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Introducing offshore wind energy in the sea space: Canary Islands case study developed under Maritime Spatial Planning principles

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ABSTRACT

In this study, we define a novel methodological approach for introducing Offshore Wind Energy (OWE) facilities into sea space, determining the most suitable locations with regard to the five clusters: oceanographic potential; environmental sensibility; restrictions related to marine conservation; Land–Sea interactions; and avoiding potential conflict with current maritime and coastal activities.

The methodology was tested along 1.583 km of the Canary Islands coastline and across more than 50 000 km^2 of related offshore areas. We have identified marine areas that have significant wind&depth potential, minimal impact on the marine environment, compatibility with marine conservation and conflict avoidance with operative economic maritime and coastal sectors (such as coastal tourism, fisheries, aquaculture, maritime transport, etc.). Suitability maps were developed with Decision Support System INDIMAR, a novel tool that analyses the OWE facilities' relationship with each cluster parameter, introducing weights calculated by an Analytical Hierarchy Process.

OWE development needs to find a balance of all five clusters reflecting on Ecosystem-Based Management components that should be mirrored in the Maritime Spatial Planning (MSP) strategy, including options with tradeoffs among sectorial growth, conflict prevention and environmental protection & conservation.

1. Introduction

Offshore Wind Energy (OWE) production in North Europe kicked off in the early 2000s, and the new installations coming up demanded new marine spatial areas. This emerging marine sector was strongly supported by the Renewable Energy Roadmap, which set an overall mandatory target of 20% for the proportion of renewable energy consumption by 2020 and zero greenhouse gas emissions by 2050 [1]. By 2018, installed OWE capacity was 18.4 GW (WindEurope 2019) on sea space, which has resulted in (potential) conflict not only with other energy sectors such as oil & gas, but also with traditional activities like fisheries, maritime transport and coastal tourism [2–4].

Through the last decade, a new policy instrument named Maritime Spatial Planning (MSP), mainly promoted under the umbrella of UNESCO, has been used to resolve future potential conflicts originating due to the introduction of OWE infrastructures, especially in Europe [3, 5]. The Intergovernmental Oceanographic Commission (IOC) of the UNESCO recognized the necessity of MSP processes at least in the Exclusive Economic Zones (EEZ) of maritime states and organized the first international workshop [6] in 2006 to underpin its worldwide implementation. As a result, the first international MSP initiative was developed, which provided a framework and a type of guidance, documenting worldwide applications and the current state of play. In parallel with the UNESCO initiative, the European Commission included MSP as one of the cross-cutting policies within the Integrated Maritime Policy (IMP, COM/2007/0575), to provide a more coherent and coordinated approach in resolving maritime issues. The pilot MSP projects were initiated in the Baltic and the North Sea, followed by numerous European initiatives in the Eastern Atlantic and the Mediterranean and Black Seas that should support European Member States (MS) to deliver the first milestone of the MSP process, a spatial plan to allocate maritime sectors and activities. In this sense, a spatial plan of the marine space, linking sustainable maritime use and preservation of the marine environment, is required by the Directive 2014/89/EU and needs to be delivered in 2021 by MS for all European Seas.

Over the last 10 years, MSP has been used as a planning policy within the North Sea and Baltic regions, mainly to avoid or mitigate conflict following the introduction of OWE facilities. OWE ventures in the North Sea have been successful due to the favorable conditions of the natural

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Abbreviations

AHP	Analytical Hierarchy Process
CDDA	Nationally Designated Protected Areas Inventory
EBM	Ecosystem Based Management
EEZ	Exclusive Economic Zone
EMODnet	European Marine Observation and Data Network
GES	Good Environmental Status
IUCN	International Union for Conservation of Nature
MPAs	Marine Protected Areas
MS	Member States
MSFD	Marine strategy Framework Directive 2008/56/EC
MSP	Maritime Spatial Planning
NetCDF	Network Common Data Form
NIS	Non-Indigenous Species
OWE	Offshore Wind Energy
QDs	Quality Descriptors
SDI	Spatial Data Infrastructure
SEA	Strategic Environmental Assessment

environment, especially the sea's shallowness [7–9], which allowed installation of wind parks more than 50 miles from the coastline, at less than 50 m depth. Sea depth and the related gradients are strongly related to the economic sustainability of the OWE sector [8,10]. For the wind industry to survive, it is vital that costs are significantly reduced for future projects through efficient support structure and design, cheaper fabrication, and quicker installation and maintenance, including the commissioning process [11].

The economic viability of OWE is changing quickly with the arrival of new technology: floating offshore wind structures, novel materials and new designs [12,13]. Europe's floating wind fleet is the largest worldwide (70%), with a total capacity of 45 MW by the end of 2019. Floating OWE facilities are already operative in Norway; Hywind Tampen is the largest OWE facility, with 11 turbines installed that produce a reported 88 MW. France has four testing sites that test different technologies, reporting more than 100 MW. UK and Portugal have constructed one floating OWE site each, reporting 50 MW and 25 MW, respectively. Most of these initiatives are still demonstration projects, testing different floating concepts with the objective of reducing cost or upscaling previous demonstrators (WindEurope 2019).

The Canary Islands, a Spanish archipelago of volcanic origin located in the Central East Atlantic Ocean, have huge potential for renewable energy, with more than 400 MW installed on land, mainly near the shores. Potential is even higher in the nearby marine areas (Fig. 1), as there are no offshore physical barriers [14,15], and in the channels between the islands where the wind strength increases due the Venturi effect [16] (Fig. 1). Nevertheless, the potential for OWE is hindered due to the geomorphology of these volcanic islands, with sea bottoms showing, in most cases, steep gradients and reaching great depths near the coasts. Thus, even with the technology developed within the oil and gas sector, installing turbines more than one mile from the coastline is considered not economically feasible, as the construction and maintenance costs would be prohibitively high. In recent years, though, with the emergence of new floating technologies, the potential for OWE at the Canary Islands has improved vastly, as there are novel possibilities of installing facilities in deeper waters and going to offshore areas where wind strength is also more elevated. At the moment the Canary Islands are in the pilot phase, testing the floating technology with a WIP10+ European funded project. Additionally, the Wind2Power 1:6 scale prototype of 200 kW was successfully tested at The Oceanic Platform of the Canary Islands (PLOCAN) site (WindEurope 2019, PLOCAN website[1]).

Current developments and the results of the demonstration projects suggest that the OWE sector will have considerable potential for growth in the waters surrounding the Canary Islands. Diverse studies have been carried out till date, on exploitation and site selection for the offshore wind facilities at the Canary Islands, assessing potential based on the wind strength and including the restriction factors [14–17]. Introduction of the new sector needs to be studied and planned based on the offshore wind potential [10,18], but also including analysis to avoid conflict with the currently operative sectors and to reduce or, if possible, even avoid pressures on the marine environment [7,19,20].

The Canary Islands boast more than 1500 km of coastline and almost 450 000 km^2 of Exclusive Economic Zone (EEZ). In the framework of the current process of MSP, these numbers point to the need for efficient methods to at least understand the implications of the development of emerging maritime sectors; for instance, the OWE sector under the Ecosystem-Based Management (EBM) approach could cover extensive areas, while minimizing conflict with the existing activities and the environment.

As part of the research objectives of an EU Interreg PLASMAR project (MAC/1.1a/030), we have studied the implications of the OWE sector's arrival and development in the waters of the Canarias archipelago. We analyzed its environmental suitability and also identified the potential conflicts arising from this emerging Blue Growth sector. We reviewed the state-of-the-art on OWE pressures and possible mitigation actions for discovering potential conflicts and avoiding them. For this task we used a newly developed Decision Support System (DSS) tool, INDIMAR, which identifies the most suitable location in the marine realm for the OWE sites, taking into consideration the marine environment, potential conflicts with current maritime and coastal uses, as well as economic operability within the framework of the EBM approach.

In this contribution, we have assessed the fitness and predictability of the INDIMAR tool to enhance Blue Growth policies at a regional level, in this case determining the potential zoning and suitability of specific marine areas for OWE around the Canary Islands. At the same time, we did a preliminary evaluation of the potential conflict of OWE with other marine activities (associated with extant or emerging maritime sectors), with the involvement of diverse maritime actors at expert and stakeholder levels.

2. Materials and methods

2.1. Data collection

To make data collection more efficient, avoiding redundant data sets and making (spatial) information manageable, within the PLASMAR project the required data sets were organized within five clusters: Data on marine environment structured following Good Environmental Status (GES) of Marine strategy Framework Directive 2008/56/EC (MSFD); Spatial data and information on Marine Protected Areas (MPAs); Coastal Land use; Oceanography data; information collected on Current Maritime Activities.

Data were compiled from European data initiatives such as the European Marine Observation and Data Network (EMODnet), the Copernicus Earth observation programme, or the Spatial Data Infrastructure (SDI) of the European Environment Agency; on the national level information was harvested from SDI Spain and the Spanish Oceanographic Institute; and local data gathered from regional and island administrations, research projects and local data infrastructures (Spatial Data Infrastructures CANARIAS, University Las Palmas de Gran Canaria

[1] https://www.plocan.eu/en/the-w2power-prototype-test-is-successfully-completed-in-the-plocan-test-site/.

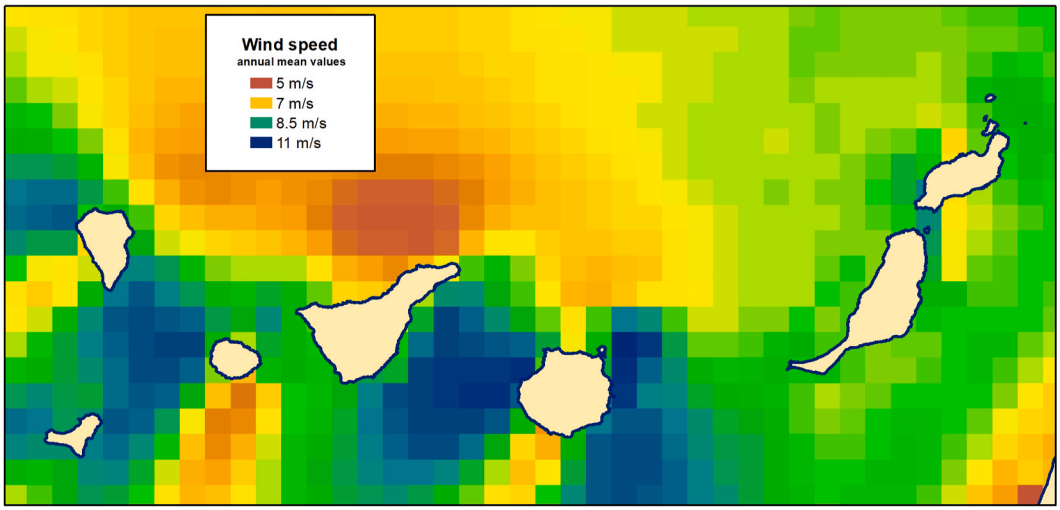

Fig. 1. Wind potential in Macaronesia and the Canary Islands - obtained calculating arithmetic mean for Copernicus Marine two-year time daily series, product delivered by the PLASMAR project (MAC/1.1a/030).

Geoportal, Pilotaje del Litoral Canario, etc.).

Each parameter included within the five clusters was analyzed for its relevance to OWE, and in the cases where they were relevant, the quantitative relationship was identified. These analyses and weights were delivered reviewing available state of the art, scientific literature and technical reports, mainly from the North of Europe (North Sea and Baltic), where OWE parks are operational for the past 20 years, as well as taking into consideration the experts' and stakeholders' inputs.

2.2. Marine environment data listed by the Marine Strategy Framework Directive following Good Environmental Status

Data on the marine environment are structured following the Marine Strategy Framework Directive 2008/56/EC (MSFD), which described the Good Environmental Status (GES) of the European marine waters using 11 Quality Descriptors (QDs) and 39 related Criteria Elements.

The information on benthic habitats for the Canary Islands is the integration of two data sets. The first data set—Canary Islands benthic habitats 0–50 m depth—was extracted from *Ecocartográficos* studies, environmental and ecological surveys delivered by diverse under-contract consultancies for the Spanish Ministry of Environment during the period 2000–2008. The second data set on marine habitats used is the harmonized EMODnet product,[2] a data set with extensive coverage (beyond the Canary Islands EEZ), though not rich in detail. Both data sets are harmonized applying INSPIRE Directive 2007/2/EC European spatial information standard, data model on Habitats & Biotopes, which resolves semantic issues with benthic habitats' common classification and facilitates integration.

As the species distribution data of marine birds, turtles and mammals was unavailable, we used the considerable information associated with the Canary Islands Natura 2000 Network of Marine Protected Areas. For the analysis, it was assumed that there is high probability of species appearance in areas where species conservation is targeted by the specific Natura 2000 protected marine area.

During the first cycle of implementation of MSFD, the Spanish Ministry of Environment published spatial data within the Spanish SDI,[3] including assessments of the Non-Indigenous Species (QD 2); Sea floor Integrity (QD 6); Hydrographic alteration (QD 7); accumulation of Marine debris (QD 10); and areas potentially impacted by Marine noise (QD 11). These spatial data sets—assessments, covering the entire EEZ of Canaries, delivered within MSFD implementation—were included in the data collection and used in the study for OWE suitability analyses.

2.3. Spatial data and information on MPAs

For the analysis of suitability within MPAs, we used two databases, both provided by the European Environment Agency. The first is the Nationally Designated Protected Areas Inventory (CDDA), covering the whole of Europe and updated annually. CDDA has a Protected Area Categories System defined by the International Union for Conservation of Nature (IUCN), divided into seven categories according to their management and protection objectives [21,22]. The second database used is the Natura 2000 Network, listing protected areas designated under the Birds 79/409/EEC and/or Habitat Directive 92/43/EEC, protecting marine birds or/and marine species or/and marine habitats. From both data sets we extracted MPA areas and protected coastal land areas, including the objectives and targets of conservation.

2.4. Coastal Land use

The potential land–sea interactions involving OWE facilities and coastal land use were analyzed. During the data collection process, it was difficult to find a standardized and detailed *Land use* data set for the whole archipelago. Still, for the purpose of mapping coastal areas we used the European Land cover CORINE 2018 data set, complemented by regional data sets available at local SDIs (IDE Canarias,[4] Pilotaje del Litoral Canario[5]). CORINE 2018 covers the entire Canary Islands archipelago, and is available as a harmonized product with standard classification for the whole of Europe. For the purpose of this study, we analyzed harbor areas, urban areas (including coastal tourism areas), industrial or commercial units and beach areas; agricultural and forest areas were considered but not included in the analysis.

2.5. Oceanographic data

Data collection for the oceanographic data was straightforward, as

[2] The European Marine Observation and Data Network (EMODnet); www.emodnet.eu.

[3] https://www.idee.es SDI Spain, Infrastructure de Datos Espaciales España (IDEE).

[4] https://www.idecanarias.es SDI Canarias.

[5] https://www.pilotajelitoralcanario.es Coastal SDI Canarias.

Canary Islands EEZ is covered by harmonized Copernicus Marine Environment Monitoring Service (CMEMS) products. Downloaded products from CMEMS were: coverage time series on wind, currents and waves observations, that should be considered within the Oceanography data cluster. CMEMS products are coverage time series, provided in network Common Data Form (NetCDF). NetCDF is a format for storing multidimensional scientific data, where variables (in our case wind, currents and wave observations) are displayed through time in two-dimensional space [23]. To manage coverage time series, we calculated basic statistics as maximum, minimum, percentiles (10, 90) and arithmetical mean. In this way we statistically summarized several large time series coverages into one single coverage file [24–26].

For wind speed, the WIND_GLO_WIND_L3_NRT_OBSERVATIONS _012_002 – CMEMS product, which contains daily gridded near-real time scatter-meter wind vector, was supplemented with wind stress components, wind stress amplitude and wind stress curl and divergence, the observations for which were initiated on January 01, 2016 (Copernicus quality information document on wind observations, 2019).

For wind time series, we used bi-annual average wind speed, basic statistics—calculated on more than 700 values series—per analyzed cell ($0.125^\circ \times 0.125^\circ$, that within the longitude and latitude of Canary Islands is around 14 km^2). We assumed that annual average statistics, as currently often used for the identification of OWE locations ([10,19,27]), are appropriate for the analysis as include and affected by outliers (e.g. storm wind events).

For bathymetry we used the GEBCO_2020 global product, combined with local data extracted from the previously mentioned *Ecocartográficos* studies, providing detailed bathymetry data set till 50 m depth.

2.6. Current maritime activities

The data on current maritime activities were mainly compiled from regional and national databases. Most of the information on current maritime activities (operative aquaculture and designated areas, artificial reefs, wrecks, submarine cables, whale watching, diving, military areas, research areas, seaweed cultivation, nautical sports, etc.) was collected from the regional spatial data infrastructures, SDI Canarias and Coastal SDI Canarias. Data on fisheries were directly provided by Instituto Español de Oceanografía. For maritime traffic density, we used the Human Activities EMODnet European product, *Vessels density maps* based on the ship reporting data of the Automatic Identification System, as collected by coastal stations and satellites.

2.7. DSS INDIMAR tool, parameter weights and OWE suitability calculation

The collected data were introduced into the INDIMAR spatial data Decision Support System (DSS) for sectoral zoning and MSP purposes. In the framework of the PLASMAR project, DSS INDIMAR was designed by the ECOAQUA Institute as a Geographical Information System (GIS) web application. To reduce time of computing and facilitate post processing, we decreased the area analyzed from the overall Canaries Exclusive Economic Zone (EEZ) to an area up to 30 km From the coastline around each of the islands. This decision, which made our analyses more rapid and efficient, was justified as most of the maritime activities are confined within a 30 km coastal belt (except for inter-island maritime transport), due to the great depths around and between the islands. Then, the Canary Islands areas included in the analysis were divided into fragments, based on 10" arc square cells (about 300 m^2). Each cell includes encoded spatial information on the marine environment; MPAs; Land–Sea interaction; oceanography; and current maritime uses.

DSS INDIMAR was used for calculating the suitability (R) of OWE facilities' location, classified from 0 to 10, where R = 0 means absolutely unsuitable location, and R = 10 is the most appropriate site. Suitability (R) is calculated for each cell, as a sum of parameter weights and sum of parameter contributions:

$$R = \Sigma\, pWi^* CVi$$

Where contribution (CV) can be positive (1), neutral (0) or negative (−1), excluding (R = 0), with the condition that:

$$\Sigma\, pWi = 100$$

After inclusion of data for parameters relevant for OWE facilities, DSS INDIMAR was used for analysis of:

1. Potential for OWE related to the oceanography parameters (Table 1);
2. Suitability based on environmental sensibility, following MSFD GES (Table 1);
3. Potential combination/exclusion of OWE facilities within MPAs (Table 1);
4. Land–sea interaction, avoiding conflict and seeking compatibility with land activities in the coastal areas (Table 1);
5. Identifying suitable areas, including co-use and avoiding conflict with existing maritime activities (Table 1).

The ultimate result was a superposition of all previous five cluster suitability analyses, applying all previously used criteria to find the most suitable locations for OWE facilities in the Canaries. Still, one of the hardest issues to address within this study was to determine weights, the significance of each parameter included in the INDIMAR application. Although we analyzed the relation of each parameter with the OWE sector, this did not answer the question of which cluster would have more significance, nor help define the exact parameter weights. To resolve this problem, we adopted the Analytical Hierarchy Process (AHP), a technique used in engineering to solve complex problems, including spatial planning for renewable energy projects [19,28–30]. AHP is one of the most widely used multicriteria decision-making techniques, and its use is based on relatively easy procedures as well as on the possibility of evaluating any inconsistency [20,31].

3. Results

3.1. The Canary Islands' OWE potential based on physical oceanographic parameters

Average wind power at 50 m height, which exceeds 8,5 m/s, is assumed as a high-potential OWE resource, in terms of economic sustainability [10,19]). A number of European atlases point to wind resources including values higher than 8,5 m/s for the coastal zone and offshore as excellent, and as an argument for the development of OWE facilities [32–35]. Marine Copernicus Observation values that we managed for this study were obtained by the scattering technique, which provides wind speed on the sea surface.

Wind speed values at 50 m depth are significantly higher than on the surface [36–38], and can be calculated applying the wind profile power relationship formula, simplifying atmospheric conditions [39]. For this study we used the values provided by the Marine Copernicus product, calculating average wind speed values for the surface, which ranged from 5,98 m/s to 11, 46 m/s, classified as follows:

5.98–7.00 m/s – No potential.
7.00–8.50 m/s – neutral potential.
8.50–11.46 m/s – High potential.

Sea depth is another key criterion that mainly affects the cost of turbine installation. The foundation cost almost triples for an increase in depth from 10–20 m to 40–50 m. The offshore wind turbine installations in Europe had an average sea depth of 20 m and 22.4 m in 2013 and 2014, respectively [40,41]. In terms of economic viability for offshore wind farms, a monopole foundation is suitable for depths up to 35 m, jacket type till 50 m and for deeper foundations an advanced jacket is needed, while floating technologies are currently under development [38]. For this study we classified depth till 150 m as having positive

Table 1
Five data clusters, structured to facilitate data collection required for OWE analysis: Data on marine environment structured following Good Environmental Status (GES) of Marine strategy Framework Directive 2008/56/EC (MSFD); Spatial data and information on Marine Protected Areas (MPAs); Coastal Land use; Oceanography data; collected information on Current Maritime Activities. Structure used within the PLASMAR project (MAC/1.1a/030) for data collection.

Marine Environment Data CLUSTER: Structured following Marine Strategy Framework Directive 2008/56/EC GES
1. Benthic habitats (Quality Desriptor 1):
- DATASET Hábitats Ecocartográficos Armonizados EUNIS;
- EMODnet EUSeaMap (2019) Broad-Scale Predictive Habitat Map - EUNIS classification
2. Sensitive marine species distribution (Quality Desriptor 1):
- Marine birds: Canary Island Natura 2000 Network
- Marine turtles: Canary Island Natura 2000 Network
- Marine mammals: Canary Island Natura 2000 Network
3. Non Indigenous Species distribution (Quality Desriptor 2):
- Assessments of the Non Indigenous Species for first cycle of MSFD, Canarias
4. Sea floor Integrity (Quality Desriptor 6):
- Assessments of the Sea floor Integrity for first cycle of MSFD, Canarias cycle of MSFD, Canarias
5. Hydrographic alteration (Quality Desriptor 7):
- Assessments of the Hydrographic alteration for first cycle of MSFD, Canarias
6. Accumulation of the maine debris (Quality Desriptor 10):
- Assessments of the Accumulation of the maine debris for first cycle of MSFD, Canarias
7. Marine noise (Quality Desriptor 11):
- Assessments of the Accumulation of the maine debris for first cycle of MSFD, Canarias

Oceanographic data CLUSTER
1. Copernicus Marine Environment Monitoring Service products
- wind speed (surface observation)
- currents speed
- waves significnat hights
2. Bathymetry:
- Ecocartogarficos (<50m of depth)
- GEBCO_2020 global product (>50 of depth)

Coastal Land Use CLUSTER
1. Coastal land use: European Land cover CORINE data set 2018:
- harbour areas
- urban areas
- airport areas
- industrial or commercial units
- agricultural areas
- beaches, dunes and sands
- forest areas
2. Dsitance to the coast line

Marine Conservation CLUSTER: Spatial data and information on Marine Protected Areas
1. Nationally Designated Protected Areas Inventory (CDDA)
- categories according to their management objectives
2. European Natura 2000 descriptive database
- target of marine conservation

Current Maritime Activities CLUSTER
1. Localy collected data sets:
- operative and designated aquaculture areas
- artificial reefs
- wrecks
- submarine cables
- whale watching
- scuba diving sites
- military areas
- research areas
- seaweed cultivation
- submarine outfalls
- nautical sports
2. Fisheries data, Instituto Español de Oceanografía
3. **Maritime traffic density**: Human Activities EMODnet product, Vessels density maps

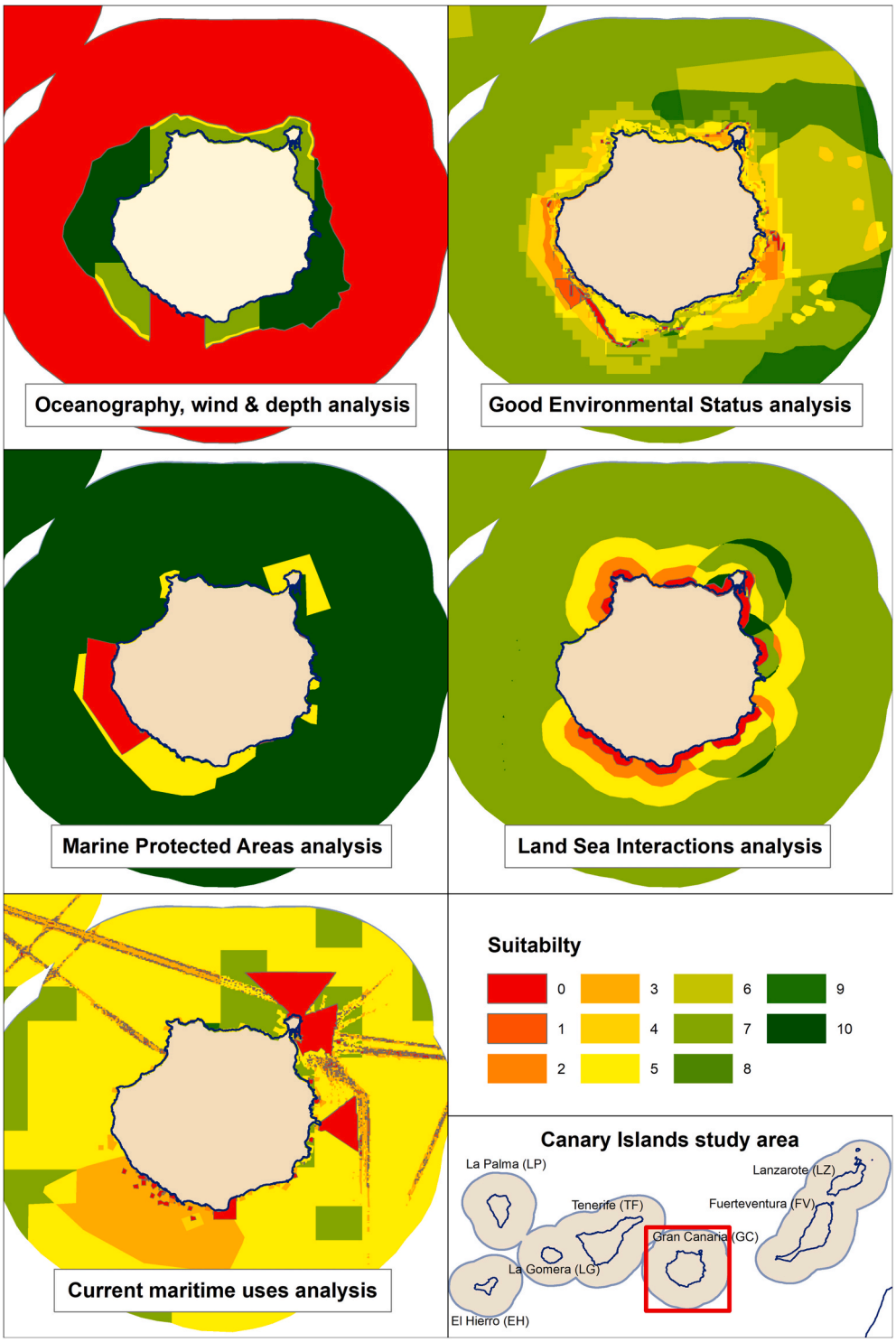

Fig. 2. OWE suitability analyses delivered by Decision Support System INDIMAR (Gran Canaria Island detail): Wind & depth potential; Suitability based on environmental (GES) sensibility; Marine Protected Areas sensitivity analysis; Land–Sea Interaction analysis; Current maritime uses conflict/suitability analysis. Delivered with PLASMAR project (MAC/1.1a/030).

potential, as most of the offshore wind demonstration projects are at 100–150 m (WindEurope 2019). We classified depths from 150 to 300 m as having neutral potential, as these require higher cost of installation and maintenance, and beyond 300 m as restrictive.

After including wind speed and bathymetry parameters and the related ranges, we developed the OWE potential analysis for the Canary Islands. Although we performed an overall analysis for the entire Canaries archipelago, in Fig. 2 it is possible to observe the OWE potential based on the physical oceanographic data set for the Gran Canaria Island. We did not include waves and currents, even though the relevant data were available, as these two parameters are mostly related to the design of OWE floating structures, which are still in the pilot, testing and demonstration phases of development [42].

3.2. MSFD Good Environmental Status suitability

Within project PLASMAR, more than 100 technical and scientific recent reports were analyzed, to determine the state of the art and to understand the major OWE environmental issues with marine environment. For this study we were following the MSFD GES framework; as a checklist we followed 11 quality descriptors (QD) and the related 39 criteria elements to deliver a detailed review of scientific and technical reports [43].

OWE turbine tower masts and foundations attract marine organisms, acting as an artificial reef and consequently increasing the benthic biodiversity and conceivably drawing pelagic species. In the soft bottom substrates, foundations and turbine masts are providing new and different habitats, which is considered as habitat gain that results in increased species abundance close to OWF foundations [44–49]. Polygons with EUNIS classification listed as special areas of conservation within the Habitat Directive 92/43/EEC were restricted for OWE. Polygons with broad classification (e.g., A5.26 - Circalittoral muddy sand) were assessed based on substrate; for soft substrates we included positive contribution due to the expected artificial reef effect [50–52], while for hard ones we expect higher impact, especially in the construction phase [53,54], and therefore we included negative contribution.

Based on the QD1 biodiversity list of sensitive species, birds are the unique group that show increased mortality during the operative phase of OWE [55–59]. The species distribution of mammals, birds, cephalopods and fish is impacted mainly during the construction phase [60–62]. Therefore, Natura 2000 areas designated for the protection of marine birds and/or turtles and/or mammals were assumed as being areas with high profile for conservation of those targeted species, so these polygons were included in the analysis applying negative contributions.

Modified habitats such as the wind turbine structures—similar to artificial reefs—can be colonized by Non-indigenous species (NIS) – QD2. OWE maritime structures can indirectly increase vectors enabled by anthropogenic introduction (ballast waters, fouling on ship hulls, marine debris, etc.) or natural introduction by means such as currents and loop current eddies [51,52,63,64]. To anticipate the potential of increasing distribution vectors related to the OWE facilities' location, we used MSFD Quality Descriptor 2 assessment maps on NIS distribution status for the Canary Islands. We included areas with presence and distribution range as negative contribution in the GES analysis.

OWE impact on commercial fish stocks (QD3) includes both negative and positive effects [51]. Wind turbines, both fixed and floating facilities, may act as artificial reefs and/or fish aggregating devices that concentrate marine fish and facilitate their capture [44,65,66]. Furthermore, OWE facilities may create fishery exclusion zones acting as marine protected areas where trawling and gillnetting, for example, are prohibited [67], and have been shown to lead to higher abundance and larger specimens of certain fish, including commercially-exploited species [68–70]. To include this parameter in GES analysis, it was necessary to carry out a detailed study of the OWE floating platform facilities' impact on the fish stocks. Because the floating technology is in the development/pilot phase, these types of studies are not available. Additionally, commercial species stocks' distribution data were not available; moreover, there is uncertainty about the policy decisions on whether commercial fisheries will be allowed within designated OWE areas.

Table 2
Significance parameters/clusters—defined weights based on pairwise comparison, for three groups: researchers involved in PLASMAR project (MAC/1.1a/030),; external experts; maritime sectors' stakeholders (MarSP project workshop).

Cluster	Parameter	Weights		
		PLASMAR	External experts	MSP stakeholders
GES	Biodiversity (Benthic habitats)	11.65	7.97	7.06
	Biodiversity (Mammals)	5.29	3.02	3.17
	Biodiversity (Birds)	16.11	19.08	12.44
	Non-indigenous species	2.33	0.92	1.08
	Population of commercial fish species	10.83	6.97	1.84
	Energy, including underwater noise data	9.63	4.92	3.85
MPA	Natura 2000 Network	7.71	12.9	26.42
Land Use	CORINE	3.17	1.8	8.44
	Distance to the coast	1.56	0.98	1.69
Oceano-graphy	Depth/bathymetry	2.74	3.04	2.99
	Wind	5.73	5.15	20.95
Current	Aquaculture facilities	1.65	1.66	0.23
Maritime Activities	Fishery areas/efforts	7.91	3.57	0.59
	Maritime traffic lanes/intensity maps	5.91	7.71	0.8
	Aggregate extraction (Dredging/Sand extraction)	1.52	0.71	2.39
	Cables	3.65	7.57	2.38
	Military area	1.31	11.19	3.42
	Seaweed cultivation	1.29	0.84	0.27

Extant studies show that a number of the ecosystem processes and properties are sensitive to changes generated by OWE installations [71], and can alter food webs – QD4. Food web guild increment/decrement could have a significant impact on the ecosystem [58,59,72–75]; even these relationships need to be further researched, especially with empirical studies and/or ecosystem modeling that can identify OWE impact expected in the biogeographic conditions of the Canary Islands.

Reported impacts for shallow seas (Baltic and North Sea) related to the eutrophication status (QD5) and local downwelling processes that can generate a turbulent wake, contributing to vertical mixing and an increase of nutrient concentrations [75,76], are negligible due to the oligotrophic state and hydrodynamics of the Canary Islands.

The surface area of the OWE foundations and related materials, such as submerged electric cables and other support structures, does not occupy a large extent of the sea floor [48,51,77,78]. Adequate selection of the seabed substrate (sand, gravel, etc.) for foundations can minimize impact and permanent change (QD6). Rocky substrates may require more complicated engineering solutions that can have a higher impact and cause potentially greater and more significant permanent changes. New types of foundations and anchoring solutions for floating base turbines will be required, so the impact on the seabed and permanent change needs further research. To include QD6 in the GES analysis, we used the EMODnet habitat product that includes substrate type information, favoring a soft (with positive contribution) rather than hard (with negative contribution) substrate. For the QD6 suitability analysis, MSFD assessment on sea floor integrity data set is also included,

Table 3
OWE suitability analysis applying project PLASMAR profile (km2).

ISLAND	Suitability level										
	0	1	2	3	4	5	6	7	8	9	10
LANZAROTE	42560.09	13.32	32.86	44.20	42.96	45.42	92.26	38.90	0.08	0.00	0.00
FUERTEVENTURA		14.26	50.76	441.66	395.32	222.55	213.23	61.73	12.17	0.00	0.00
GRAN CANARIA		0.65	30.48	39.12	129.85	202.56	281.86	70.23	0.14	0.00	0.00
TENERIFE		6.13	13.81	22.69	72.84	92.40	56.94	7.86	0.00	0.00	0.00
LA GOMERA		1.06	0.65	1.67	2.57	52.12	21.10	0.00	0.00	0.00	0.00
LA PALMA		0.00	0.00	26.43	23.56	28.09	20.10	8.14	4.37	0.00	0.00
EL HIERRO		0.00	0.00	3.22	7.44	66.22	20.53	5.91	2.93	0.00	0.00
TOTALS	42560.09	35.42	128.55	578.98	674.55	709.36	706.02	192.78	19.68	0.00	0.00

Table 4
OWE suitability analysis applying external experts profile (km2).

ISLAND	Suitability level										
	0	1	2	3	4	5	6	7	8	9	10
LANZAROTE	42554.48	3.65	15.01	58.96	43.38	23.20	35.56	108.64	24.22	0.00	0.00
FUERTEVENTURA		10.02	31.57	181.96	697.85	245.01	99.43	110.65	35.88	0.00	0.00
GRAN CANARIA		0.49	8.05	48.72	60.14	31.65	186.38	410.14	9.89	0.00	0.00
TENERIFE		2.97	6.45	24.74	12.13	21.06	127.10	73.48	6.61	0.00	0.00
LA GOMERA		1.06	0.42	0.23	2.42	0.08	12.37	61.75	0.00	0.00	0.00
LA PALMA		0.00	0.00	15.81	29.62	4.67	24.51	27.96	8.30	0.59	0.00
EL HIERRO		0.00	0.00	0.91	8.03	2.94	62.54	24.53	7.28	0.00	0.00
TOTALS	42554.48	18.18	61.50	331.33	853.57	328.60	547.88	817.15	92.17	0.59	0.00

Table 5
OWE suitability analysis applying MSP stakeholders profile (km2).

ISLAND	Suitability level										
	0	1	2	3	4	5	6	7	8	9	10
LANZAROTE	42592.80	56.97	47.25	18.18	0.00	0.00	19.79	94.71	62.63	0.00	0.00
FUERTEVENTURA	0.00	158.82	726.33	265.78	0.00	0.00	13.95	135.17	97.49	1.51	0.00
GRAN CANARIA	0.00	65.43	32.85	7.89	32.22	0.05	25.27	109.53	62.90	311.27	105.15
TENERIFE	0.00	25.61	11.46	1.40	0.00	0.92	59.92	129.49	36.78	1.41	0.00
LA GOMERA	0.00	0.52	0.00	1.67	0.76	0.00	1.82	0.66	0.00	71.59	0.00
LA PALMA	0.00	3.59	25.06	12.34	6.05	0.51	0.00	10.23	18.76	21.48	13.05
EL HIERRO	0.00	0.00	0.00	3.18	7.60	0.81	0.00	45.53	1.65	33.82	14.00
TOTALS	42592.80	310.94	842.94	310.43	46.62	2.29	120.74	525.32	280.20	441.08	132.19

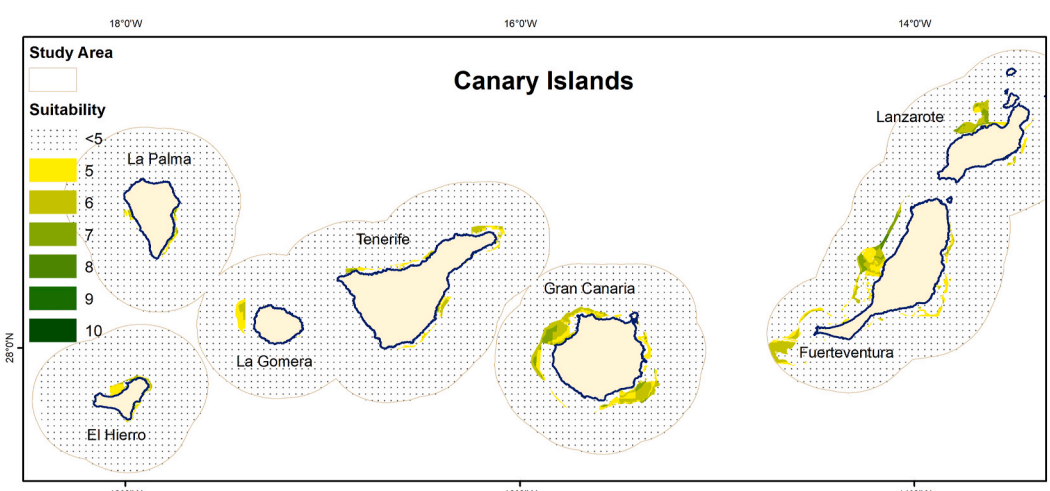

Fig. 3. OWE suitability analysis for Canary Islands, delivered by DSS INDIMAR, applying project experts profile, PLASMAR project (MAC/1.1a/030).

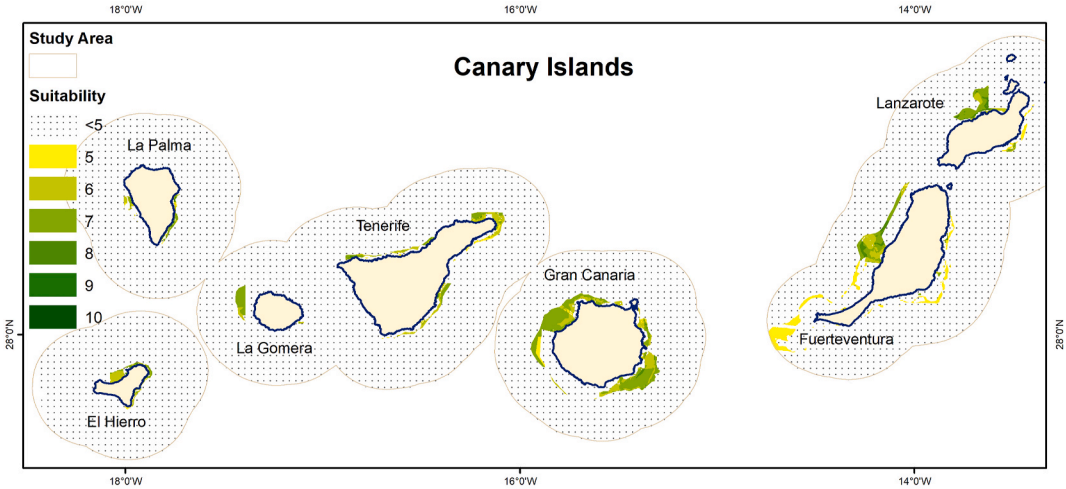

Fig. 4. OWE suitability analysis for Canary Islands delivered by DSS INDIMAR applying external OWE experts profile, PLASMAR project (MAC/1.1a/030).

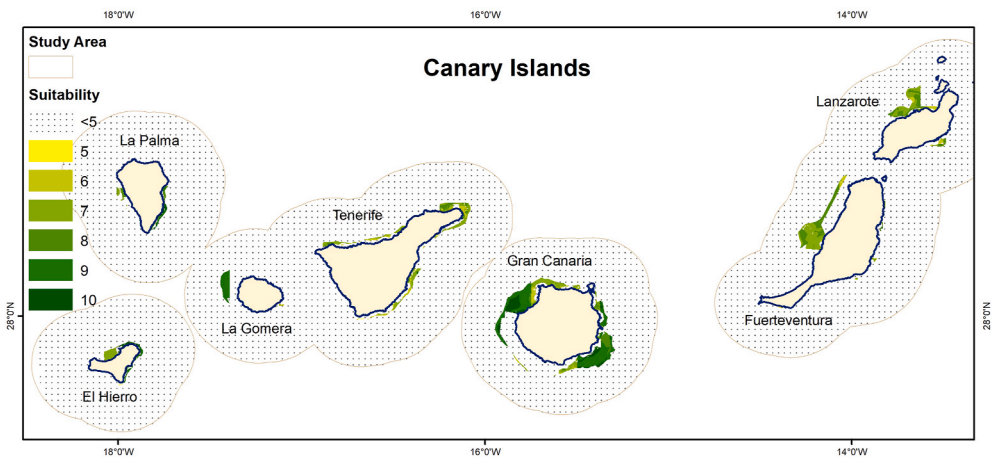

Fig. 5. OWE suitability analysis for Canary Islands delivered by DSS INDIMAR applying MSP stakeholders profile, PLASMAR project (MAC/1.1a/030).

avoiding any cumulative impact on the seabed.

Previous studies from the Baltic and North seas suggest that OWE parks/facilities can change the hydrographical conditions—QD7 including currents, waves, turbidity and salinity—which can affect marine ecosystems in the shallow and coastal areas [50,75,79–82]. Their Impact in the Canary Islands is not considered significant, mainly due to the depth gradients of the analyzed offshore and coastal areas.

In the construction phase and during the maintenance operations, the risk of acute pollution (oil spills) or introduction of contaminants into the environment due to an accident or collision is increased. Within the review, no technical reports or scientific publications on further relationship of OWE facilities to levels of contaminants in the environment (QD8) or/and in fish and seafood (QD9) were either found or considered.

No technical reports were found in the review process, concerning any link between marine litter/micro-litter (QD10) and OWF in either the construction or the operational phases. Still, decommissioning processes after the life cycle of the OWF can be a possible source of marine litter. As the first ever decommissioning of an offshore wind energy project took place only in 2016, until now there are not enough reports that can confirm this as a real threat. A study on sustainable decommissioning, delivered by Topham and McMillan [83], examines difficulties in foundations' decommissioning. Turbine foundations during the operative phase develop new habitats that attract pelagic and benthic species. A decommissioning process that involves abandoning the foundation is less stressful than extracting it from the seabed. Areas assessed with litter impact (MSFD) were included in the analysis with negative contribution.

Impulsive noise coming from OWE has three phases: the short-term potential impact during pre-construction; the short-term intensive impact during construction; and the physiological and/or masking effects that may occur over a long period while the wind farm is in operation [53]. During the pre-construction phase, there is a risk to marine mammals, sea turtles and fish, particularly due to collision and disturbance from vessel movements associated with surveying and installation. During the construction phase, noise and vibration from pile driving and other works may affect the animals over a large area [60–62,84]. The noise impact on marine mammals is more severe during the construction of wind farms than during their operation [85]. During operation, underwater sound levels are unlikely to reach dangerous levels or mask acoustic communication of marine mammals [86,87], and this is generally considered an insignificant impact on the marine environment [50,88,89]. We included areas that are assessed as having elevated noise potential (within MSFD implementation QD11), with negative contribution.

In Fig. 2 can be observed (Gran Canaria island) integrated suitability analysis for all Quality Descriptors. We assessed suitability considering environmental sensitivity for OWE facilities location, based on the MSFD GES and applied to the whole Canary Islands archipelago.

3.3. MPAs' sensitivity

OWE facilities under certain conditions may even be more efficient means of conservation than ordinary marine protected areas. Offshore wind farms can create a refuge for benthos, fish and marine mammals. On the other hand, offshore wind farms can negatively affect several species of seabirds, essentially those occupying preferred feeding or wintering grounds. We assumed co-locating OWE farms with MPAs scenarios, as they contribute to the energy needs of society and to economic development, and provide biodiversity protection [90].

For analysis of suitability within MPAs (Fig. 2, Gran Canaria Island detail), we used two data bases, CDDA and Natura 2000, compiling protected areas designated under the Birds 79/409/EEC and/or Habitat Directive 92/43/EEC. CDDA has a Protected Area Categories System defined by the International Union for Conservation of Nature (IUCN), divided into seven categories according to their management objectives. According to IUCN, renewable energy generation is suitable in the categories IV, V and VI.

Applying Natura 2000 data, we excluded all the areas that are designated for any marine bird species' conservation. For all the other Natura 2000 sites, we included the possibility of building OWE parks, as they can provide a physical barrier that disables a number of fishing practices and other maritime uses [90].

3.4. Coastal Land use suitability, applying land–sea interactions

For the purpose of mapping coastal area activities, we mainly used the European Land Cover CORINE data set based on the photo-interpretation of satellite images. Land–sea interactions, suitability and possible conflicts with coastal land activities are analyzed and can be observed using maps (Fig. 2, Gran Canaria Island detail).

Using the CORINE Land Cover data set, we analyzed potential OWE distance to the ports and harbors, based on the studies delivered for the North Sea [91], adapted to the environment of the Canary Islands, excluding marine space from port areas till 1000 m, and including negative contribution till 3000 m, to avoid issues with maritime traffic. Distances from 3 km to 10 km apart were classified positive, as being distances appropriate for the maintenance operations for smaller OWE facilities within the islands.

For coastal urban areas (including areas with heightened tourism development) and those with beach, sand and dunes, based on the landscape impact we excluded coastal waters within 2000 m; we classified the first 5000 m as providing a negative contribution and those 10 000 as neutral [92]. The area beyond 10 000 m was classified as positive due to low conflict with coastal activities based on the visual impact.

Coastal waters till 5000 m in front of industrial areas were included in the analysis with positive contribution.

The cost of electricity transmission cable installation in coastal areas increases tremendously with distance [41,92]. We Included distance to the coast as a parameter related to the sea cables' extension, which was classified as positive within the first 1000 m and beyond that as neutral.

3.5. Conflict assessment with current maritime uses

Many authors of MSP studies include conflict assessment analysis, using the matrixes which superpose the maritime activities, identifying potential conflicts, possible co-use or even multi-use [93,94]. This exercise was also delivered for regional archipelagic conditions in the MarSP project, gathering local stakeholders in a set of 4 workshops [95].

Applying conflict assessment analysis, for OWE we excluded areas with operative aquaculture sites, cable areas, military areas and wreck areas. Fishing areas data set was included in the analysis, where we considered possible multi-use with conflict potential. Areas with high maritime traffic density, proposed areas for aquaculture sites, diving sites, whale watching activities and nautical sports, including surfing, windsurfing and kitesurfing, were included in the analysis as areas with conflict potential (Fig. 2, Gran Canaria Island detail).

3.6. Cluster & parameter significance: project, OWE experts' and stakeholders' weights analyses

To superpose all the delivered cluster suitability analyses (Oceanography, GES, MPA, Coastal Land use, Maritime uses) and integrate the results, it was necessary to determine the significance of each cluster parameter. We employed the statistical Analytical Hierarchy Process (AHP), applying pairwise comparisons and assigning weights to each parameter.

We obtained parameter weights by applying AHP with researchers who are involved in the PLASMAR project, working on OWE zoning. Further, we applied the same method with OWE external experts who are not directly connected with the PLASMAR project. Finally, the method for assigning the weights was again applied with diverse maritime sectors' stakeholders during the MSP process workshop delivered within the MarSP project.

Applying the defined weights to INDIMAR DSS (Table 2), we obtained three different profiles for offshore suitability at the Canary Islands. Each profile identifies areas with corresponding suitability levels, applying different criteria defined by PLASMAR researchers, external OWE experts and maritime stakeholders (Table 2, Figs. 3–5, Tables 3–5).

4. Discussion

For a preliminary offshore wind energy assessment, long-term wind data are necessary. To make it possible, for wind speed satellite observations in this study we used a product provided by the Copernicus Marine Service, as a daily time series for a period of 2 years. However, products derived from satellite observations cover vast areas (the data product also includes the Madeira and Azores archipelagos), with less precision at lower scales. The first assessment was based on the sea surface wind speed observations, and it provides the locations of areas within the Canary Islands that have high potential for OWE development (Fig. 2, Gran Canaria Island detail). In previous studies that compared satellite observations and meteorological models, in situ measurements were found to provide the most precise results (as expected), though offset by poor spatial coverage and a short measurement period [96]. Soukissian & Papadopoulos's (2015) study concluded that satellite observation usually slightly overestimates, while the modeled data underestimates wind speed with respect to in situ measurements, although both can cover a wide area and longer time periods. In situ measurement should be applied to confirm and precisely adjust identified areas obtained by satellite observation, but this is not necessary within the MSP and sector zoning process. In situ surveys and buoy and mast observations, to obtain precise results and fine tune OWE facilities' locations to get the most efficient results, should be delivered by investors interested in concessions for use of marine areas for commercial energy production.

The second parameter included in the analysis was bathymetry, identifying areas that extend up to 150 m depth. As current floating platform pilot projects go till 100 m depth, we expect that the economical threshold will soon reach 150 m. We included depths till 300 m as likely within the planning for the next 10 years, accounting for technology development and translating bathymetry thresholds to greater depths. Areas with depths beyond 300 m were excluded from the analysis, as building, managing and maintaining OWE facilities at this moment can have elevated costs, with the attendant risk of financial failure. Applying two parameters, areas with high potential were reduced, following the depth gradient and clearly identifying areas between islands where wind speed elevates due to the Venturi effect [16].

Applying two limiting factors, wind speed and depth, we identified extensive areas with high potential, around the Islands. This is an opportunity for introducing the OWE sector, choosing suitable areas that

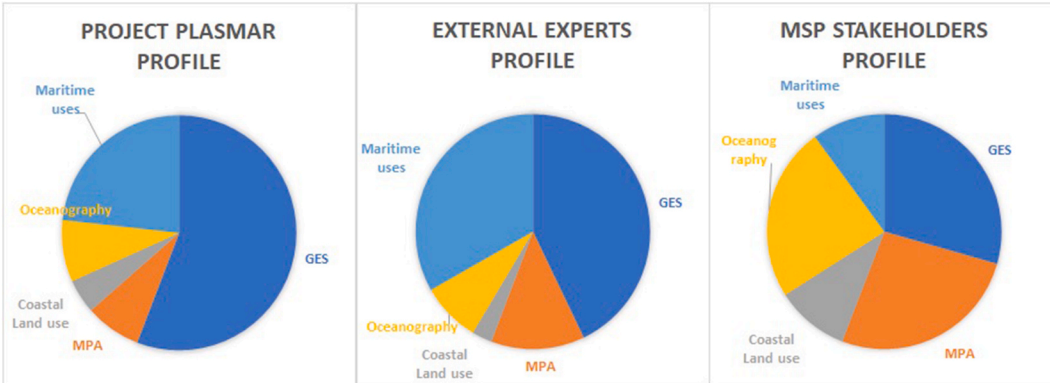

Fig. 6. - AHP results, cluster weights profiles by project experts, external experts and MSP stakeholders. PLASMAR project (MAC/1.1a/030).

will minimize environmental issues, avoiding incompatibility with MPAs and conflict with current maritime uses and coastal land activities. The objective of this study was to introduce a new sector, applying as few tradeoffs as possible with the marine environment and maritime and coastal activities.

To minimize environmental tradeoffs, we analyzed suitability of OWE facilities in relation to the marine environment (Fig. 5). As we organized data collection within five data clusters, it was necessary to understand what type of marine environmental data was necessary to be included in the analysis. It was clear that we needed to structure a marine environmental data cluster, to understand what exactly includes biodiversity and how to shape it; and what are the relevant OWE environmental impacts beyond biodiversity.

EU environmental legislation includes the framework on MSFD GES, following and extending the framework of Good Ecological Status applied for coastal waters in the Water Framework Directive 2000/60/EC. The GES framework integrates wider EU environmental legislation (such as the Habitat Directive, Birds Directive, Water Framework Directive, etc.), including only components that apply to the sea [97]. The Commission Decision (EU) 2017/848 document describes the GES in detail, as restructured and amended in 2017, replacing the previous versions from 2010 on GES criteria and methodological standards. The framework established was fine tuned to cover biodiversity, functionality of marine ecosystems, eutrophication balance, non-indigenous species, marine debris and noise pressures, including hydro-morphological, physical & chemical properties. GES requirements were defined as 11 Quality Descriptors and related 39 criteria elements which we used as a check-list for analyzing environmental issues for the OWE sector. To understand the relevant parameters within the marine environmental data cluster, an exhaustive *state of the art* review focusing on environmental issues was delivered, following the GES checklist [43].

Numerous studies have pointed out that OWE facilities act as artificial reefs, and this has (positive and negative) impacts on the benthic and pelagic habitat distribution (QD1), concentrating commercial fish species (QD3) around such facilities as alternate ecosystems and food chains (QD4). For the analysis, we restricted sensitive and endemic habitats and identified areas with suitable soft bottom desert habitats. Still, it is difficult to assess when OWE facilities will provide a positive effect, when alternating broader ecosystem and concentrating species around OWE facilities' structures. Within the state of the art, we have more than 20 years of experience on turbine mast technologies (in the North Sea and Baltic), and to understand positive/negative impacts and related spheres of influence we need to deliver empirical studies with new floating technologies. This uncertainty should not stop development of the OWE sector, but in future concessions the Environmental Impact Assessment process should include study and assessment of the type of habitats and distribution and commercial species' biomass distribution, including food chain models. In this way we could compare the environmental status preceding an OWE facility with the trends obtained through monitoring surveys during the construction and operational phases [98–100].

GES suitability analysis identified areas away from the coastline. Analysis included marine birds' distribution parameter, due to potential species mortality, which can restrict offshore areas. It was very difficult to find marine birds distribution maps, assessed and provided by experts, applying taxa distributional models [101]. To include marine birds in the analysis, as strongly recommended in the reviewed literature, we used polygons of the Canary Islands' extensive Natura 2000 network sites (that cover more than 35% of the territorial waters), as areas with potentially high distribution and frequency. In this manner we included negative contribution regarding marine species distribution for more than 12 000 km^2. Nevertheless, applying marine sentinels' distribution maps developed by the specialists applying distribution models would provide more reliable analysis, for minimizing marine birds' mortality related to OWE.

Studying the GES suitability (Fig. 5) helped us identify areas where we expect the installation of OWE facilities to cause fewer issues with the marine environment. Analysis included sensitivity mapping, identifying areas where OWE environmental tradeoff can seriously decrease the perspective for maintaining GES, which is a fundamental MSFD requirement. It supports an ecosystem approach, including detailed study of the marine environment for the whole archipelago, which can be a solid foundation for the Strategic Environmental Assessment (SEA) required by SEA Directive 2001/42/EC [2,41].

In the analysis of marine conservation suitability, we considered the possibility of combining MPAs with OWE facilities [102], excluding areas that necessitate marine birds' protection. OWE floating turbines can physically restrict access for shipping, some fishery and any other maritime activities that can threaten MPA targets. Integrating environmental conservation (species and habitats) with energy production should be further investigated, especially for the new floating technologies, assuming a lower impact on marine environment compared with other energy sources and current OWE technologies.

It was possible to analyze land–sea interactions due to availability of the CORINE data set, which provided land cover information for the entire coastal areas of the Canaries, as a harmonized data product. The land cover classes were used as surrogates for land use information for coastal areas, and suitability analysis was carried out, mainly avoiding the areas with conflict potential, such as urban and touristic areas. Areas in front of harbors were restricted, but proximity was evaluated positively regarding maintenance operations. The map on coastal uses suitability provided potential areas without and with tradeoffs, mainly with the tourism sector, which is highly relevant for the Canary Islands' economy.

For analysis of suitability with current maritime uses, it was possible to apply co-use and multi-use opportunities, but these were not applied as they are still in the experimental phase and depend on the security,

safety and other regulations that have not yet been adopted at the present time [103]. We applied published conflict matrices, delivered at local stakeholder workshops on the MarSP project [95]. Conflict matrices are frequently very similar, most can be delivered using common sense, although they can still vary due to local regulations and applied rules. Suitability analysis provides areas with the relevant tradeoffs or even potential conflict, analyzing planned aquaculture, current maritime traffic routes, nautical sports, maritime tourism as well as whale watching and diving sites. The analysis results include restrictions in the form of military areas, 37 historical wreck sites, areas in the proximity of submarine cables, as also operational aquaculture production sites.

To obtain a final suitability map for OWE facilities at the Canary Islands, all five clusters and related parameters needed to be superposed. Still, for the superposition analysis, it was necessary to define the weights for the inputs and the significance for each parameter and related data cluster. To finalize the analysis, the defined parameter weights had to be introduced in the DSS INDIMAR. Defining the parameters' weights/significance in the suitability analysis was a complicated task within this study. AHP facilitated the definition of the weights by applying a pairwise analysis for all the parameters and clusters.

During the first tests of the AHP method, we understood that the results, weights of parameters and clusters would depend on many factors relating to the person or group doing the inquiry, including their professional occupation, involvement in the MSP process, whether they are in favor of the OWE development or are part of a community potentially in conflict with OWE, their sensitivity to the marine environment, understanding of OWE technical requirements, etc. This raises a very important question: Who should define weights to be applied in AHP, for introduction of OWE in the Canary Islands?

For testing the methodology, we applied AHP survey along with the PLASMAR project personnel working on OWE zoning, and further with OWE external experts and finally with stakeholders invited to the MarSP project, MSP involvement workshop (Table 2).

Each weights profile (Fig. 6) shows cluster significance, but also what are the acceptable tradeoffs for each investigating group. The first group (PLASMAR project) includes maximum consideration for the marine environment, but the group is also open to tradeoffs with MPAs, as they are amenable to exploring possibilities of combining OWE and extensive marine conservation in the Canary Islands. External OWE experts have a similar consideration of potential conflict with maritime sectors, as to the impact on the marine environment. Stakeholders, the third group, do not believe in OWE tradeoffs with MPAs, but include lowest weights related to the marine environment. They prioritize natural (wind & depth) capacities, and consider as more relevant potential conflict with coastal land activities (tourism) rather than with traditional maritime sectors.

It can be deduced from the three developed profiles (Fig. 6), that each group has their priorities on different EBM components, but considering each of them, following data clusters and a holistic method. If we use PLASMAR project profile, the OWE zoning prioritizes minimizing tradeoffs with the marine environmental component; the external experts group steers for zoning, with priority for the resolution of conflicts with the maritime sector and mitigating impact on the marine environment; and finally, the stakeholders profile focuses on marine conservation, energy potential and mitigating conflict with the most profitable coastal sector in the Canary Islands, tourism.

The MSP process needs to find a balance of all three EBM components; environmental, social and economic, that should be reflected in the MSP strategy, including options with tradeoffs for sectoral growth, conflict prevention and environmental protection.

Observing the maps (Figs. 3–5) obtained for each of the profiles for the entire Canary Islands archipelago, it is clear that the PLASMAR project environmental approach was the most restrictive (Fig. 3). The maximum suitability level 8 includes an area less than 20 km^2 divided between the islands of Fuerteventura, El Hierro and La Palma. Still, there is an almost 200 km^2 level 7 suitable area divided among all the islands except La Gomera, which is covered by Natura 2000 protection targeting marine birds and thus excluding this area for OWE facilities.

The profile by the OWE external experts (Fig. 4) is less restrictive, and INDIMAR identified even a small area (0,59 km^2) with suitability level 9 at the La Palma Island. It identified 90 km^2 with high suitability (level 8) covering all the islands except La Gomera. For lower suitability levels extensive areas are identified covering all the islands, including La Gomera, being offshore areas out of the Natura 2000 network.

Finally, the MSP stakeholders profile (Fig. 5), which includes a less restrictive approach, identified 132 km^2 with maximum suitability level, including more than 100 km^2 at Gran Canaria for OWE facilities. Lower levels of suitability cover the wide offshore areas, 441 km^2 for level 9 and 280 km^2 for level 8.

DSS INDIMAR analyzes the long Canary Islands coastline (15 020 Km) and the corresponding offshore sea (52.426 km^2), identifying potential areas for the OWE facilities that should be included or at least considered in the first Canary Islands Maritime Spatial Plan, which is expected to be finalized during mid-2021. Still, exact locations for concessions should be selected within the results, but applying in situ detailed wind measurement and updating environmental information through the Environmental Impact Assessment process, following the data cluster structure.

The development and introduction of OWE operational facilities in the Canary Islands can be based on any of the three obtained zoning profiles (project PLASMAR; external experts; MSP stakeholders), or even a hybrid version, including weights related to the governance strategy that bear more relevance for marine environment and/or development of the sector and/or preventing conflict. The same governance strategy will need to define relations with the traditional fishery sector, including whether multiuse will be permitted in areas operating OWE facilities, or towards combining OWE facilities as a barrier for environmental conservation.

To define OWE governance strategy and relations with traditional sectors such as fisheries and/or marine conservation, we still need to understand the impact on the commercial species distribution and the endangered species/habitat considered as well as the changes in the marine ecosystems produced by the installation of wind turbines or the size of the OWE facilities. For a proper answer to this question, we recommend modeling techniques in combination with monitoring practices, including pre- and post-operational site monitoring. The next necessary step is to understand which fisheries practices are compatible with the new OWE floating technologies and what are the possibilities of combining these two sectors. Finally, governance decisions should be defined in the stakeholders' involvement process, clearly communicating tradeoffs to all communities and exploring the best and holistic solutions in effective discussions based on updated data and scientific knowledge.

5. Conclusion

The developed DSS INDIMAR tool coupled with the AHP methodology is useful for introducing OWE facilities into marine space, with the objective of applying as few tradeoffs as possible. Testing it in the case of the Canary Islands, it was found to be advantageous for the analysis of other potential archipelagos, extended coastal systems and related offshore areas.

To analyze OWE suitability, it is necessary to collect essential spatial information following the five clusters framework, including data on oceanographic potential; environmental sensibility; restrictions related to marine conservation; coastal areas *Land use*; and information on operational maritime sectors. Data products provided by European data initiatives such as EMODnet, Copernicus Marine and European Environment Agency SDI are very useful as they cover extended marine areas (entire EEZ); nevertheless, these should be combined with regional and local data of coastal areas. These data sets are delivered mainly by in situ

monitoring, providing higher precision but significantly lower coverage.

For marine environment cluster collection, we found it very useful to follow the Marine Strategy Framework Directive GES, as a check list structured by 11 quality descriptors and related 39 criteria elements. The GES checklist is also suitable for analyzing environmental issues related to the OWE sector and defining environmental sensibility and suitability.

For analyzing OWE sector conflict potential and *Land-Sea* interactions, the European *Land cover* product CORINE is adequate. If the CORINE data set is updated with local *Land use* data collections, *Land–Sea* interaction analysis will provide more detailed suitability results. For analyzing OWE conflict potential with operative maritime sectors, conflict matrices can be applied, which frequently are very similar, and can vary due to local regulations and applied rules.

To obtain a final suitability map for OWE facilities, all five clusters' analysis results needed to be superposed. AHP is suitable for defining weights, applying pairwise analysis for all the parameters and clusters. During the initial experiments with the AHP method, we understood that the results, weights of parameters and clusters will depend on many factors relating to the person or group doing the inquiry, including their professional occupation, involvement in the MSP process, whether they are in favor of the OWE development or are part of a community potentially in conflict, their sensitivity to the marine environment, understanding of OWE technical requirements, etc. Testing the method, applying pairwise analysis, we could deduce that each group has their priorities within the five clusters, but considering all EBM components. The profiles obtained indicate what are the acceptable tradeoffs as to the policy on environment, marine conservation, economic potential or conflict mitigation for each investigating group.

The MSP process needs to find a balance of all five clusters reflecting on EBM components that should be mirrored in the MSP strategy, including options with tradeoffs regarding sectoral growth, conflict prevention and environmental protection & conservation. Still, the exact locations for concessions should be selected within the highest scoring suitability areas, applying in situ detailed wind measurements and updating key environmental information required in the Environmental Impact Assessment process.

CRediT author statement

Andrej Abramic: Conceptualization; Methodology; Investigation; Formal analysis; Writing - Original Draft; Writing - Review & Editing. **Alejandro Garcia Mendoza**: Methodology; Formal analysis. **Ricardo Haroun:** Writing - Review & Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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