Marine Policy 180 (2025) 106786

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Unlocking multi-use synergies: Spanish industry perspectives on offshore wind and aquaculture integration

Carlos V.C. Weiss *, Bárbara Ondiviela *, Elvira Ramos, Lucía Meneses, Raúl Guanche, José Juanes

IHCantabria - Instituto de Hidráulica Ambiental de la Universidad de Cantabria, Santander, Spain

ARTICLE INFO

Keywords:
Blue economy
Marine spatial planning
Floating wind energy
Aquaculture
Multi-use
Stakeholder perception

ABSTRACT

The expansion of the blue economy requires sustainable solutions for optimizing marine resource use. The multi-use approach, increasingly integrated into Marine Spatial Planning (MSP), foster synergies between sectors such as wind energy and aquaculture. However, its implementation remains limited. This study develops a multi-use assessment framework for floating offshore wind energy and aquaculture, providing a national sectoral perspective to support MSP policy formulation through stakeholder-informed recommendations. The framework consists of three steps: *i)* technical suitability analysis; *ii)* evaluation of sectoral perceptions, and *iii)* SWOT analysis. By integrating technical suitability assessments—including energy production, energy evacuation, species requirements, structural survivability, and operation and maintenance—with stakeholder surveys and workshops, the framework provides a structured basis for advancing policy strategies. Technical analyses indicate significant multi-use potential within the Spanish Exclusive Economic Zone. Floating wind energy emerges as a driving activity in high-energy offshore areas, while aquaculture drives multi-use development in more sheltered zones. Stakeholders recognize economic and operational synergies, betting on the development of symbiotic multi-use in the short term. However, regulatory fragmentation, administrative barriers and environmental impact uncertainties are underscored challenges. The findings emphasize the need for coordinated regulatory frameworks and enhanced cross-sector collaboration to integrate multi-use into national maritime policies. The study provides a decision-support framework for policymakers and industry stakeholders to enhance governance and spatial planning strategies for offshore multi-use development.

1. Introduction

The development of the blue economy, which is inherently sustainable by definition [118], requires alternative strategies to ensure the efficient use of marine resources [62,103]. In this sense, the rapid and diversified Blue Growth has fostered ocean multi-use approaches [60]. This is primarily driven by the rapid expansion of the wind energy industry [125] and its competition for space with other uses, such as aquaculture, fishing, conservation and deep-sea mining [82]. Multi-use refers to the shared use of resources in close geographical proximity by one or multiple users [106]. This approach seeks to enhance resource efficiency and minimize the ecological footprint of the blue economy [122], while offering economic and technical benefits [2,4].

The combined exploitation of different activities has long been recognized as a prerequisite for future growth and development since its inception [27]. The Blue Growth strategy has promoted multi-use through its two main drivers: wind energy and aquaculture [32]. Additionally, Directive 2014/89/EU on Marine Spatial Planning (MSP, [41], the strategy for the development of marine renewable energies [33], and the new approach to a sustainable blue economy [34] have consistently promoted and encouraged multi-use. From an MSP perspective, multi-use can help mitigate conflicts arising from the increasing exploitation of ocean resources [11]. In this regard, MSP plans in different countries have been encouraging combined exploitation [99,105], tending to be not just a sustainable planning option but a key issue in MSP [16].

Offshore wind energy and aquaculture play key roles in the energy transition and food security, respectively [128]. In addition, both activities are driven by different political agendas, such as the Sustainable Development Goals of the 2030 Agenda [119] and climate change

* Corresponding authors.
E-mail addresses: dacruzcv@unican.es (C.V.C. Weiss), barbara.ondiviela@unican.es (B. Ondiviela), ramose@unican.eslucia (E. Ramos), meneses@unican.es (L. Meneses), guancher@unican.es (R. Guanche), juanesj@unican.es (J. Juanes).

https://doi.org/10.1016/j.marpol.2025.106786
Received 9 October 2024; Received in revised form 17 April 2025; Accepted 29 May 2025
Available online 5 June 2025

mitigation policies [42]. In this context, several EU-funded projects (from the first MERMAID,[1] H2OCEAN[2] and TROPOS[3] to the more recent UNITED[4] and MULTI-FRAME[5]) have played a crucial role in exploring the technical, economic, and governance dimensions of multi-use development. These projects have contributed to analyzing the feasibility of multi-use, developed design concepts for multi-use platforms, and investigated policy and regulatory frameworks to facilitate their adoption. Furthermore, scientific research has provided methodological advancements that support multi-use. Studies have explored the legal constraints and co-management prospects of integrating offshore wind farms with aquaculture [13]; identified the main barriers and the potential contribution of multi-use platforms to Blue Growth [122]; evaluated the ecological and economic benefits of combining low-trophic aquaculture with offshore wind farms [77], and proposed spatial planning tools to optimize site selection for renewable energy and aquaculture facilities [128].

Despite the comprehensiveness of these initiatives, numerous concerns remain regarding the multi-use of wind energy and aquaculture [20]. An assessment framework focused on the regional scale of planning is needed to identify specific advantages and hurdles of multi-use [111]. While a growing body of research has provided a holistic view of the technical, legislative and socio-economic dimensions, considering stakeholder perspectives on some occasions (e.g., [23]; [91], a critical step remains necessary to unlock the national development of multi-use: the engagement of both sectors to conciliate opinions in an analytical framework at decision-making scale (i.e., horizontal integration;[117]. As multi-use strategies gain traction in the development of blue economy within MSP, both national sectors are planning their next steps. The engagement of key stakeholders in the transition to multi-use is fundamental to the formulation of common solutions for a legal and technical development framework. Thus, it can be incorporated into a comprehensive MSP with the vertical integration of different levels of government and other stakeholders [34].

The aim of this study is to develop a multi-use assessment framework for floating offshore wind energy and aquaculture, providing a national sectoral perspective to support MSP policy formulation through stakeholder-informed recommendations. This study assesses the technical suitability, the perception of the energy and aquaculture industries, and the main Strengths, Weaknesses, Opportunities and Threats (i.e., SWOT analysis) for multi-use in the Spanish Exclusive Economic Zone (EEZ).

2. Study area

Spain's EEZ is divided into five maritime demarcations: North Atlantic, South Atlantic, Straigh and Alboran, Levantine-Balearic, and Canary Islands [35]. This study focuses on the peninsular demarcations (Fig. 1). The management of maritime space falls under the responsibility of the Ministry for Ecological Transition and the Demographic Challenge (MITECO), which approved the Maritime Spatial Plans (known as POEMs in Spanish) in February 2023 [86]. These plans establish guidelines for sustainable maritime use, defining priority and high-potential zones for offshore wind energy and high-potential zones for aquaculture. Although they do not designate specific areas for multi-use development, they emphasize the importance of 'facilitating the multiple use of maritime space' (Royal Decree 150/2023; [85].

Currently, Spain has no floating wind farms or offshore aquaculture facilities in operation, nor any existing multi-use initiatives. The Spanish Roadmap for the Development of Offshore Wind and Marine Energy sets the goal of reaching between 1 and 3 gigawatts of installed capacity in floating offshore wind energy by 2030 [84], representing 40 % of the European target for floating wind [132]. The Spanish wind industry has become one of Europe's knowledge and supply hubs for the international market EPO/IEA. [30] and is recognized for its advancements in floating prototypes development [28]. Meanwhile, although the aquaculture sector remains coastal and lacks designated offshore development zones in the POEM, there is growing interest in transitioning to offshore operations. In this sense, the aquaculture sector could leverage the wind industry's technological maturity to advance through the multi-use approach.

3. Methodology

This study proposes a multi-use assessment framework to guide the development of the floating offshore wind energy and aquaculture national sectors through evidence-based recommendations. The framework comprises three steps (Fig. 2): *i)* Analysis of the technical suitability for their combined exploitation; *ii)* Evaluation of the national sector's perception of the multi-use approach and *iii)* SWOT analysis to assess the feasibility of multi-use.

3.1. Technical suitability

A suitability index (SI) was applied to identify zones with favorable conditions for multi-use, considering energy exploitation alongside seaweed and fish farming (i.e., multi-use possibilities). The spatial analyses were based on a compilation of long-term time series data with high spatial and temporal resolution (cf., Supplementary Material, Table A1). The SI was based on the approach developed and applied at various temporal and spatial scales by [125,128,127,126,124]. This index represents: *i)* the probability of meeting the favorable conditions for energy production and evacuation in the wind industry; *ii)* the biological requirements of aquaculture species; and *iii)* the operation and maintenance (O&M) activities, as well as the structural survivability, for both sectors:

3.1.1. Energy production

Wind speed at hub height (*Ws*) and Available potential (*Ap*) were considered to assess the quality and availability of the energy resource. The *Ws* was parametrized according to the power curve of the 10 MW turbine referenced by DTU [7], cf., Fig. 3a). Significant wave height *(Hs)* was used as a constraint in the operation of the turbines. Eq. 1 shows the SI for wind energy production (SI_{EP}).

$$SI_{EP} = \min\left(Ws_p, \quad \frac{t_{Ap}}{\bar{t}}, \quad \frac{t_{Hs}}{\bar{t}}\right) \tag{1}$$

where *min* is the minimum value found among the analyzed aspects. Ws_p is the parametrization of the mean speed (Fig. 3a). t_{Ap} and t_{Hs} are the time, at the temporal resolution of the evaluated variable, that the variable (A_p and H_s) remained within the production thresholds (Table 1) throughout time series ($\bar{t}$).

3.1.2. Energy evacuation

The suitability of a site for energy evacuation was estimated by calculating the Euclidean distance to the nearest electrical substations up to a radius of 80 km (Table 1). Substations with available access capacity for the Electric Park Module (i.e., generators connected "non-synchronously") were considered. The Energy Evacuation index (SI_{EE}) was established by parameterizing the Euclidean distance according to Fig. 3b.

3.1.3. Species requirements

The species requirements assessment was based on growth predictor variables: sea surface temperature (*sst*) and salinity (*sal*), with

[1] https://cordis.europa.eu/project/id/288710

[2] https://cordis.europa.eu/project/id/288145

[3] https://cordis.europa.eu/project/id/288192

[4] https://doi.org/10.3030/862915

[5] https://www.submariner-network.eu/multi-frame

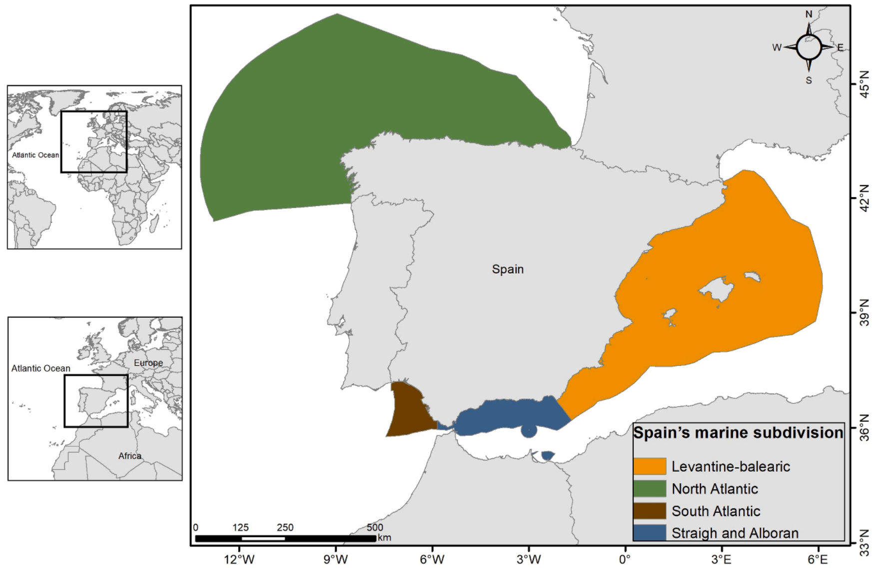

Fig. 1. Study area comprising the four Spanish maritime demarcations within the EEZ.

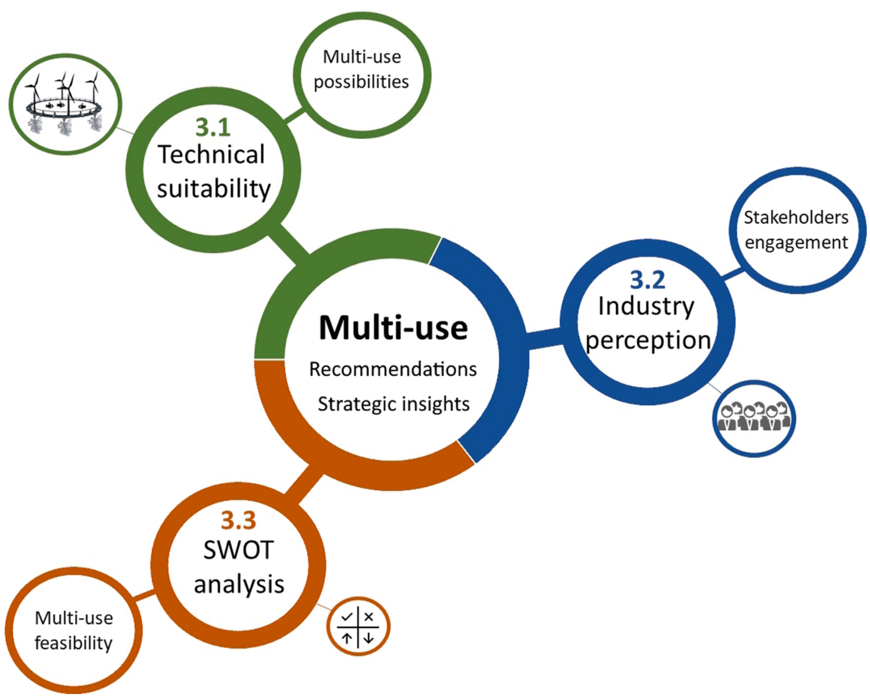

Fig. 2. Multi-use assessment framework outlining three steps to support the formulation of recommendations for the integrated development of the wind energy and aquaculture sectors.

photosynthetically active radiation (*PAR)* considered only for seaweeds. The suitability of the environmental conditions to the species requirements was established according to the percentage of time that *sst*, *sal* and *PAR* remained within the biological thresholds for each species (Table 2) in concomitance (*con*). The 20 species analyzed were selected according to their high commercial potential and farming background on the national and international market. The SI for the species requirements was generated according to Eq. 2 for fish ($SI_{Sp\ Fish}$) and Eq. 3 for seaweed farming ($SI_{Sp\ Seaweed}$).

$$SI_{Sp\ Fish} = con(\frac{t_{sst}}{\bar{t}}, \frac{t_{sal}}{\bar{t}}) \tag{2}$$

$$SI_{Sp\ Seaweed} = con(\frac{t_{sst}}{\bar{t}}, \frac{t_{sal}}{\bar{t}}, \frac{t_{PAR}}{\bar{t}}) \tag{3}$$

where t_{sst}, t_{sal} and t_{PAR} are the time, at the temporal resolution of the evaluated variable, that the variable (*sst*, *sal* and *PAR*) remained at the conditions defined in the thresholds throughout the time series ($\bar{t}$).

3.1.4. *Structural survivability*

Aspects related to the integrity and durability of the offshore wind and aquaculture structures have been considered to assess the severity of the met-ocean conditions on the site. For slope, zones with less than 25 % were excluded (SI=0). The bathymetry was parameterized according to Fig. 3c, considering depths between 40 and 200 m (Table 1).

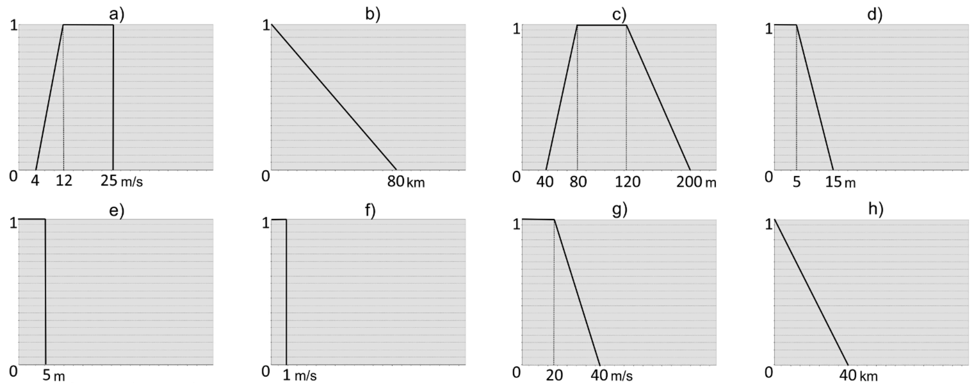

Fig. 3. Parameterization ($_p$) of the analyzed aspects on a normalized scale from 0 to 1 for: **a)** Wind speed (Ws_p); **b)** Distance from substations (Ds_p); **c)** Bathymetry (Bat_p); **d)** 50-year return period for significant wave height ($Hs50wind_p$); **e)** $Hs50aqua_p$; **f)** 50-year return period for current velocity ($C50_p$); **g)** 50-year return period for wind speed ($Ws50_p$); **h)** Distance from ports (Dp_p).

Table 1
Technical aspects, thresholds and source of information for wind energy and aquaculture exploitation.

Aspects	Thresholds			Sources of information
	Wind	Seaweed	Fish	
Energy production				
Wind speed (120 m hub high) (*Ws*, m/s)	4 ≤*Ws*≤ 25	_	_	[6]; [7]; [66]; [67]
Available wind energy potential (120 m hub high) (*Ap*, W/m^2)	≥ 400	_	_	
Significant wave height (*Hs*, m)	≤ 5	_	_	
Energy evacuation				
Distance from substations (km)	≤ 80	_	_	[1]; [6]; [132]
Structural survivability				
50-year return period for wind speed (*Ws50*, m/s)	≤ 40	_	_	[1]; [19]; [24]; [112]; [114]; [132]
50-year return period for significant wave height (*Hs50*, m)	≤ 15	≤ 5	≤ 5	
50-year return period for current velocity (*C50*, m/s)	_	≤ 1	≤ 1	
Bathymetry (m)	40 ≤ Bat ≤ 200	40 ≤ Bat ≤ 200	40 ≤ Bat ≤ 200	
Slope (%)	≤ 25	≤ 25	≤ 25	
O&M activities				
Wind Speed (*Ws*, m/s)	≤ 15	≤ 15	≤ 15	[1]; [5]; [19]; [79]; [112]; [132]
Significant wave height (*Hs*, m)	≤ 2	≤ 1	≤ 1	
Distance from ports (km)	≤ 40	≤ 40	≤ 40	

The calculation of the 50-year return period used the Peak Over Threshold method, assuming the frequency using a Poisson process, and the intensity using a Generalized Pareto Distribution [83]. The extreme conditions for *Hs50wind, Hs50aqua, C50 and Ws50* were parameterized according to Fig. 3d, e, f, g, respectively. The structural survivability index was obtained according to Eq. 4 for wind energy ($SI_{SS\ Wind}$) and Eq. 5 for aquaculture ($SI_{SS\ Aqua}$).

$$SI_{SS\ Wind} = \min\left(Bat_p, \quad Hs50wind_p, \quad Ws50_p\right) - slope \tag{4}$$

$$SI_{SS\ Aqua} = \min\left(Bat_p, \quad Hs50aqua_p, \quad C50_p\right) - slope \tag{5}$$

3.1.5. O&M activities

For logistics activities, the possibility of carrying out O&M activities has been considered for both sectors, considering the weather windows available and the distance to the ports. The distance from ports was estimated by calculating the Euclidean distance to the nearest port within a 40 km radius, parameterized according to Fig. 3 h (i.e., Dp_p). For *Hs* and *Ws*, the number of 8-hour weather windows of average annual duration in which these aspects were within the optimal thresholds for working is evaluated (cf., Table 1). The site was considered to have full accessibility when it had 1095 access windows. The SI for the O&M activities of both sectors ($SI_{O\&M}$) is shown in Eq. 6.

$$SI_{O\&M} = \frac{3Hs + 2Ws + Dp_p}{6} \tag{6}$$

3.1.6. Multi-use possibilities

The technical suitability for each activity was established by integrating the SI of each evaluated aspect. Integration was carried out according to the main economic factors that determine the feasibility of developing these activities. Thus, a 70 % CAPEX (capital expenditures) and 30 % OPEX (operational expenditures) were considered for wind energy [18] and the critical value of the aspects evaluated for aquaculture (i.e., minimum value, as it is considered a more susceptible activity; [53]. The integrations were performed according to Eqs. 7, 8, and 9 for wind energy, fish farming, and seaweed farming, respectively.

$$SI_{Wind} = \frac{(0.2 * SI_{EP} + 0.3 * \quad SI_{EE} + \quad 0.4 * SI_{SS\ Wind} + \quad 0.1 * SI_{O\&M})}{1} \tag{7}$$

$$SI_{Fish} = \min(SI_{SS\ Aqua}, \quad SI_{O\&M}, SI_{Sp\ Fish}) \tag{8}$$

$$SI_{Seaweed} = \min(SI_{SS\ Aqua}, SI_{O\&M}, SI_{Sp\ Seaweed}) \tag{9}$$

Different combinations of SI_{Wind}, SI_{Fish}, and $SI_{Seaweed}$ were carried out to determine the multi-use possibilities, considering the minimum value found at each point on the analysis grid (*min*). For instance, the multi-use possibilities for the three activities were obtained from Eq. 10. The discussion of the results was based on the zones with multi-use possibilities with SI values above 0.5.

$SI_{MU} = \min\ (SI_{Wind}, SI_{Fish}, SI_{Seaweed})$ (10)

3.2. Industry perception

The assessment of stakeholder perceptions of the combined use of aquaculture and floating offshore wind energy was carried out through

Table 2
Species requirements, thresholds and source of information for fish and seaweed farming.

Species requirements	Temperature (*sst*, °C)	Salinity (*sal*, PSU)	Photosynthetically Active Radiation (*PAR*, mol/m^2 day)	Sources of information
Fish				
Gilthead seabream *Sparus aurata*	$14 \leq sst \leq 28$	$30 \leq sal \leq 40$	_	[3]; [43]; [69]; [107]
Atlantic Bluefin tuna *Thunnus thynnus*	$15 \leq sst \leq 30$	$30 \leq sal \leq 38$	_	[3]; [47]; [69]; [115]; [116]; [133]
Meagre *Argyrosomus regius*	$14 \leq sst \leq 28$	$29{,}5 \leq sal \leq 39{,}1$	_	[3]; [26]; [44]; [78]; [88]; [104]
European seabass *Dicentrarchus labrax*	$14 \leq sst \leq 26$	$30 \leq sal \leq 40$	_	[3]; [45]; [65]; [69]; [71]; [101]
Greater amberjack *Seriola dumerili*	$14 \leq sst \leq 28$	$30 \leq sal \leq 38$	_	[3]; [17]; [48]; [68]; [116]
Red porgy *Pagrus pagrus*	$15 \leq sst \leq 26$	$31{,}6 \leq sal \leq 38$	_	[3]; [8]; [69]
Atlantic cod *Gadus morhua*	$4 \leq sst \leq 15$	$6 \leq sal \leq 38$	_	[3]; [49]
Blackspot seabream *Pagellus bogaraveo*	$12 \leq sst \leq 21$	$34{,}5 \leq sal \leq 37{,}8$	_	[3]; [8]
Atlantic salmon Salmo salar	6 ≤ sst ≤ 18	10 ≤ sal ≤ 38	_	[3]; [52]; [57]; [69]; [89]
Rainbow trout Oncorhynchus mykiss	6 ≤ sst ≤ 18	10 ≤ sal ≤ 38	_	[3]; [50]; [92]
Wreckfish Polyprion americanus	12 ≤ sst ≤ 20	32,4 ≤ sal ≤ 37,8	_	[3]
Common Dentex dentex dentex	15 ≤ sst ≤ 28	35,4 ≤ sal ≤ 38,8	_	[3]; [8]; [69]
Dusky grouper Epinephelus marginatus	14 ≤ sst ≤ 23	33,2 ≤ sal ≤ 37,2	_	[3]; [64]; [69]
Flathead grey mullet Mujil cephalus	15 ≤ sst ≤ 30	30 ≤ sal ≤ 38	_	[3]; [46]
Common dolphinfish Coryphaena hippurus	20 ≤ sst ≤ 30	16 ≤ sal ≤ 36,4	_	[3]; [93]
Seaweed				
Saccharina latissima	10 ≤ sst ≤ 15	30 ≤ sal ≤ 40	8,6 ≤ PAR≤ 43,2	[12]; [63]; [70]; [95]; [110]
Porphyra sp	10 ≤ sst ≤ 15	30 ≤ sal ≤ 40	6 ≤ PAR≤ 43,2	[63]; [70]; [95]
Himanthalia elongata	10 ≤ sst ≤ 17	30 ≤ sal ≤ 40	6 ≤ PAR≤ 43,2	[63]; [70]; [113]; [134]
Codium tomentosum	10 ≤ sst ≤ 16	30 ≤ sal ≤ 40	6 ≤ PAR≤ 17,3	[56]; [70]; [72]; [76,109]; [131]; [134]
Chondrus crispus	10 ≤ sst ≤ 15	28 ≤ sal ≤ 40	5,6 ≤ PAR≤ 34,5	[10]; [15]; [70]; [75]; [108]; [109]

an online survey and workshops. A 10-question online survey was divided into 6 sections: *i)* general information; *ii)* multi-use topics; *iii)* planning phase; *iv)* investment phase (CAPEX); *v)* O&M phase (OPEX); and *vi)* decommissioning phase (DECEX). The first five questions were about general information (e.g., field of expertise) and multiple-choice questions on general aspects of multi-use among the evaluated sectors. The other questions (sections *ii* to *vi*) sought to find the main advantages and hurdles in the different phases of implementing multi-use projects. The key stakeholders rated different aspects within each project phase using a seven-point Likert scale from *-3* (most important hurdles) to *+ 3* (most important advantages), with the option of not answering a certain aspect (i.e., Don't Know/Don't Answer option). Likert-type scales are often used to measure stakeholder perceptions in management, policy and conservation issues (e.g., [74]; [96]. The survey was distributed to key stakeholders (i.e., national energy and aquaculture sectors[6]), and was made available for contributions for one month. A total of 15 stakeholders responded, with 60 % representing the aquaculture sector and 40 % the offshore wind energy sector. In the analysis of responses, the same weight of importance was given to both sectors to ensure a balanced interpretation of their perspectives.

The contributions of both sectors were also made in two virtual workshops. The first workshop (38 participants) was organized with a broader outreach strategy to gather input across sectors and aimed to discuss the methodology and results of the technical suitability analysis, as well as to validate the preliminary survey findings. The second workshop (9 participants) was more targeted and focused on validating the SWOT analysis (cf., Section *3.3*), with the goal of identifying key aspects to be addressed in the development of these sectors through the multi-use approach and supporting the formulation of strategic recommendations. To ensure a focused discussion on strategic priorities, participation was limited to stakeholders with relevant experience in multi-use initiatives. Stakeholders for both the online survey and the workshops were selected through collaboration with national industry associations — APROMAR (aquaculture) and AEE (wind energy) — to ensure representation of the sectors directly involved in multi-use implementation. The participants included professionals from companies and organizations active in the national energy and aquaculture sectors. This approach helped ensure that stakeholder input was both inclusive in the exploratory phase and focused during the validation stage, thus strengthening the reliability of the findings.

3.3. SWOT analysis

Based on the technical suitability and the findings of the survey, a SWOT analysis regarding the multi-use feasibility was carried out:

- Strengths: positive aspects of feasibility for multi-use.
- Weaknesses: negative aspects of feasibility for multi-use.
- Opportunities: elements that might benefit multi-use.
- Threats: elements that might be a barrier to multi-use.

The sectoral diagnosis made it possible to identify strengths and weaknesses that the sectors face in implementing multi-use (i.e., internal factors), as well as the main opportunities and threats that intervene in achieving combined exploitation in the Spanish context (i.e., external factors). Internal factors refer to the intrinsic part of the system, covering all the inherent aspects over which it has control (e.g., financial,

[6] Red Empresarial de Acuicultura de España (APROMAR), Asociación Empresarial Eólica (AEE) and, national wind energy and aquaculture companies.

technical, human resources, competitive position). On the other hand, external factors constitute elements that might affect the internal system, i.e., the area of influence on multi-use between these sectors (e.g., sociocultural, economic, political and technological aspects). These aspects were discussed based on an international literature review.

Based on a technical, participatory, consensus-driven, and prioritized approach, strategic recommendations were formulated to support the development of multi-use in the national context.

4. Results and discussion

This section is divided into four parts. Section 4.1 addresses the technical suitability for multi-use between floating offshore wind energy and aquaculture in Spain's EEZ. The SI for each aspect assessed for wind energy exploitation, fish and seaweed farming, as well as for multi-use possibilities, are available in the Supplementary Material (Fig. A1 to A8). Section 4.2 shows the results of the survey on the perception of national sectors. The SWOT for the feasibility of multi-use is discussed in Section 4.3. Key lessons and recommendations for multi-use development in Spain are presented in Section 4.4.

4.1. Technical suitability

Considering the maximum number of suitable fish and seaweed species, Fig. 4 shows the zones with multi-use possibilities between floating wind energy and aquaculture (SI > 0.5). The Mediterranean Sea shows great technical possibilities for energy and fish production. In this region, the determining factor for multi-use is the suitability for wind exploitation, since most of the species analyzed presented favorable conditions. The zones with multi-use possibilities are mainly in the Balearic Sea (total area of 23.053 km^2). Zones with the highest SI (> 0.7, white polygons) are concentrated on the Alicante coast (303 km^2) and the south-west of the Mallorca Island (508 km^2). Possible multi-use combinations of wind energy would be with the farming of European seabass, Atlantic Bluefin tuna, Greater amberjack, Gilthead seabream, Meagre, Common dentex and Flathead grey mullet (the first five species were produced in Spain in 2021; [51]). Furthermore, the Catalan coast is also a hotspot for multi-use (> 0.7, white polygons), considering the farming of Greater amberjack, Gilthead seabream and Meagre (822 km^2), Wreckfish (345 km^2) and Blackspot seabream (58 km^2) with wind energy production. Multi-use possibilities are also identified with Red porgy, Atlantic salmon and Rainbow trout in this region, but with lower SI and smaller areas for the last two species (maximum SI of 0.68).

In the North Atlantic region, the feasibility of multi-use is primarily determined by aquaculture suitability, given the severe met-ocean conditions and challenges related to structural survivability [19] and the susceptibility of farmed species [53]. Three zones in this region show multi-use possibilities: the coast of the Basque Country and Cantabria (SI of up to 0.68 in a total area of 978 km^2); Asturias (SI of up to 0.58 in a total area of 462 km^2); and a small zone in the Galician coast (SI of up to 0.51 in a total area of 222 km^2). In addition to the species mentioned for the Mediterranean Sea, Dusky grouper also presents possibilities for multi-use; as well as Atlantic cod and *Himanthalia elongata* farming emerging as possible combinations off the Galician coast (SI of 0.51). The Gulf of Cadiz also has zones with favorable conditions for multi-use between wind and farming of up to 13 different species (SI of up to 0.62 in a total area of 1.542 km^2). Possible combinations with floating wind energy are found with the same species as in the North Atlantic region, except for the last two mentioned in the case of the Galician coast.

4.2. Industry perception

Survey responses revealed stakeholders' interest in fostering synergies between the aquaculture and offshore wind sectors, particularly through symbiotic use (cf., Supplementary Material, Figs. A9, A10). In this type of multi-use, activities share provisioning services and basic functions, such as crew transportation, ports, and monitoring data [106].

Stakeholders emphasized the need to designate suitable zones in Spain's MSP plans (Royal Decree 150/2023; [85] to promote multi-use (cf., Supplementary Material, Fig. A11). The offshore wind sector advocated for adjusting spatial restrictions in the national MSP to allow joint exploitation in high-potential areas (e.g., aquaculture zones with wind energy potential). Meanwhile, the aquaculture sector highlighted its offshore potential, particularly in synergy with floating wind, which is not reflected in the current MSP plan. Both sectors identified economic and technical advantages as primary drivers of multi-use development, while administrative and legal barriers were cited as major obstacles.

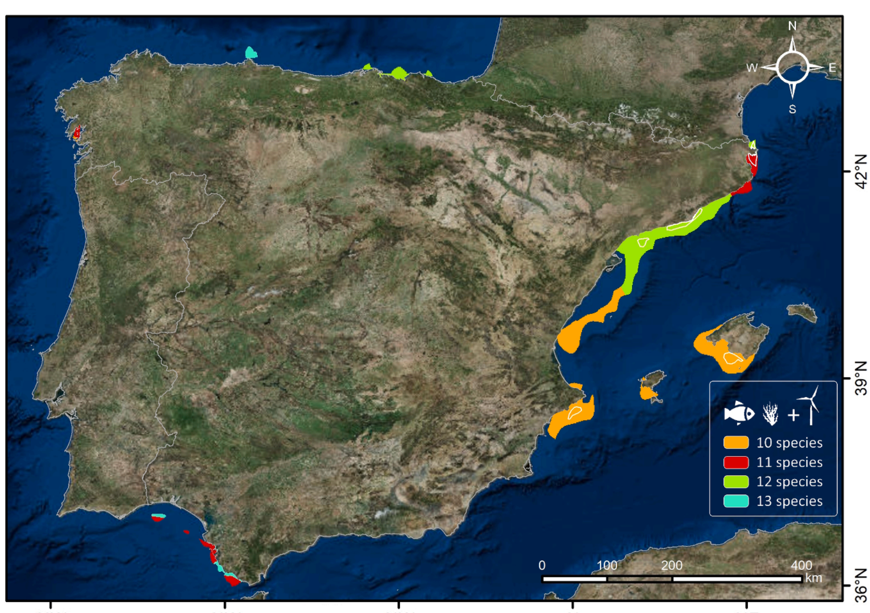

Fig. 4. Zones with the multi-use possibilities (SI > 0.5) between floating wind energy and aquaculture, with the maximum number of fish and seaweed species suitable for farming. White polygons indicate zones with high SI (> 0.7). Image source: Esri, Maxar, Earthstar Geographics, IGN, and the GIS User Community.

Environmental impact studies were deemed essential by the aquaculture sector, whereas pilot projects were prioritized by the wind sector (cf., Supplementary Material, Fig. A12).

Fig. 5 illustrates the advantages and hurdles of multi-use at different project phases. In the planning phase, optimizing operational space and improving efficiency (i.e., production per area) were key advantages (Fig. 5a). Cooperation was also considered beneficial, although 40 % of energy sector participants viewed differing technological maturity as a challenge. In the investment phase (CAPEX), 80 % of stakeholders recognized energy autonomy for offshore installations as an advantage, especially in powering aquaculture plants (Fig. 5b). Shared infrastructure and staff were seen as cost-saving measures.

The main hurdles identified in the O&M phase (Fig. 5c) involved potential negative impacts on farmed species and the socio-ecological environment, with 80 % of aquaculture stakeholders expressing concern. However, both sectors agreed that technological solutions and further research could mitigate these risks. Infrastructure collisions were another concern, particularly for the wind sector (60 %), given the potential for aquaculture equipment to damage wind devices [135,23]. In the decommissioning phase, stakeholders recognized the benefit of specialized technical resources (Fig. 5d). Repurposing decommissioned structures for future use was also discussed as a viable multi-use strategy [106].

4.3. Multi-use feasibility

Economic and technical synergies were the main drivers of multi-use feasibility (cf. Section 4.2), aligning with recent studies on technical viability [4,124] and economic benefits [22,2]. Conversely, the lack of a robust policy framework remains a key barrier [23,120]. Regulatory

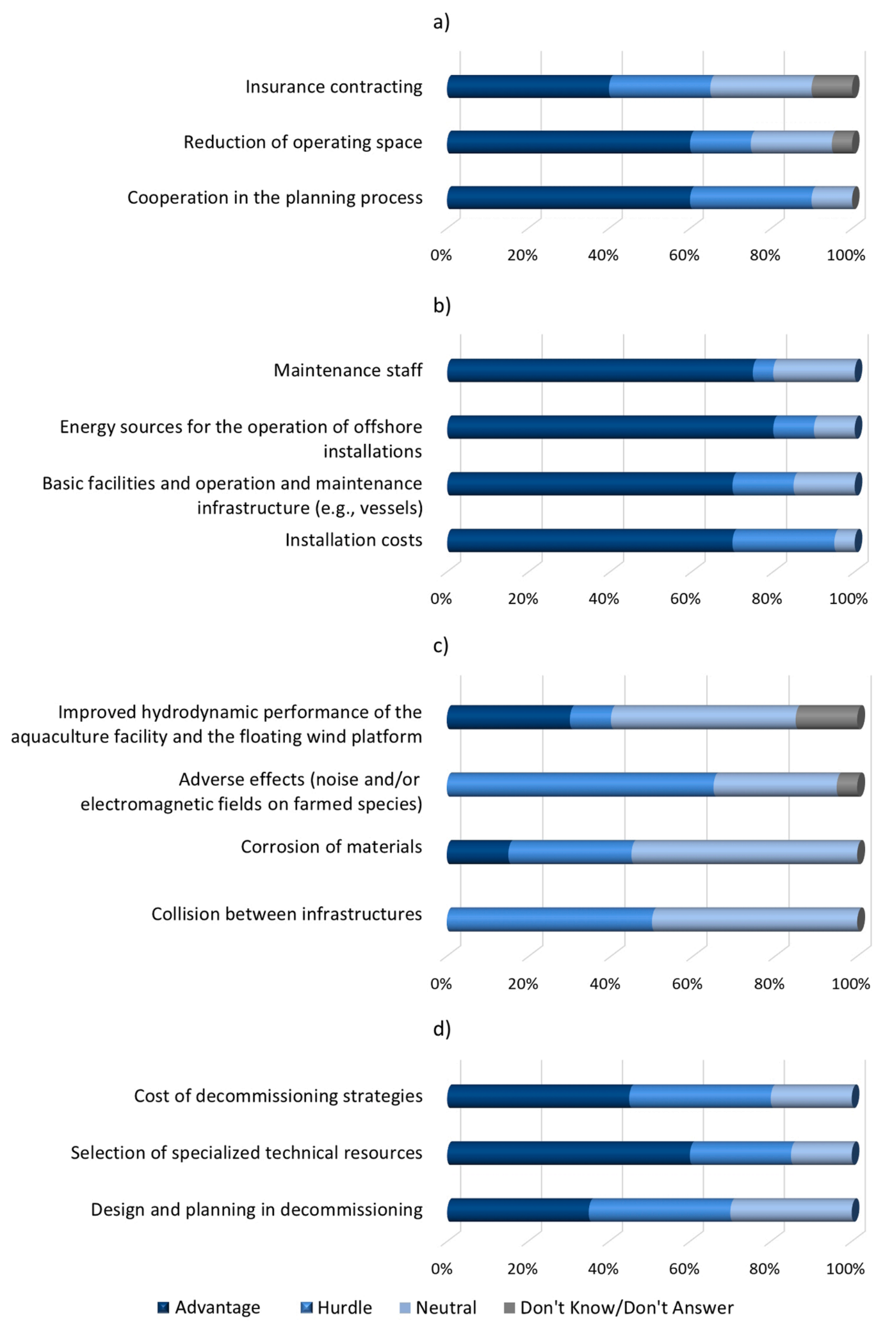

Fig. 5. Stakeholder perceptions of advantages, hurdles, or neutrality in different project phases: **a)** planning; **b)** investment (CAPEX); **c)** O&M (OPEX); **d)** decommissioning (DECEX).

fragmentation exacerbates the administrative burden [20], with offshore wind farms governed nationally and aquaculture regionally in Spain. Although Spain's MSP plan encourages multi-use, a structured regulatory framework is needed for effective licensing and coordination. The MSP Directive 2014/89/EU supports "multi-purpose uses" [41], highlighting the importance of recognizing overlapping operational limits for joint activities [122], as suggested by the sectors. In addition, a regulatory framework for multi-use development could facilitate public-private cooperation, for example in the repurposing of oil and gas platforms [23,106].

A SWOT analysis of multi-use feasibility in Spain's EEZ is presented in Fig. 6. Stakeholder perceptions align with international research, emphasizing strengths such as space optimization [4] and improved hydrodynamic behavior [136]. Economic benefits include shared mooring systems [21], logistics and O&M cost reductions [22], and lower decommissioning expenses [16]. Additionally, multi-use facilitates environmental monitoring by integrating impact assessments [97] and enhancing data collection [102]. However, the need for standardized monitoring protocols remains a challenge [123].

Opportunities include increased social acceptance, especially for marine fish farming [9]. The national and sectorial commitment to meeting the objectives defined in the European agendas for blue growth and sustainable development (e.g., Sustainable Development Goals, European Green Deal, climate change mitigation) are highlighted by stakeholders as a "mandatory" opportunity.

The environmental impacts of the combined exploitation of these activities are still unknown and are therefore a weakness for the feasibility of multi-use. The existing information comes from theoretical scenarios of the individual projection of activities [2] and through methods for assessing cumulative effects (e.g., [129,130]. The sector's concerns are addressed in different studies, for example, aquaculture could produce biofouling in wind devices, thus increasing the corrosion of the material [73]. According to Rezaei et al. [98], one of the main impacts of floating wind energy is the electromagnetic field and noise, which could affect farmed species. The release of substances used to contain corrosion and biofouling from wind turbines can, for example, contaminate seaweed farming [121]. Additionally, the different lifespans of offshore wind and aquaculture facilities complicate planning.

The primary threats to multi-use in Spain stem from limited sectoral cooperation. While collaboration was recognized as a potential advantage in planning (cf. Fig. 5a), stakeholders in the second workshop acknowledged that dialogue remains limited. This study is among the first to foster cross-sector interaction in Spain. Cooperation barriers arise from technological maturity gaps, investment differences, and regulatory inconsistencies. Addressing these challenges requires policy intervention and enhanced industry collaboration.

4.4. Lessons learned and recommendations for multi-use development in Spain

Spain's MSP plans outline a regulatory framework for maritime activities but currently lack specific provisions for multi-use projects. The absence of targeted incentives limits sectoral engagement, generating uncertainty for investors and reinforcing the need for clear implementation guidelines. Building on the multi-use assessment framework proposed in this study — which systematically identifies suitable areas and captures stakeholder perceptions — this section presents key lessons learned and practical recommendations to support the future development of multi-use between floating wind energy and aquaculture in Spain. These insights, informed by national sectoral perspectives and relevant international experiences, aim to guide strategic decision-making and inform future updates to Spain's MSP strategies.

4.4.1. Economic and financial aspects

The novelty of multi-use technologies results in limited funding opportunities, as investors prioritize more established methods. Uncertainty regarding business cases and insurance contracting further complicates financing due to potential mutual impacts between economic activities. Financial incentives such as tax benefits or public-private funding mechanisms should be introduced to mitigate these risks.

There are currently no commercial multi-use facilities in Spain for these industries. However, wind farms with an installed capacity between 200 and 500 MW are planned in the priority zones defined in the MSP plans (Royal Decree 150/2023; [85]. The lowest are planned for the Canary Islands and those with the highest installed capacity for the North Atlantic region. Regarding offshore aquaculture, planned investments include farms with capacities of up to 15,000 tons/year and structures of approximately 150 m in diameter. The preferred zones for European seabass and Meagre farming are the Mediterranean Sea and the Canary Islands. In the Mediterranean Sea, a project with an investment of around 250 million euros is currently undergoing environmental licensing, while a planned Canary Islands project was canceled due to bureaucratic barriers.

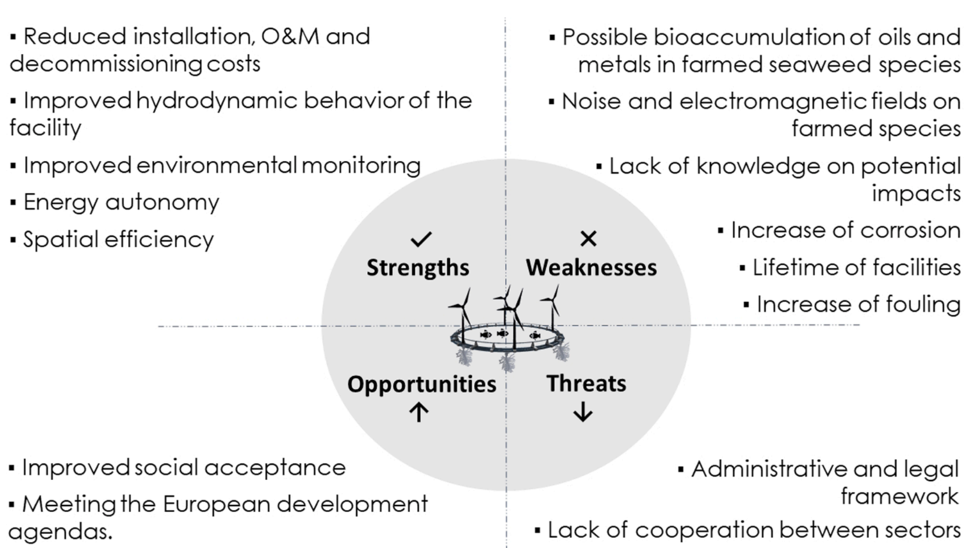

Fig. 6. SWOT analysis for the multi-use feasibility of floating offshore wind energy and offshore aquaculture.

4.4.2. Multi-use development zones

Due to Spain's continental shelf characteristics, wind-aquaculture multi-use must rely on floating solutions, particularly for fish farming integration. Initial multi-use installations could be located at depths of 80–120 m (based on stakeholder criteria and technical suitability analysis, cf. Fig. 3c). Stakeholders propose pilot projects within 20 km of the coast. However, the priority zones for wind energy defined in Spain's MSP are located far from the coast, while the aquaculture zones are restricted to nearshore areas.

Explicit inclusion of multi-use zones in MSP plans is essential for successful blue economy development. Lessons from the North Sea indicate that dedicated multi-use zones facilitate coordinated governance and reduce administrative barriers. Countries such as the Netherlands (via "Area Passports" in the 2020 North Sea Agreement; [58]) as well as Germany and Denmark (through overlapping priority zones in their MSP 2021) provide successful examples [36,37].

While this study provides an initial site selection analysis (Section 4.1), further research is required at an implementation scale, considering specific technologies, species, and operational needs (e.g., O&M activities). The selection of multi-use zones should also address conflicts with other maritime activities [82] and environmental compatibility [90]. The lack of inland infrastructure, such as suitable electrical substations, remains an obstacle.

4.4.3. Type of multi-use

Both sectors are betting on symbiotic use (e.g., [100] in the short term, other types of multi-use are, however, not ruled out in the long term, such as multi-purpose platforms (e.g., [136]. Indeed, multi-purpose platforms are also identified as a viable alternative by the aquaculture sector (40 % of participants) for their potential to integrate wind technology within a single structure.

Existing real-world projects offer insights into best practices. The floating wind sector has operational farms, such as Hywind Tampen (Norway, 140 km offshore, 260–300 m depth; [31]. As for aquaculture, different types of cages have been developed (cf., [19], some of which have been tested under real conditions (e.g., rigid semi-submerged cage - Ocean farm 1; [25]. For multi-use real projects, lessons can be learned from the combination of bottom-fix offshore wind with the farming of, for example, seaweed and bivalves [14]. Moreover, a wind, solar and fish multi-use farm was recently commissioned in China (Shanghai [29].

4.4.4. Multi-use driving activity

Pilot projects should consider aquaculture as a driving activity in sheltered zones (e.g., Mediterranean Sea) and wind energy in seas with severe met-ocean conditions (e.g., North Atlantic region). The farming of European seabass, Atlantic Bluefin tuna, Greater amberjack, Gilthead seabream and Meagre in offshore cages (e.g., [59]; [127] could be considered for the multi-use with wind exploitation in the Mediterranean Sea and/or Gulf of Cadiz. In this case, commercial turbines with lower installed capacity could be considered (e.g., 5-MW NREL, [66], or lower installed capacity to meet the energy needs of the aquaculture plant; [4].

For multi-use projects where wind energy is the driving activity, in addition to the species mentioned above, Atlantic salmon and Rainbow trout farming could be combined with projects utilizing larger wind turbines on the North Atlantic coast (e.g., 10-MW DTU, [7], and 15-MW IEA, [54]. In addition, the farming of *Himanthalia elongata* could be explored for a wind-driven multi-use pilot project along the Galician coast (cf., Section 4.1). With a better-established industrial value chain, wind energy as a driving activity could boost the development of offshore aquaculture.

4.4.5. Legislation for multi-use

As highlighted in Section 4.3, administrative and legal barriers are among the greatest challenges to multi-use development. The lack of a dedicated regulatory framework, complex licensing procedures, and insufficient sectoral coordination discourage investment. Streamlining regulatory processes is critical to providing legal certainty and fostering multi-use project development.

International examples demonstrate that regulatory clarity facilitates investment and sectoral collaboration. The Netherlands' "Area Passports" coordinate multi-use activities within offshore wind farms, promoting legal certainty and enabling public-private partnerships [58]. Belgium and Poland have integrated multi-use into their tendering procedures for offshore wind farms [38,39], providing valuable insights for Spain.

4.4.6. Environmental concerns

The cumulative impact of multi-use operations on marine biodiversity and ecosystem dynamics remains poorly understood. Lessons learned from the exploitation of fixed offshore wind structures [98] and coastal aquaculture [61] can help minimize environmental impacts. However, further empirical assessment is needed to evaluate the effects on marine ecosystems and species. Studies such as Maar et al. [77] indicate that integrating offshore wind farms with low-trophic aquaculture can support global sustainability goals by providing ecosystem services such as nutrient uptake, carbon sequestration, and biodiversity enhancement. Another study examined the potential environmental impacts of combining offshore wind energy and mussel farming in the Belgian Continental Shelf from a life-cycle perspective [94]. The authors concluded that, compared to equivalent land-based systems, offshore multi-use is more sustainable in preserving ecosystem quality. However, land-based activities may have advantages in terms of human health impacts and fossil fuel consumption during device manufacturing, as they are less dependent on heavy materials and transportation. Therefore, site-specific studies should be conducted to assess the potential environmental impacts and establish adaptive management strategies.

Uncertainty about potential environmental impacts concerns both investors and regulatory bodies. Compliance with environmental legislation and management regulations is required not only before installation (e.g., environmental licenses) but also throughout operation and decommissioning (e.g., environmental monitoring). Studies related to environmental liability, including the prevention and remediation of prior environmental damage, are necessary to assess risks associated with multi-use development (Directive 2004/35/EC; [40]. Additionally, the possible impacts of offshore wind energy on farmed species and vice versa (e.g., biofouling, noise pollution, and electromagnetic effects) must be rigorously evaluated before large-scale deployment.

4.4.7. Social awareness

As multi-use is a relatively new concept, raising public awareness remains a challenge. Concerns about landscape impacts and conflicts with tourism activities are highlighted as key social challenges. Public acceptance is critical for the successful development of multi-use projects. Resistance from local communities, as observed in offshore wind farm proposals in Spain (e.g., Mar de Trafalgar, which faced strong local opposition), underscores the importance of early stakeholder engagement. While multi-use could enhance public perception by linking wind energy to food production and economic benefits for coastal communities [9], transparent communication and localized socio-economic assessments are essential to building trust.

Public awareness campaigns are recommended to clarify the real risks and benefits of combining these activities. These campaigns should be informed by pilot project studies, which can provide in-situ evaluations of associated challenges. Society could also express its opinion on the multi-use between these activities within the framework of a Social License to Operate (SLO, e.g., [9]. The SLO concept extends beyond passive acceptance of a development - it was initially developed in the mining sector to promote active community support and trust in project developers. In addition to fostering legitimacy, an SLO can facilitate community consent and reduce investment risks related to social opposition [87,80]). This framework could provide commercial developers with valuable guidance to mitigate social risks associated with multi-use projects.

4.4.8. Research and technological innovation

Pilot projects will be crucial in testing site-specific feasibility, generating empirical data that can inform future MSP revisions and optimize spatial planning. Investment in research and technological innovation is necessary to evaluate operational feasibility, environmental compatibility, and stakeholder engagement strategies. These efforts will help minimize environmental risks, optimize economic benefits, and assess social perceptions.

Although multi-use has been the subject of several studies [2], research focused on site-specific sea conditions and exploitation technologies is essential for its commercialization. The lack of knowledge about risks associated with combined offshore activities remains a major constraint on development (cf. weaknesses and threats in Section 4.3). As an initial step, multi-use potential assessments and impact evaluations (environmental, social, and economic) should be applied to determine feasibility (e.g., Multi-Use Assessment Approach, [81]; Ocean Multi-Use Assessment Framework, [55].

5. Conclusion

This study advances the discussion on multi-use integration within MSP by proposing a methodological framework adaptable to various policy contexts. The findings contribute to the ongoing debate on optimizing marine resource allocation while addressing socio-environmental concerns. While Spanish MSP acknowledges the potential of multi-use, it lacks concrete mechanisms for implementation. This research underscores the need for clear regulatory pathways and highlights key industry concerns – such as regulatory barriers, environmental uncertainties, and the lack of structured cross-sector collaboration – that must be addressed to improve policy effectiveness.

The proposed multi-use assessment framework provides a structured approach for evaluating the feasibility of integrating floating offshore wind energy and aquaculture within existing governance structures, primarily from a sectoral decision-making perspective. It highlights how multi-use can offer economic opportunities, improve spatial efficiency, and has the potential to enhance public perception of offshore projects, provided that regulatory, social, and environmental barriers are effectively addressed.

Although multi-use presents a promising strategy to maximize marine resource efficiency and reduce environmental footprints, its implementation requires a holistic and adaptive approach. This alignment must integrate technical feasibility with social, regulatory, and environmental considerations. This study provides insights into the sectoral dynamics of offshore multi-use, highlighting key recommendations and sectoral lessons, while recognizing critical barriers that must be addressed to facilitate its adoption. It lays the foundation for further research and policy development in this evolving field. Thus, it is essential to consider the broader marine spatial context. Spain's MSP framework (Royal Decree 150/2023) acknowledges that offshore activities must be compatible with existing uses, such as fishing, navigation, and marine protected areas. Future studies should integrate spatial compatibility assessments, social and environmental impact evaluations, and stakeholder engagement within a comprehensive MSP process.

CRediT authorship contribution statement

C. Weiss Carlos V.: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Elvira Ramos:** Writing – review & editing, Validation, Methodology, Formal analysis, Data curation. **Ondiviela Barbara:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Raúl Guanche:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization. **Lucía Meneses:** Writing – review & editing, Validation, Methodology, Formal analysis, Data curation. **José Juanes:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Acknowledgements

C.V.C. Weiss is grateful to the Universidad de Cantabria (UC) for the Augusto González de Linares and Margarita Salas Grants (POS-UC-2019-06 and RMS-04, respectively). This work is framed in the project "ACUFLOT", supported by the Biodiversity Foundation of the Ecological Transition and Demographic Challenge Ministry of Spain and the IHCantabria - Instituto de Hidráulica Ambiental de la Universidad de Cantabria. This contribution has been supported by the MEDAQUA-project (FPCUP WP 2020 (Ares (2020)2271454) and MSP-project (SGA#20/WP2021; Action 2021-2-33) funded by the European Commission (Directorate-General for Defence Industry and Space) and by FPCUP Work Programme.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2025.106786.

Data availability

Data will be made available on request.

References

[1] 4COffshore 2022. Maps: Global Offshore Map (4C Offshore Windfarm Map). Available from: http://www.4coffshore.com/offshorewind/.
[2] K.A. Abhinav, M. Collu, S. Benjamins, H. Cai, A. Hughes, B. Jiang, S. Jude, W. Leithead, C. Lin, H. Liu, L. Recalde-Camacho, N. Serpetti, K. Sun, B. Wilson, H. Yue, B.-Z. Zhou, Offshore multi-purpose platforms for a Blue Growth: A technological, environmental and socio-economic review, Sci. Total Environ. V. 734 (10) (2020) 138256, https://doi.org/10.1016/j.scitotenv.2020.138256.
[3] Aquamaps, 2019. Computer generated distribution maps, with modelled year 2050 native range map based on IPCC RCP8.5 emissions scenario. Available from: https://www.aquamaps.org.
[4] V. Aryai, R. Abbassi, N. Abdussamie, F. Salehi, V. Garaniya, M. Asadnia, A.-A. Baksh, I. Penesis, H. Karampour, S. Draper, A. Magee, A. Keng, K. Shearer, C. Sivandran, S. Yew, L.K. Cook, D. Underwood, M. Martini, A. Heasman, K. Abrahams, J. Wang, C-M, Reliability of multi-purpose offshore-facilities: Present status and future direction in Australia, Process Saf. Environ. Prot. V. 148 (2021) 437–461, https://doi.org/10.1016/j.psep.2020.10.016.
[5] S. Astariz, J. Abanades, C. Perez-Collazo, G. Iglesias, Improving wind farm accessibility for operation & maintenance through a co-located wave farm: Influence of layout and wave climate, Energy Convers. Manag. V. 95 (2015) 229–241, https://doi.org/10.1016/j.enconman.2015.02.040.
[6] Aymamí, J., García, A., Lacave, O., Lledó, L., Mayo, M., Parés, S. 2011. Análisis del recurso. Atlas eólico de España. Estudio Técnico PER 2011-2020. IDEA – Instituto para la Diversificación y Ahorro de la Energía. Available from: https://www.idae.es/uploads/documentos/documentos_11227_e4_atlas_eolico_A_9b90ff10.pdf.
[7] Bak, C., Zahle, F., Bitsche, R., Kim, T., Yde, A., Henriksen, L.C., Natarajan, A., Hansen, M.H. 2013. Description of the DTU 10 MW Reference Wind Turbine. DTU Wind Energy Report-I-0092. DTU Wind Energy. 138 pp.
[8] M.L. Bauchot, J.C. Hureau, Sparidae, in: J.C. Quero, J.C. Hureau, C. Karrer, A. Post, L. Saldanha (Eds.), Check-List fishes East. Trop. Atl. (CLOFETA). 2 (1990) 790–812 (JNICT, Lisbon; SEI, Paris; and UNESCO, Paris.).
[9] S.-L. Billing, G. Charalambides, P. Tett, M. Giordano, C. Ruzzo, F. Arena, A. Santoro, F. Lagasco, G. Brizzi, M. Collu, Combining wind power and farmed fish: Coastal community perceptions of multi-use offshore renewable energy installations in Europe, Energy Res. Soc. Sci. V. 85 (2022) 102421, https://doi.org/10.1016/j.erss.2021.102421.
[10] N.L. Bird, L.C.M. Chen, J. McLachlan, Effects of Temperature, Light and Salinity on Growth in Culture of *Chondrus crispus*. *Furcellaria lumbricalis*, *Gracilaria tikvahiae* (Gigartinales, Rhodophyta), and *Fucus serratus* (Fucales, Phaeophyta), Bot. Mar. 22 (8) (1979) 521–528, https://doi.org/10.1515/botm.1979.22.8.521.
[11] M. Bocci, S.J. Sangiuliano, A. Sarretta, J.O. Ansong, B. Buchanan, A. Kafas, M. Caña-Varona, V. Onyango, E. Papaioannou, E. Ramieri, A. Schultz-Zehden, M. F. Schupp, V. Vassilopoulou, M. Vergílio, Multi-use of the sea: A wide array of

opportunities from site-specific cases across Europe, PLoS One V. 14 (4) (2019), https://doi.org/10.1371/journal.pone.0215010.
[12] J. Borum, M.F. Pedersen, D. Krause-Jensen, P.B. Christensen, K. Nielsen, Biomass, photosynthesis and growth of *Laminaria saccharina* in a high-arctic fjord, NE Greenland, Mar. Biol. 141 (1) (2002) 11–19.
[13] B.H. Buck, G. Krause, H. Rosenthal, Extensive open ocean aquaculture development within wind farms in Germany: the prospect of offshore co-management and legal constraints, Ocean Coast. Manag. V 47 (2004) 95–122, https://doi.org/10.1016/j.ocecoaman.2004.04.002.
[14] B.H. Buck, G. Krause, B. Pogoda, B. Grote, L. Wever, N. Goseberg, N.S. Schupp, A. Mochtak, D. Czybulka, The German Case Study: Pioneer Projects of Aquaculture-Wind Farm Multi-Uses, in: B. Buck, R. Langan (Eds.), Aquaculture Perspective of Multi-Use Sites in the Open Ocean, Springer, Cham, 2017, https://doi.org/10.1007/978-3-319-51159-7_11.
[15] A. Cabello-Pasinia, E. Aguirre-von-Wobeser, F.L. Figueroa, Photoinhibition of photosynthesis in *Macrocystis pyrifera* (Phaeophyceae), Chondrus crispus (Rhodophyceae) Ulva Lact. (Chlorophyceae) Outdoor Cult. Syst. J. Photochem. Photobiol. B: Biol. 57 (2000) (2000) 169–178.
[16] H. Calado, E.A. Papaioannou, M. Caña-Varona, V. Onyango, J. Zaucha, J. Przedrzymirska, T. Roberts, S.J. Sangiuliano, M. Vergílio, Multi-uses in the Eastern Atlantic: Building bridges in maritime space, Ocean Coast. Manag. V. 174 (2019) 131–143, https://doi.org/10.1016/j.ocecoaman.2019.03.004.
[17] Chambers, M.D., Ostrowski, A.C. 1999. Development of bluefin trevally (Caranx melampygus) and greater amberjack (Seriola dumerili) for offshore aquaculture. In: Stickney, R.R. (Ed.), Joining Forces with Industry: Proceedings of the Third International Conference on Open Ocean Aquaculture, Corpus Christi, Texas (USA). Sea Grant College Program Publication, Texas A&M University, p. 132–141.
[18] Christensen, E.D., Calberg, L.K. (Editors). 2015. Go offshore - Combining food and energy production. ISBN: 978-87-7475-424-4.
[19] Y.I. Chu, C.M. Wang, J.C. Park, P.F. Lader, Review of cage and containment tank designs for offshore fish farming, Aquaculture V. 519 (2020) 734928, https://doi.org/10.1016/j.aquaculture.2020.734928.
[20] E. Ciravegna, L. van Hoof, C. Frier, F. Maes, H.B. Rasmussen, A. Soete, S.W.K. van den Burg, The hidden costs of multi-use at sea, Mar. Policy V. 161 (2024) 106017, https://doi.org/10.1016/j.marpol.2024.106017.
[21] P. Connolly, M. Hall, Comparison of pilot-scale floating offshore wind farms with shared moorings, Ocean Eng. V. 171 (2019) 172–180, https://doi.org/10.1016/j.oceaneng.2018.08.040.
[22] G. Dalton, T. Bardócz, M. Blanch, D. Campbell, K. Johnson, G. Lawrence, T. Lilas, E. Friis-Madsen, F. Neumann, N. Nikitas, S.T. Ortega, D. Pletsas, P.D. Simal, H. C. Sørensen, A. Stefanakou, I. Masters, Feasibility of investment in Blue Growth multiple-use of space and multi-use platform projects; results of a novel assessment approach and case studies V. 107 (2019) 338–359, https://doi.org/10.1016/j.rser.2019.01.060.
[23] D. Depellegrin, C. Venier, Z. Kyriazi, V. Vassilopoulou, C. Castellani, E. Ramieri, M. Bocci, J. Fernandez, A. Barbanti, Exploring Multi-Use potentials in the Euro-Mediterranean sea space, Sci. Total Environ. V. 653 (2019) 612–629, https://doi.org/10.1016/j.scitotenv.2018.10.308.
[24] DNV. 2010. Det Norske Veritas (DNV). OFFSHORE STANDARD - DNV-OS-E301 (Position Mooring). Available from: http://www.dnv.com/.
[25] DNV. 2020. Det Norske Veritas (DNV). OCEAN FARM 1 receives first ever offshore fish farming class certificate from DNV GL. Available from: https://www.dnv.com/news/ocean-farm-1-receives-first-ever-offshore-fish-farming-class-certificate-from-dnv-gl-165626/.
[26] N.J. Duncan, A. Estevez, H. Fernández-Palacios, L.R. Vallés, Aquaculture production of meagre (*Argyrosomus regius*): Hatchery techniques, ongrowing and market. Advances in aquaculture hatchery technology, Chapter: 17, Publisher: Woodhead Publishing, 2013, pp. 519–541, https://doi.org/10.1533/9780857097460.3.519 (Editors: Geoff Allan and Gavin Burnell).
[27] ECORYS, Deltares, OCEANIC 2012. Blue Growth: Scenarios and drivers for Sustainable Growth from the Oceans, Seas and Coasts. Glue Growth Final Report. Client: European Commission, DG MARE. Rotterdam/Brussels. MARE/2010/01.
[28] EIT InnoEnergy. 2020. The Iberian region as a hub for technology development and industrial leadership in the field of floating offshore wind. Summary Report. Enzen.
[29] Shanghai Electric. 2023. Floating Wind Power and Fishery Integrated Project Completed. Available from: https://www.shanghai-electric.com/group_en/c/2023-10-25/569438.shtml.
[30] EPO/IEA 2021. Patents and the energy transition: Global trends in clean energy technology innovation. International Energy Agency (IEA) and European Patent Office (EPO). ISBN: 978-3-89605-270-4.
[31] Equinor, 2024. Hywind Tampen: the world's first renewable power for offshore oil and gas. Available from: https://www.equinor.com/energy/hywind-tampen.
[32] European Commission, 2012. Blue Growth: Opportunities for marine and maritime sustainable growth. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Commitee and the Committee of the Regions Com. 494, European Commission, Brussels.
[33] European Commission, 2020. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the regions: An EU Strategy to harness the potential of offshore renewable energy for a climate neutral future. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX%3A52020DC0741.
[34] European Commission, 2021. On a new approach for a sustainable blue economy in the EU Transforming the EU's Blue Economy for a Sustainable Future. Communication from the Commission to the European Parliament. Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions. Brussels.
[35] European Commission, 2025a. Spain: Maritime Spatial Plan(s). Available from: https://maritime-spatial-planning.ec.europa.eu/countries/spain.
[36] European Commission, 2025b. Germany: Maritime Spatial Plan(s). Available from: https://maritime-spatial-planning.ec.europa.eu/countries/germany.
[37] European Commission, 2025c. Denmark: Maritime Spatial Plan(s). Available from: https://maritime-spatial-planning.ec.europa.eu/countries/denmark.
[38] European Commission, 2025d. Belgium: Maritime Spatial Plan(s). Available from: https://maritime-spatial-planning.ec.europa.eu/countries/belgium.
[39] European Commission, 2025e. Poland: Maritime Spatial Plan(s). Available from: https://maritime-spatial-planning.ec.europa.eu/countries/poland.
[40] European Union, 2004. Directive 2004/35/CE of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage. Available from: http://data.europa.eu/eli/dir/2004/35/oj.
[41] European Union, 2014. DIRECTIVE 2014/89/EU of the EUROPEAN PARLIAMENT and of the COUNCIL: Establishing a Framework for Maritime Spatial Planning. Available from:http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0089&from=EN.
[42] European Union, 2020. REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law'). Available from: https://data.consilium.europa.eu/doc/document/PE-27-2021-INIT/en/pdf.
[43] FAO 2005a. Cultured Aquatic Species Information Programme. Sparus aurata. Cultured Aquatic Species Information Programme. Text by Colloca, F., Cerasi, S. In: FAO Fisheries and Aquaculture Department. Rome.
[44] FAO 2005b. Cultured Aquatic Species Information Programme. Argyrosomus regius. Cultured Aquatic Species Information Programme. Text by Stipa, P., Angelini, M. In: FAO Fisheries and Aquaculture Department. Rome.
[45] FAO 2005c. Cultured Aquatic Species Information Programme. Dicentrarchus labrax. Cultured Aquatic Species Information Programme. Text by Bagni, M. In: FAO Fisheries and Aquaculture Department. Rome.
[46] FAO 2009. Mugil cephalus. In Cultured aquatic species fact sheets. Text by Saleh, M.A. Edited and compiled by Valerio Crespi and Michael New.
[47] FAO 2015. Cultured Aquatic Species Information Programme. Thunnus thynnus. Cultured Aquatic Species Information Programme. Text by De la Gándara, F. In: FAO Fisheries Division. Rome.
[48] FAO 2016. Cultured Aquatic Species Information Programme. Seriola dumerili. Cultured Aquatic Species Information Programme. Text by Herrera, J., Agius, R. V. In: FAO Fisheries and Aquaculture Department. Rome.
[49] FAO 2023a. Gadus morhua. Cultured Aquatic Species Information Programme. Text by Håkon Otterå. Fisheries and Aquaculture Division. Rome. Updated 2010-11-26. https://www.fao.org/fishery/en/culturedspecies/gadus_morhua/en.
[50] FAO 2023b. Oncorhynchus mykiss. Programa de información de especies acuáticas. Texto de Cowx, I. G. División de Pesca y Acuicultura. Roma. https://www.fao.org/fishery/es/culturedspecies/oncorhynchus_mykiss_es/es.
[51] FAO 2024. Global aquaculture production Quantity (1950 - 2021). Food and Agriculture Organization of the United Nations (FAO). Available from: https://www.fao.org/fishery/statistics-query/en/aquaculture/aquaculture_quantity [accessed 9 Jan. 2024].
[52] FAO 2004. Cultured Aquatic Species Information Programme. Salmo salar. Cultured Aquatic Species Information Programme. In: FAO Fisheries and Aquaculture Department. Rome.
[53] M. Føre, K. Frank, T. Norton, E. Svendsen, A. Alfredsen, T. Dempster, H. Eguiraun, W. Watson, A. Stahl, L.M. Sunde, C. Schellewald, K.R. Skøien, M.O. Alver, D. Berckmans, Precision fish farming: A new framework to improve production in aquaculture, Biosyst. Eng. V. 173 (2018) 176–193, https://doi.org/10.1016/j.biosystemseng.2017.10.014.
[54] E. Gaertner, J. Rinker, L. Sethuraman, F. Zahle, B. Anderson, G. Barter, N. Abbas, F. Meng, P. Bortolotti, W. Skrzypinski, G. Scott, R. Feil, H. Bredmose, K. Dykes, M. Shields, C. Allen, A. Viselli, Défin. IEA Wind 15-Megawatt Offshore Ref. Wind Turbine Tech. Report. Available (2020) (www.nrel.gov/publications).
[55] A.V. Gerven, T.R.H. Kerkhove, M. Lago, A. Araujo, M. Berge, O. Mashkina, A. Ziemba, G. El Serafy, J. Tamis, R. Jongbloed, G. Piet, M.J.C. Rozemeijer, S. Degraer, Facilitating an integrated assessment of impacts in marine multi-use: The Ocean Multi-use Assessment Framework (OMAF), Mar. Policy V. 173 (2025) 106570, https://doi.org/10.1016/j.marpol.2024.106570.
[56] A. Gonzalez, J. Beltran, B. Santelices, Colonisation and growth strategies in two Codium species (*Bryopsidales, Chlorophyta*) with different thallus forms, Phycologia 53 (4) (2014) 353–358, https://doi.org/10.2216/13-251.1.
[57] G.J. Gooley, S.S. De Silva, P.W. Hone, L.J. McKinnon, B.A. Ingram, Cage Aquaculture in Australia. A Developed Country Perspective to integrated Aquaculture Development Within Inland Waters, in: I.C. Liao, C.K. Lin (Eds.), Cage Aquac. Asia: Proc. First Int. Symp. . Cage Aquac. Asia (2000) 2–37. Asian Fisheries Society, Manila, and World Aquaculture Society — Southeast Asian Chapter, Bangkok.
[58] GROW 2023. Advancing multi-use in offshore wind farms. Roadmap for the Dutch North Sea (Road2SID report). Availeble from: https://grow-offshorewind.nl/files/downloads/Road2SID2023.pdf.
[59] R. Guanche, A.F. Jurado, B. Ondiviela, J. Juanes, Dispositivo flotante offshore de acuicultura para el cultivo de diversas especies de peces, Spain Pat. ES 2 (2016), 578 429, 26-07-2016.

[60] J. Guyot-Téphany, B. Trouillet, S. Diederichsen, E. Juell-Skielse, J.B. Thomas, J. McCann, C. Rebours, M. Scherer, P. Freeman, F. Gröndahl, J.P. Walsh, I. Lukic, Two decades of research on ocean multi-use: achievements, challenges and the need for transdisciplinarity, npj Ocean Sustain. V. 3 (2024) 8, https://doi.org/10.1038/s44183-024-00043-z.

[61] A. Hala, F. Chougule, K. Cunha, M.E. Mendes, M.C. Oliveira, I. Bradley, T. Forbes, J. Speranza, L.G, Life cycle assessment of integrated multi-trophic aquaculture: A review on methodology and challenges for its sustainability evaluation, Aquaculture V. 590 (2024) 741035, https://doi.org/10.1016/j.aquaculture.2024.741035.

[62] B.S. Halpern, M. Frazier, J. Potapenko, K.S. Casey, K. Koenig, C. Longo, J. S. Lowndes, R.C. Rockwood, E.R. Selig, K.A. Selkoe, S. Walbridge, Spatial and temporal changes in cumulative human impacts on the world's ocean, Nat. Commun. V. 6 (2015), https://doi.org/10.1038/ncomms8615.

[63] D. Hanelt, C. Wiencke, U. Karsten, W. Nultsch, Photoinhibition and recovery after high light stress in different developmental and life-history stages of *Laminaria saccharina* (Phaeophyta), J. Phycol. 33 (3) (1997) 387–395.

[64] P.C. Heemstra, J.E. Randall, FAO Species Catalogue. Vol. 16. Groupers of the world (family *Serranidae*, subfamily *Epinephelinae*). An annotated and illustrated catalogue of the grouper, rockcod, hind, coral grouper and lyretail species known to date. Rome: FAO. FAO Fish. Synop. 125 (16) (1993) 382.

[65] Hossu B., Korkut A.Y., Salnur S. 2005. Investigation on feeding tables for sea bass (Dicentrarchus labrax L., 1758) in net-cage (Pinar Marine Company) culture. In: Montero D. (ed.), Basurco B. (ed.), Nengas I. (ed.), Alexis M. (ed.), Izquierdo M. (ed.). Mediterranean fish nutrition. Zaragoza: CIHEAM, p. 35-43 (Cahiers Options Méditerranéennes; n. 63).

[66] J. Jonkman, S. Butterfield, W. Musial, G. Scott, Technical Report). Availablre from, Défin. a 5-MW Ref. Wind Turbine Offshore Syst. Dev. (2009). ⟨https://www.nrel.gov/docs/fy09osti/38060.pdf⟩. NREL/TP-500-38060.

[67] J. Jonkman, A. Robertson, W. Popko, F. Vorpahl, A. Zuga, M. Kohlmeier, et al., Results of Coupled Simulations of an Offshore Wind Turbine with Jacket Support Structure. Conference Paper, NREL/CP-5000-54124.. Offshroe Code Comparison Collaboration Continuation (OC4), Phase I, Engineers Conference., Rhodes, Greece, 2012.

[68] M. Jovera, A. García-Gómez, A. Tomás, F. De la Gándara, L. Pérez, Growth of Mediterranean yellowtail (*Seriola dumerilii*) fed extruded diets containing different levels of protein and lipid, Aquaculture V. 179 (1999) 25–33, https://doi.org/10.1016/S0044-8486(99)00149-0.

[69] I. Katavić, T.-J. Herstad, H. Kryvi, P. White, V. Franičević, N. Skakelja, Guidelines to marine aquaculture planning, integration and monitoring in Croatia, Proj. "Coast. zone Manag. Plan Croat. " (2005) 78 (Zagreb).

[70] S. Katz, Z. Kizner, Z. Dubinsky, M. Friedlander, Responses of *Porphyra linearis* (Rhodophyta) to environmental factors under controlled culture conditions, J. Appl. Phycol. 12 (3-5) (2000) 535–542, https://doi.org/10.1023/A:1008138227520.

[71] S. Kavadias, J. Castritsi-Catharios, A. Dessypris, Annual cycles of growth rate, feeding rate, food conversion, plasma glucose and plasma lipids in a population of European sea bass (*Dicentrarchus labrax*) farmed in floating marine cages, J. Appl. Ichthyol. V. 19 (2003) 29–34, https://doi.org/10.1046/j.1439-0426.2003.00346.x.

[72] K.Y. Kim, D.J. Garbary, 2007. Photosynthesis in *Codium fragile* (Chlorophyta) from a Nova Scotia estuary: responses to desiccation and hyposalinity, Mar. Biol. 151 (2007) 99107.

[73] J. Klijnstra, X. Zhang, S. van der Putten, C. Röckmann, Technical risks of offshore structures, in: B. Buck, R. Langan (Eds.), Aquaculture Perspective of Multi-Use Sites in the Open Ocean, Springer, Cham, 2017, https://doi.org/10.1007/978-3-319-51159-7_5.

[74] S.E. Lester, E.O. Ruff, K. Mayall, J. McHenry, Exploring stakeholder perceptions of marine management in Bermuda, Mar. Policy V. 84 (2017) 235–243, https://doi.org/10.1016/j.marpol.2017.08.004.

[75] X. Li, P. Zhao, G. Wang, D. Li, J. Wang, D. Delin, Effects of temperature and irradiance on early development of *Chondrus ocellatus* Holm (Gigartinaceae, Rhodophyta), Chin. J. Oceanol. Limnol. 28 (3) (2010) 508–513.

[76] K. Luning, Seweeds. Their Environment, Biogeography, and Ecophysiology, 544, John Wiley & Sons, 1990.

[77] M. Maar, A. Holbach, T. Boderskov, M. Thomsen, B.H. Buck, J. Kotta, A. Bruhn, Multi-use of offshore wind farms with low-trophic aquaculture can help achieve global sustainability goals, Commun. Earth Environ. V 4 (2023) 447, https://doi.org/10.1038/s43247-023-01116-6.

[78] S. Martínez-Llorens, J. Espert, J. Moya, M.J. Cerdá, A.T. Vidal, Growth and nutrient efficiency of meagre (*Argyrosomus regius*, Asso1801) fed extruded diets with different protein and lipid levels. International Journal of Fisheries and Aquaculture, V 3 (2011) 195–203.

[79] M. Martini, R. Guanche, I.J. Losada, C. Vidal, Accessibility assessment for operation and maintenance of offshore wind farms in the North Sea, Wind Energy V. 20 (2015) 637–656, https://doi.org/10.1002/we.2028.

[80] C. Mather, L. Fanning, Social licence and aquaculture: Towards a research agenda, Mar. Policy V. 99 (2019) 275–282, https://doi.org/10.1016/j.marpol.2018.10.049.

[81] McCann, J., Hodson, C., Walsh, J.P., Freeman, P., Lukic, I., Tephany, J.G., Trouillet, B., Thomas, J.-B., Juell-Skielse, E., Gröndahl, F., Rebours, C., Diederichsen, S., Scherer, M., Weiss, C.V.C., Lima, F.A.V., dos Santos, B.A.Q. 2023. Ocean Multi-Use Assessment Approach (MUAA). @MULTI-FRAME Project. ISBN: 979-8-218-17554-2. Availabre from: https://www.submariner-network.eu/multi-frame-publication-page.

[82] J.C. Medeiros, C.V.C. Weiss, M.E.G. Scherer, T.B.R. Gandra, J. Bonetti, Spatial compatibility between emerging marine economies and existing uses in the Exclusive Economic Zone of southern Brazil, Reg. Stud. Mar. Sci. V. 78 (2024) 103763, https://doi.org/10.1016/j.rsma.2024.103763.

[83] F.J. Méndez, M. Menéndez, A. Luceño, I.J. Losada, Estimation of the long-term variability of extreme significant wave height using a time-dependent Peak Over Threshold (POT) model, J. Geophys. Res. V. 111 (2006) 1–13, https://doi.org/10.1029/2005JC003344.

[84] MITECO 2022. Ministerio para la Transición Ecológica y el Reto Demográfico. Roadmap for the development of offshore wind and marine energy in Spain. Available from: https://www.miteco.gob.es/content/dam/miteco/es/ministerio/planes-estrategias/desarrollo-eolica-marina-energias/enhreolicamarina-pdf_accesible_tcm30-538999.pdf.

[85] MITECO 2023. Ministerio para la Transición Ecológica y el Reto Demográfico. Real Decreto 150/2023, de 28 de febrero, por el que se aprueban los planes de ordenación del espacio marítimo de las cinco demarcaciones marinas españolas. «BOE» núm. 54, de 4 de marzo de 2023, páginas 32350 a 32578 (229 págs.). BOE-A-2023-5704. Available from: https://www.boe.es/eli/es/rd/2023/02/28/150.

[86] MITECO 2025. Ministerio para la Transición Ecológica y el Reto Demográfico. Ordenación del espacio marítimo. Available from: https://www.miteco.gob.es/es/costas/temas/proteccion-medio-marino/ordenacion-del-espacio-maritimo.html.

[87] K. Moffat, A. Zhang, The paths to social licence to operate: An integrative model explaining community acceptance of mining, Resour. Policy V. 39 (2014) 61–70, https://doi.org/10.1016/j.resourpol.2013.11.003.

[88] M.C. Monfort, Present market situation and prospects of meagre (*Argyrosomus regius*), as an emerging species in Mediterranean aquaculture. Food and agriculture organization of the United Nations, Stud. Rev. N. 89 Gen. Fish. Comm. Mediterr. (2010). ISSN: 1020-9549.

[89] S.S. Nath, J.P. Bolte, G.R. Lindsay, J. Aguilar-Manjarrez, Applications of geographical information systems (GIS) for spatial decision support in aquaculture, Aquac. Eng. V. 23 (2000) 233–278, https://doi.org/10.1016/S0144-8609(00)00051-0.

[90] Ondiviela, B., Guanche, R., Ramos, E., Meneses, L., Weiss, C.V.C., Kotta, J., Juanes, J. Under review. Multi-use in the Mediterranean for the transition to clean energy and sustainable aquaculture.

[91] V. Onyango, E. Papaioannou, M.F. Schupp, J. Zaucha, J. Przedzymirska, I. Lukic, M.C. Varona, A. Schultz-Zehden, I. Giannelos, R. Läkamp, I. van de Velde, Is Demonstrating the Concept of Multi-Use Too Soon for the North Sea? Barriers and Opportunities from a Stakeholder Perspective, Coast. Manag. V. 48 (2) (2020) 77–95, https://doi.org/10.1080/08920753.2020.1728206.

[92] L.M. Page, B.M. Burr, A field guide to freshwater fishes of North America north of Mexico, Houghton Mifflin Harcourt, Boston, 2011, p. 663p.

[93] B.J. Palko, G.L. Beardsley, W.J. Richards, Synopsis of the biological data on dolphin-fishes, *Coryphaena hippurus* Linnaeus and *Coryphaena equiselis* Linnaeus. FAO Fish. Synop, NOAA Tech. Rep. NMFS Circ. 130 (1982) 443.

[94] L.V.L. Peña, B. Bas, J. Dewful, S.W.K. van den Burg, S.E. Taelman, Environmental Life Cycle Assessment of multi-use of marine space: A comparative analysis of offshore wind energy and mussel farming in the Belgian Continental Shelf with terrestrial alternatives, J. Clean. Prod. V. 470 (2024) 143271, https://doi.org/10.1016/j.jclepro.2024.143271.

[95] C. Peteiro, N. Sánchez, B. Martínez, Mariculture of the Asian kelp *Undaria pinnatifida* and the native kelp *Saccharina latissima* along the Atlantic coast of Southern Europe: An overview, Algal Res. 15 (2016) 9–23.

[96] C. Pita, G.J. Pierce, I. Theodossiou, Stakeholders' participation in the fisheries management decision-making process: Fishers' perceptions of participation, Mar. Policy V. 34 (5) (2010) 1093–1102, https://doi.org/10.1016/j.marpol.2010.03.009.

[97] Przedrzymirska, J., Zaucha, J., Depellgrin, D., Fairgrieve, R., Kafas, A., Calado, H., Vergílio, M.S., Varona, M.C., Lazić, M., Schultz-Zehden, A., Papaioannou, E., Bocci, M., Läkamp, R., Giannelos, I., Kovacheva, A., Buck, B. 2018. Multi-use of the sea: from research to practice. GLOBMAR 2018 - Global Maritime Conference. V. 58, DOI: https://doi.org/10.1051/shsconf/20185801025.

[98] F. Rezaei, P. Contestabile, D. Vicinanza, A. Azzellino, Towards understanding environmental and cumulative impacts of floating wind farms: Lessons learned from the fixed-bottom offshore wind farms, Ocean Costa Manag. V. 243 (2023) 106772, https://doi.org/10.1016/j.ocecoaman.2023.106772.

[99] F. Rezaei, P. Contestabile, D. Vicinanza, A. Azzellino, C.V.C. Weiss, J. Juanes, Soft vs. Hard Sustainability Approach in Marine Spatial Planning: Challenges and Solutions, Water V. 16 (10) (2024) 1–24, https://doi.org/10.3390/w16101382.

[100] Röckmann, C., Stuiver, M., Burg, S.V.D., Zanuttigh, B., Zagonari, F., Airoldi, L., et al. 2015. MERMAID Project - Platform Solutions. Brussels: MERMAID Project.

[101] J.P.-L. Ruyet, K. Mahé, N. Le Bayon, H. Le Delliou, Effects of temperature on growth and metabolism in a Mediterranean population of European sea bass, *Dicentrarchus labrax*, Aquaculture V. 237 (2004) 269–280, https://doi.org/10.1016/j.aquaculture.2004.04.021.

[102] S.J. Sangiuliano, Analysing the potentials and effects of multi-use between tidal energy development and environmental protection and monitoring: A case study of the inner sound of the Pentland Firth, Mar. Policy V. 96 (2018) 120–132, https://doi.org/10.1016/j.marpol.2018.08.017.

[103] M.E.G. Scherer, G.D. Sardinha, V. de Souza, T.B.R. Gandra, S.R. Floeter, A.M. R. Liedke, A.R. Rodrigues, J. Bonetti, V. Gomes, L. Fernandes, D.S. Ferrari, F. C. Silva, L.A. Conti, D. Pedreschi, M.A. Gasalla, Under pressure: an integrated assessment of human activities and their potential impact on the ecosystem

components of the Southern Brazilian continental shelf, npj Ocean Sustain. V. 3 (2024) 9, https://doi.org/10.1038/s44183-024-00044-y.
[104] D. Schuchardt, H. Fernández-Palacios, J. Roo, C.M. Hernández-Cruz, Estabulación y mantenimiento de un stock de reproductores de corvina (*Argyrosomus regius*, Asso, 1801), en Canarias, Libro De. Actas Toma II XI Congr. Nac. De. Acuic., Vigo. Pontevedra.: Graf. Salnes SL (2007) 727–730.
[105] A. Schultz-Zehden, I. Lukic, J.O. Ansong, S. Altvater, R. Bamlett, A. Barbanti, M. Bocci, et al., Ocean Multi-Use Action Plan, MUSES Proj. (2018) (Edinburgh).
[106] M.F. Schupp, M. Bocci, D. Depellegrin, A. Kafas, Z. Kyriazi, I. Lukic, A. Schultz-Zehden, G. Krause, V. Onyango, B. Buck, Toward a Common Understanding of Ocean Multi-Use. Front. Mar. Sci. (2019) https://doi.org/10.3389/fmars.2019.00165.
[107] I. Seginera, J. Ben-Asher, Optimal harvest size in aquaculture, with RAS cultured sea bream (*Sparus aurata*) as an example, Aquac. Eng. V. 44 (2011) 55–64, https://doi.org/10.1016/j.aquaeng.2011.03.001.
[108] J. Serôdio, S. Cruz, P. Cartaxana, R. Calado, Photophysiology of kleptoplasts: photosynthetic use of light by chloroplasts living in animal cells, Philos. Trans. R. Soc. B 369 (2014) 20130242, https://doi.org/10.1098/rstb.2013.0242.
[109] Silva, M. 2018. Cultivation of Osmundea pinnatifida and Codium tomentosum, native seaweed species with commercial potential. PhD. Universidade Do Porto. 71pp.
[110] Sogn, G. 2013. PhD-thesis: Growth, survival and reproduction in the kelp Saccharina latissima – Seasonal patterns and the impact of epibionts.University of Oslo.
[111] M. Stancheva, H. Stanchev, J. Zaucha, E. Ramieri, T. Roberts, Supporting multi-use of the sea with maritime spatial planning. The case of a multi-use opportunity development - Bulgaria, Black Sea, Mar. Policy V. 136 (2022) 104927, https://doi.org/10.1016/j.marpol.2021.104927.
[112] Standard Norge 2009. Norwegian Standard NS 9415.E:2009. Marine fish farms: Requirements for site survey, risk analyses, design, dimensioning, production, installation and operation.
[113] D.B. Stengel, R.J. Wilkes, M.D. Guiry, Seasonal growth and recruitment of *Himanthalia elongata* (Fucales, Phaeophycota) in different habitats on the Irish west coast, Eur. J. Phycol. 34 (3) (1999) 213–221.
[114] TELWIND PROJECT 2018. Available form: http://www.esteyco.com/projects/telwind/.
[115] V. Ticina, I. Katavic, L. Grubisic, Growth indicies of small northern bluefin tuna (*Thunnus thynnus*, L.) in growth-out rearing cages, Aquaculture V. 269 (2007) 538–543, https://doi.org/10.1016/j.aquaculture.2007.05.029.
[116] J.W. Tucker, Kluwer Academic Publishers, Norwell Massachusetts, USA, Mar. Fish. Cult. (1998).
[117] UNESCO-IOC/European Commission 2021. MSPglobal International Guide on Marine/Maritime Spatial Planning. Paris, UNESCO. (IOC Manuals and Guides no 89).
[118] United Nations 2012. Blue Economy Concept Paper. United Nations Conference on Sustainable Development. Rio de Janeiro, 20–22 June 2012.
[119] United Nations 2015. Transforming our world: The 2030 agenda for the sustainable development - A/RES/70/1. Available from: www.sustainabledevelopment.un.org.
[120] S.W.K. van den Burg, J. Aguilar-Manjarrez, J. Jenness, M. Torrie, Assessment of the geographical potential for Co-use of marine space, based on operational boundaries for blue growth sectors, Mar. Policy V. 100 (2019) 43–57, https://doi.org/10.1016/j.marpol.2018.10.050.
[121] S.W.K. van den Burg, C. Röckmann, J.L. Banach, L. van Hoof, Governing Risks of Multi-Use: Seaweed Aquaculture at Offshore Wind Farms, Front. Mar. Sci. V. 7 (2020) 60, https://doi.org/10.3389/fmars.2020.00060.
[122] S.W.K. van den Burg, M.F. Schupp, D. Depellegrin, A. Barbanti, S. Kerr, Development of multi-use platforms at sea: Barriers to realising Blue Growth, Ocean Eng. V. 217 (2020) 107983, https://doi.org/10.1016/j.oceaneng.2020.107983.
[123] L. van Hoof, S.W.K. van den Burg, J.L. Banach, C. Röckmann, M. Goossen, Can multi-use of the sea be safe? A framework for risk assessment of multi-use at sea, Ocean Coast. Manag. V. 184 (2020) 105030, https://doi.org/10.1016/j.ocecoaman.2019.105030.
[124] C.V.C. Weiss, J. Bonetti, M.E.G. Scherer, B. Ondiviela, R. Guanche, J.A. Juanes, Towards blue growth: Multi-use possibilities for the development of emerging sectors in the Brazilian sea, Ocean Coast. Manag. V. 243 (2023) 106764, https://doi.org/10.1016/j.ocecoaman.2023.106764.
[125] C.V.C. Weiss, R. Guanche, B. Ondiviela, O.F. Castellanos, J.A. Juanes, Marine renewable energy potential: A global perspective for offshore wind and wave exploitation, Energy Convers. Manag. V. 177 (2018) 43–54, https://doi.org/10.1016/j.enconman.2018.09.059.
[126] C.V.C. Weiss, M. Menendez, B. Ondiviela, R. Guanche, I.J. Losada, J.A. Juanes, Climate change effects on marine renewable energy resources and environmental conditions for offshore aquaculture in Europe, ICES J. Mar. Sci. V. 77 (2020) 3168–3182, https://doi.org/10.1093/icesjms/fsaa226.
[127] C.V.C. Weiss, B. Ondiviela, R. Guanche, O.F. Castellanos, J.A. Juanes, A global integrated analysis of open sea fish farming opportunities, Aquaculture V. 497 (2018) 234–245, https://doi.org/10.1016/j.aquaculture.2018.07.054.
[128] C.V.C. Weiss, B. Ondiviela, X. Guinda, F. del Jesus, J. González, R. Guanche, J. Juanes, Co-location opportunities for renewable energies and aquaculture facilities in the Canary Archipelago, Ocean Coast. Manag. V. 166 (2018) 62–71, https://doi.org/10.1016/j.ocecoaman.2018.05.006.
[129] E. Willsteed, A.B. Gill, S.N.R. Birchenough, S. Jude, Assessing the cumulative environmental effects of marine renewable energy developments: establishing common ground, Sci. Total Environ. V. 577 (2017) 19–32, https://doi.org/10.1016/j.scitotenv.2016.10.152.
[130] E. Willsteed, S. Jude, A.B. Gill, S.N.R. Birchenough, Obligations and aspirations: a critical evaluation of offshore wind farm cumulative impact assessments, Renew. Sustain. Energy Rev. V. 82 (3) (2017) 2332–2345, https://doi.org/10.1016/j.rser.2017.08.079.
[131] K.L. Wilson, L.M. Kay, A.L. Schmidt, H.K. Lotze, 2015. Effects of increasing water temperatures on survival and growth of ecologically and economically important seaweeds in Atlantic Canada: implications for climate change, Mar. Biol. 162 (2015) 2431–2444.
[132] Wind Europe 2022. Offshore Wind in Europe: Key trends and statistics 2021. Belgium. Available from: https://windeurope.org/intelligence-platform/statistics/.
[133] H. Wright, Japan's Kinki first again, Fish. Farming Int. (FFI) May 2008 (2008) 22–23.
[134] M.H. Yang, G. Blunden, F.L. Huang, R.L. Fletcher, Growth of a dissociated, filamentous stage of Codium species in laboratory culture, J. Appl. Phycol. 9 (1) (1997), https://doi.org/10.1023/A:1007996207924.
[135] B. Zanuttigh, E. Angelelli, A. Kortenhaus, K. Koca, Y. Krontira, P. Koundouri, A methodology for multi-criteria design of multi-use offshore platforms for marine renewable energy harvesting, Renew. Energy V. 85 (2016) 1271–1289, https://doi.org/10.1016/j.renene.2015.07.080.
[136] Y. Zhai, H. Zhao, X. Li, M. Feng, Y. Zhou, Effects of aquaculture cage and netting on dynamic responses of novel 10MW barge-type floating offshore wind turbine, Ocean Eng. V. 295 (2024) 116896, https://doi.org/10.1016/j.oceaneng.2024.116896.