 [17].

On the Southern Mediterranean (Non-EU States), the Policy frameworks are less developed, with varying degrees of progress.

Algeria is working on MSP through international support like the WestMED Initiative [18], though lacks a fully implemented plan and offshore wind projects [19].

Morocco is advancing MSP via multiple initiatives, including World Bank-supported marine protection in Agadir [20], a National Coastal Plan (Law 81-12) [21], and regional schemes.

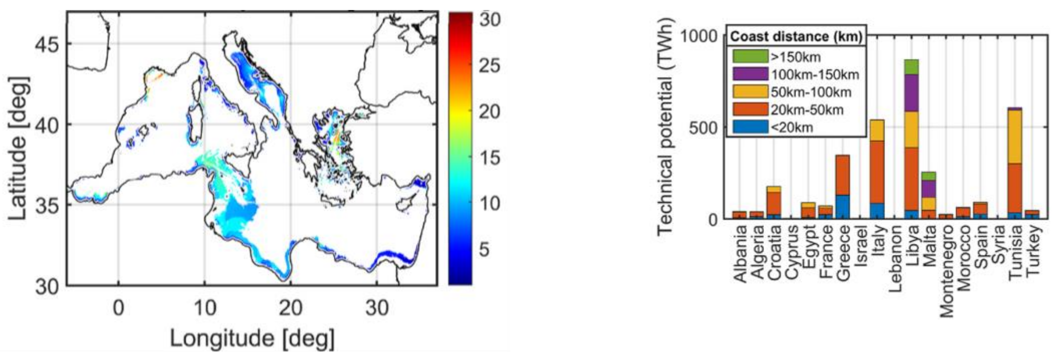
Egypt participates in the mspglobal and PROBLUE initiatives for MSP capacity building [22], and is developing a National Marine Spatial Data Infrastructure [23].

Tunisia is in early MSP development stages, while Libya has seen limited progress due to ongoing political instability [19].

Turkiye has not yet established a national MSP legislation. However, there are relevant regulatory frameworks such as the Turkish Coastal Law No. 3621 (1984) or the Sustainable Blue Economy Action Plan (Blue Plan) (2025). In April 2025, "Turkiye MSP Platform" was established and an attempt of MSP of Turkiye was published as an academic study, without representing the official opinion of Republic of Türkiye [24].

EU-funded project "Mspmed-Towards the operational implementation of MSP in our common Mediterranean Sea" [25], with the goal of supporting the implementation of six national maritime plans, as well as the project "MSPglobal2030" [26] of the Intergovernmental Oceanographic Commission of the UNESCO and the Directorate-General for Maritime Affairs and Fisheries of the European Commission, highlight the importance of establishing cross-border frameworks for maritime spatial planning for European regional seas. In "MSPglobal 2030", for the pilot project in the Western Mediterranean, an "integrated scenario" is considered aiming to reduce conflicts between different uses of the sea and the environment while promoting synergies allowing co-location, e.g. between aquaculture and wind energy. The key consideration was setting up marine integrated management at transboundary level and to make it coherent along the sea basin. Hence, sustainable tourism, sustainable maritime transport, and co-location of activities were considered, and a scenario-based MSP of the Mediterranean was generated.

One of the previous studies considered floating offshore wind energy potential in the Mediterranean (Faraggiana et al. (2024) [27]) and estimated Levelized Cost of Energy in the Mediterranean Sea. Suitable sites are optimized based on electrical grid cable design and wind farm layout optimization. The largest technical capacity potentials are obtained in Libya, Tunisia, Italy and Greece, accounting for 72.2 % of the total Mediterranean potential with a total installed capacity of 782 GW. The lowest LCOE, the largest technical resource potential and capacity factors are reached in the Gulf of Lion, in the Strait of Sicily, along the coast of Libya, and in the Aegean Sea. The Mediterranean countries with the greatest potential for floating offshore wind are Libya, Tunisia, Italy, and Greece, accounting for about 72.2 % of the total suitable area, energy production, and installed capacity in the Mediterranean Sea. [27]. The technical potential is also influenced by the distance from the coast as shown. In general, most of the potential is located less than 50 km from the coast (about 63.3 %) (Figure 1).



(a) (b)

Figure 1. (a) Floating offshore wind technical resource potential (GWh/y/km^2) across the Mediterranean Sea, (b) floating offshore wind technical energy potential for different countries shown with distance from the shore [38].

The Mediterranean region shows increasing interest in offshore wind energy, driven by the high potential of floating wind technology. Bottom-fixed wind is geographically limited, mainly to the Adriatic Sea, with an estimated potential of 46.3 TWh/year. In contrast, floating wind has a much greater potential of 4,582.6 TWh/year. A study by Pantusa & Tomasicchio (2019) [28] identified the most suitable areas for offshore wind by combining sea depth and wind speed data. These areas range from shallow (0–50 m) to deep waters (up to 500 m) with average wind speeds between 4–8 m/s. Based on optimal layouts and turbine characteristics, the maximum theoretical offshore wind output for the Mediterranean is estimated at 742 TWh/year.

2. Selection of the case studies and general methodology

Having into account the information about the Mediterranean basin described in the previous section, one can clearly see that in the southern region, most countries are still in early stages in what concerns the development of MSP. However, the proximity to already characterized regions in this basin, such as Spain and Portugal, can be a good opportunity to take into consideration similar approaches in the selection of the most interesting areas based on the available information for each topic. Also, some countries have started the development of their MSPs and have some available data that enables them to perform a general analysis of the most feasible offshore areas to locate renewable energy systems and, in particular, Energy Islands. In this sense, Morocco and Algeria were selected for this study, having into consideration their geographical location, very close to the Iberian Peninsula.

2.1 Assessment criteria for the selection of suitable locations

In a general way, the methodology in the current study followed the most common approach with the use of a Geographical Information System and the establishment of suitable selection criteria, being the results, the areas / regions suitable for the implementation of offshore renewable energy systems, enabling also the quantification of the sustainable offshore renewable potential available for a region of interest. The input data are in two categories - renewable resource mapping, and conditions / restrictions to the installation of the renewable energy systems.

In what concerns renewable potential assessment, it depends on the technology under study, and in this case, since solar and wind are the more relevant ones, numerical models (for wind assessment, for example) and/or available tools on the most used GIS (ex. Solar radiation tools). The identification of the most common restrictions to the installation of the systems is then performed with the use of the corresponding georeferenced information within the GIS and the conditions that meet the objectives of the study are defined and applied.

The criteria to be applied depend on the technology – wind, solar, wave-Tidal, etc. However, since the region under study lacks some important digital and georeferenced information (electric grid, detail on biodiversity, common uses for fisheries, military zones, among others) only aspects related to bathymetry, marine environmental protected regions, mean wind speed, and visibility from the coast are applied. It is assumed that for the definition of the suitable location for a potential energy island, the main criteria are dependent on the wind resource suitability since it is the renewable resource that corresponds to the highest technological investment. Table 1 shows the general criteria used for the definition of the areas that indicate suitable conditions for renewable energy systems development (including energy islands), and consequently, establishing the basis for the development of national MSPs.

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The shaded inputs on table 1 refer to information that was not available in suitable format for this work, or inexistent for the regions under study.

Table 1. General criteria used for the definition of the areas that indicate suitable conditions for renewable energy systems development

Type of restriction/information	Conditions	Source
Renewable resource assessment	Wind resource/Mean wind speed ≥7.0m/s (Solar potential not assessed)	Global Wind Atlas [29]
Environmentally protected areas	Exclude. According to the level of protection, conditional levels of occupation can be applied.	EMODnet [30], Copernicus marine services [31], [32]
Seabed conditions	*Type of soil (no applicable due to lack of coverage on public databases)*	*Not available at this time with the appropriate detail.*
Bathymetry and Slope	Fixed technology (Wind): $-30m \geq bat \geq 60m$ Floating technology (Wind): $-60m > bat \geq 200m$	EMODnet
Social aspects	Visibility areas established with buffers of 5 n.m. from points established in the coast near cities or potential shipping routes (not available in suitable format for this work)	Estimate included in the GIS developed for this work.
Socio-economic aspects	*Activities not considered at this time due to lack of information.*	*Not available at this time with the appropriate detail.*
Economical aspects	*LCOE and other economic indicators if available – not considered at this time.*	*Not available at this time with the appropriate detail.*
Grid Connection	*Proximity to connection points (to the electric grid), available connection capacity, high consumption areas.*	*Not available at this time with the appropriate detail for the region under study.*

3. Application of the methodology to the case studies

3.1 Morocco, Algeria and Turkey: Energy Mix

This section presents an overview of the energy profiles of Morocco, Algeria and Turkiye, focusing on their energy supply sources, electricity generation, sectoral consumption, and the evolving role of renewable energy. The data is primarily drawn from the International Energy Agency (IEA, 2024), [33], Ember(2024)[34], the Energy Institute (2024) [35], and relevant scientific literature [36].

Table 2 presents the general data related with the energy mix in each country under analysis in this paper. Morocco and Algeria show increasing electricity generation, their energy systems remain heavily fossil-fuel dependent. Morocco has made more significant progress toward integrating renewables, particularly wind, whereas Algeria's renewable sector remains underdeveloped. Both countries face opportunities and challenges in meeting long-term energy sustainability and climate goals.

Table 2. energy mix in Morocco and Algeria

Category	Morocco	Algeria
Primary Energy Supply (2022–2023)	Oil (58%), Coal (31.7%), Renewables growing	Gas (64.7%), Oil (34.9%), Minor solar
Net Energy Imports	High, relies on imports	Low, energy exporter
Top Energy Consuming Sectors	Transport (35.1%), Residential (27.5%), Industry (18.5%)	Transport & Residential (>30% each)
Electricity in Final Energy Use (2022)	18.9%	12.8%
Main Sources of Electricity (2022–2023)	Coal (68%), Wind (12.5%)	Gas (98.9%)
Electricity Generation Growth	13.7 TWh (2000) → 41.4 TWh (2022)	24.6 TWh (2000) → 90.2 TWh (2022)
Installed Capacity	2.8 GW coal, 1.6 GW gas, 1.2 GW wind	31 gas plants, 15+ built post-2000
Renewable Share in Electricity	~20% since 2018	Minimal: Solar (648 GWh), Wind (15 GWh) in 2022
Renewable Energy Goals	Continued increase in wind/solar share	Target: 15 GW renewables by 2035
Key Trend	Strong wind integration, steady renewables	Still fossil-dominated, early-stage renewables

The next section presents the identification of two suitable areas for offshore renewable energies in two of these countries in the western part of the Mediterranean basin, Morocco and Algeria.

3.2 Identification of the suitable areas for offshore renewable energy systems

The first phase of the study is the identification of the geographical distribution of mean wind speed that characterizes the region under study. The data used was obtained in the Global Wind Atlas for a height above the sea level of 150m. Figure 2 represents the mean wind speed map for both regions.

A filter with a lower limit of 7m/s was applied to the map in order to identify the values that can be more interesting for offshore wind turbines location. Although the EEZs of Morocco and Algeria present interesting locations, the great majority of the feasible areas are located far from the coast due to maritime ecological protection. Knowing that one major share of costs is associated with the cables connecting the systems to the transmission grid on the mainland, the farer we are from the coast the higher the investment costs are. Another important aspect is the depth of the sea bed and its constitution. In this case, it was not possible to have many elements of information related with the constitution of the seabed, but the bathymetric representation was performed to understand which types of technology could be installed – bottom fixed or floating.

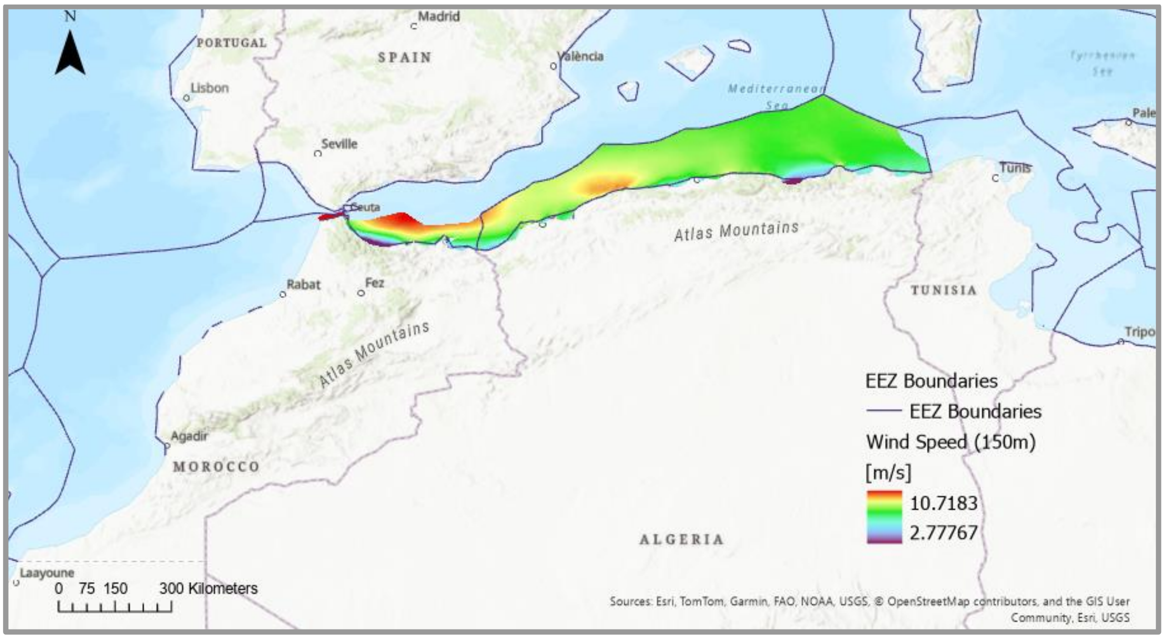

Figure 2. Spatial distribution of the mean wind speed in the coast of Morocco (Mediterranean side) and Algeria (h=150m a.s.l.)

It was found that the 100m bathymetric level is quite close to the coast in most of the area under study). However, this side of the Mediterranean basin is not very well characterized in the public databases and it is not possible to understand the evolution of the depth near the coast. Figure 3 presents suitable areas in terms of wind speed occurrence and depth in each EEZ. Selection criteria were applied to both maps according to the data included in table 1. According to this Figure, one can conclude that the existing depths are most suitable for the installation of floating systems. This can open a set of opportunities for research on floating energy islands with different renewable energy systems.

The marine ecoregion is also represented. This region represents environmental protection along the coast, and has different types of protection, which can lead to the permission to install equipment in some reserved areas. It is important to note that the Mediterranean basin is very rich in fisheries and should therefore be subject to deeper studies, especially in what concerns the consultation of the main actors in this area. On the same way, the regions of Algiers and Skikda in Algeria, and Tangier in Morocco are included on the most important shipping routes, for tourism, fisheries and other activities which make these areas less interesting for the location of the energy systems or floating energy islands. In this sense, it was considered important to analyze the visibility from the coast to the potential locations of equipment in the EEZ of both countries. For that end, a set of viewpoints were established - two near Ceuta, and the remaining along the coast and near the main coastal regions in Algeria. A viewshed tool included in ArcGIS Pro was used, having into consideration a minimum distance from the coast of 5 km. Based on these assumptions, a preliminary identification of feasible locations was performed for the coastal regions of Morocco and Algeria. Preliminary results are presented in Figure 4

The polygons representing the potential areas for development of RES and Energy Islands, have at this point a medium dimension – varying from 154 Km^2 to 600 Km^2. However, taking into consideration the preliminary analysis of these coastal regions, the location of renewable energy systems still needs further development and a large set of additional data to include in the analysis, especially on the details related with environmental protected areas.

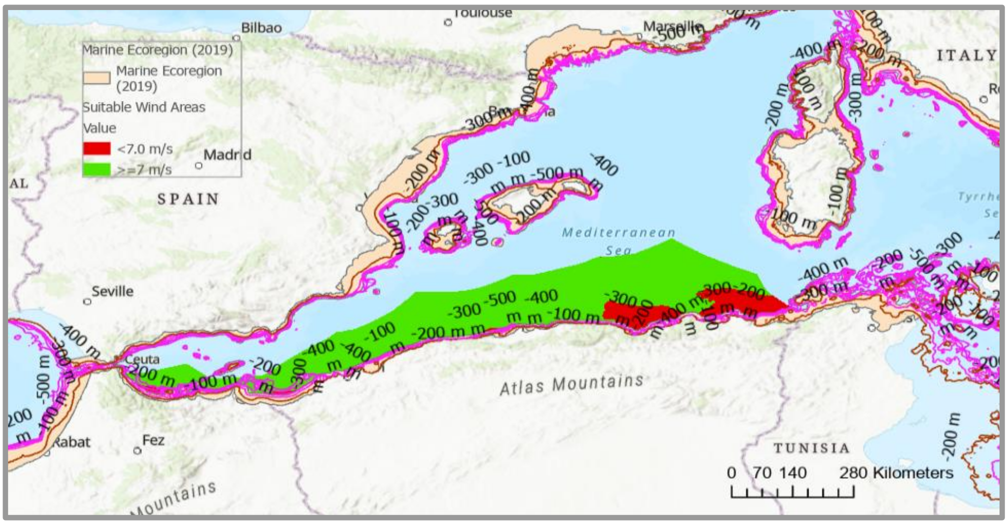

Figure 3. Representation of the areas with suitable wind speed values and bathymetry until (-500) m, along with the Ecoregion zone.

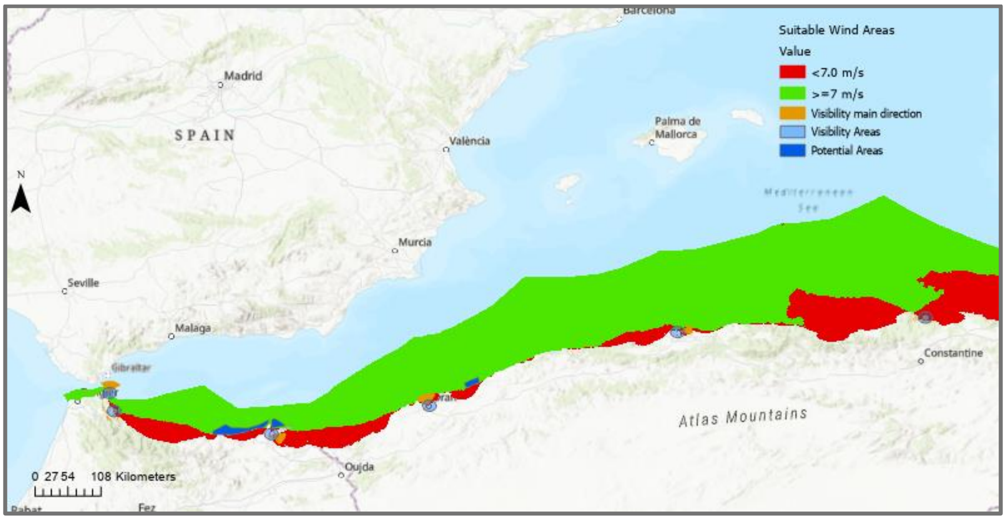

Figure 4. Viewpoints and main directions of an observer to the offshore region, and preliminary identification of the potentially interesting areas for renewable energy systems installation.

The preliminary areas (represented in blue in the image in Fig. 4) are included in the marine ecoregion. This ecoregion has different degrees of protection depending on the location and varies in the whole area under analysis, from 3% to 39%. However, the detail on the type of protection was not available for this study, with very few exceptions that are shown in the figure (in yellow), and there is the need to perform further analysis to evaluate the impact originated by the installation of these systems. In addition, the bathymetry outside this region corresponds to very high depth values (> (-200m) in most locations), and installation can be technically difficult.

4. Final notes and recommendations

Maritime Spatial Planning (MSP) plays a crucial role in supporting the sustainable development of offshore renewable energy systems, including wind, solar PV, and innovative solutions such as Floating Energy Islands. A preliminary analysis conducted along the coasts of Algeria and

Morocco highlights the strategic potential of these regions for deploying such systems. However, the absence of comprehensive environmental data across the entire coastline presents a significant limitation. Given the coastal bathymetry, floating technologies emerge as the most viable option, necessitating further investigation into seabed slope conditions.

In parallel, effective MSP must integrate consultations with key stakeholders from maritime and coastal socio-economic sectors, as well as local coastal populations, to ensure that designated zones align with both ecological sustainability and community interests. Locating Floating Energy Islands near the most populated coastal cities may offer the greatest utility and social benefit, by providing energy where demand is highest. However, further studies are needed, particularly in relation to biodiversity and the geotechnical properties of potential sites. Interconnection potential with nearby countries—such as Spain, Portugal, France, Italy, and Tunisia—should also be explored to support regional energy integration and grid stability. This initial assessment underscores the importance of advancing MSP frameworks in North African coastal states to enable informed, inclusive, and environmentally sound development of offshore renewable energy infrastructure.

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