Offshore wind power and aquaculture in the Canary Islands

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***Abstract*— Renewable energy production is a priority challenge for societies, as highlighted by the industrial policies of the European Union (EU). In parallel, there is a need to develop alternative solutions for food production and food security. In this context, aquaculture of lower trophic groups, such as bivalves and algae, is of particular interest to policy-makers, as it does not intensify pressures on terrestrial ecosystems. In this study, we intend to address one of the crucial issues related to MSP: the effective planning of sites for wind farms and aquaculture in coastal areas where space is limited. To this end, we take the island of Gran Canaria as a case study. The EU-funded AquaWind project exemplifies this potential, with the installation of the W2Power prototype, a large-scale floating offshore wind farm. This innovative technology allows wind turbines to operate in deep-sea areas, offering numerous benefits, including reduced environmental impact and cost. We compared the offshore wind distribution in same costal aquaculture sites on the wetern side of Gran Cnaria island, in order to establish the most formable conditions for the co-location of both technologies.**

Keywords— Wind, energy, sustainable, waves, Canary Islands, power, aquaculture.

I. Introduction

Co-locating offshore wind farms (OWF) with low trophic aquaculture (LTA) has been suggested as an efficient multi-use strategy providing emission-free energy, nutritious seafood, and restorative ecosystem services through capture and utilization of emission (carbon dioxide (CO_2) and nutrients) [12].

Low Trophic Aquaculture delivers important targets such as the provisioning of food and feed with fewer resources required and a low carbon footprint compared to terrestrial protein production. Infact, CO_2 and dissolved nutrients are built into seaweed biomass through photosynthesis, uptake, and growth. CO_2 is built into mussel shells by bio-calcification, whereas organic carbon (C) and nutrients are incorporated into mussel tissue through filtration of suspended particulate organic matter.

Several projects in northern Europe have modeled and tested for the combination of OWF with low-trophic aquaculture. These feasibility studies demonstrated that the multi-use of OWF combined with aquaculture of blue mussels (Mytilus spp.) and sugar kelp (Saccharina latissima) was promising in the saline North Sea.

Aquaculture, which consists of the cultivation of aquatic organisms such as fish, molluscs and algae, is crucial to island economies, providing food protein, employment and income [1]. The crystal-clear, nutrient-rich waters surrounding the Canary Islands provide an ideal environment for a variety of marine species, favouring the development of aquaculture in various forms [2]. However, it is essential that this growth takes place in a sustainable manner, with environmentally friendly farming practices and minimal environmental impact [3]. In parallel, the installation of offshore and onshore wind farms allows for the exploitation of a renewable resource to produce clean and sustainable energy [2], although it is crucial to manage landscape and social impacts through dialogue with local communities and careful planning [4]. The Canary Islands, a volcanic archipelago off the northwest coast of Africa, offer substantial opportunities for sustainable development in aquaculture and wind energy. The nutrient-rich waters around the islands support diverse marine species, fostering the growth of sustainable aquaculture, in fact they are characterised by persistent winds, offer an ideal environment for wind energy. On the other hand, The aim of the present study is to explore and model the OWF LTA concept on Gran Canaria archipelago, as a mean to contribute to multiple global SDGs. (*fig.1*).

The EU-funded AquaWind project (https://aquawind.eu/news/) represents a significant milestone in the offshore wind energy landscape. This project involves the installation of a floating platform, the W2Power prototype (https://enerocean.com/w2power/). The latter is the first large-scale floating offshore wind farm to be installed in deep waters in Europe. It is capable of accommodating two wind turbines of 6 MW each, with a total capacity of 12 MW and was installed off the south-east coast of Gran Canaria, Spain, near the town of Arinaga.(*fig.1*) in spring 2019 and has been operating successfully for over two years. The Plataforma Oceánica de Canarias (PLOCAN) (https://plocan.eu/en), was given the task of monitoring and acquiring data on the platform's behaviour and environmental impact to test and validate the technical and economic feasibility of this project.

This innovative technology utilises wind turbines mounted on floating platforms, allowing installation in deep-sea areas inaccessible to traditional ground-fixed wind turbines. The use of floating platforms offers several advantages, including greater flexibility in the choice of installation site, less influence on the marine environment, and reduced installation and maintenance costs.

The paper will focus on analysing wind intensity in the north-eastern part of the Gran Canaria Island, assessing the potential for wind energy exploitation in this specific geographical area as well as the feasibility of combining aquaculture and energy from wind turbines, through a method taken by Benassai et al. [13].

Fig. 1. Canary Islands in general, with a focues on the isle of Gran Canaria.

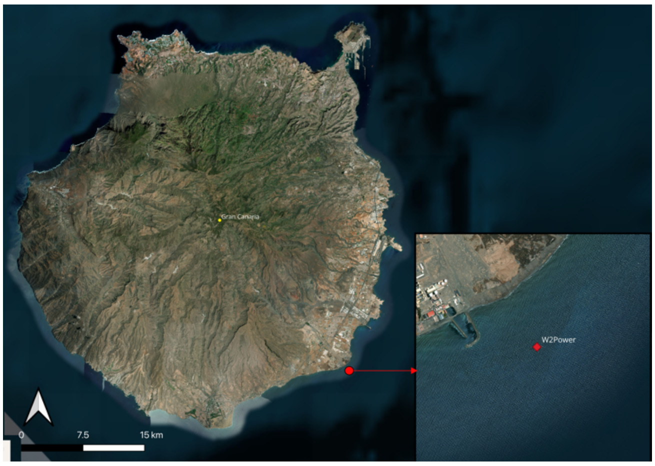

Fig. 2. Installation point of the W2Power prototype.

II. AQUACULTURE IN THE CANARY ISLANDS

Intensive aquaculture has proven to be an important economic resource for many coastal communities, not only in the Mediterranean but also in other maritime regions. This practice, which involves the commercial farming of aquatic organisms in captivity, is characterised using floating tanks or cages and the use of artificial feeds to maximise yields per unit volume.[5]. The Canary Islands, with marine farms in Lanzarote, Tenerife, La Palma and Gran Canaria, are also witnessing an expansion of this activity(*fig.2*) . The Spanish Institute for Nature Conservation (ICONA) wrote the first page of modern aquaculture in the Canaries in the 1960s, with a trout farm in La Orotava (Tenerife) that still thrives today. A subsequent milestone was the Conference on Aquaculture (CONCUMAR) held in Lanzarote in 1980, which ignited a new ferment for this sector. [6].
Between 1986 and 1989, some enterprising courageous companies entered the industrial landscape of Canary Island aquaculture. However, the path was not without obstacles: only few of them managed to survive, adapting and reinventing themselves over time [6].

In recent years, the aquaculture sector in the Canaries has experienced significant growth. In 1998, only four companies were operating in this field (see table 1), whereas today the number has risen to fourteen, demonstrating infectious dynamism and vitality (tab.1).

Alevines y Doradas S.A. (ADSA) stands out as the largest company in the sector, representing a benchmark for innovation and quality.

A hallmark of the sector's recent expansion is the adoption of offshore installations with cages. This strategic choice makes it possible to take advantage of sea currents and favourable environmental conditions, promoting healthy and sustainable growth of the animals.

The largest production units, with high production potential and significant employment impact, are located in Gran Canaria, confirming the island as a pole of excellence for modern aquaculture.[7].

In this respect, the installations of floating crop cages in Gran Canaria are concentrated in Melenara Bay (municipality of Telde), Gando Bay (municipalities of Ingenio and Agüimes) and from Punta de Tenefé to Punta de Tarajalillo (municipality of San Bartolomé de Tirajana). The base ports used by these three areas are Taliarte, Arinaga and Castillo del Romeral, respectively. (*fig.3*) There are currently two other projects under development for the municipalities of La Aldea de San Nicolás and Mogán.

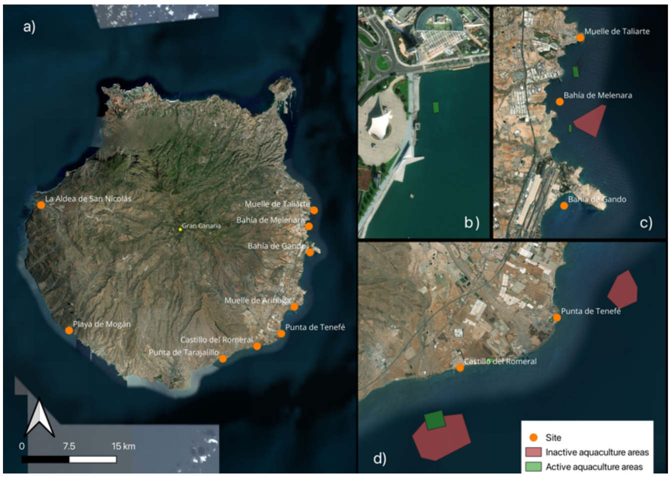

Fig. 3. Aquaculture sites in Gran Canaria. a) general shot, b) zoom on Puerto de La Luz in Las Palmas, c) zoom north-eastern coastal area, d) zoom south-eastern coastal area.

TABLE I. COMPANIES OPERATING IN THE AQUACULTURE SECTOR ON THE ISLAND OF GRAN CANARIA.

FARM	TYPE	FISH	SITE
Alevines Y Doradas, S.A. (Adsa) Castello Del Romeral	Cultivation in land-based tanks.	sole	Municipality of San Bartolomé de Tiraiana.
Productos De Crianza, S.L. (Procría)	Cultivation in floating cages	sea bass	24 Floating cages in front of the port of Castillo del Romeral
Alevines Y Doradas, S.A. (Adsa) Melenara/ Salinetas	Cultivation in floating cages	sea bass	18 floating cages in Melenara Bay (Telde)
Opulent Ocean, S.L.	Cultivation in floating cages	sea bass	24 floating cages located in front of the Punta de Tarajalillo, south of the port of Castillo del Romeral.

A. *Advantages and disadvantages*

The Canary Islands boast a higher average water temperature than the Mediterranean or other Atlantic areas, a key factor that has favoured the expansion of aquaculture in the archipelago. This warm climate favours faster growth of fish, reducing the time needed to reach commercial size.

As a result, production costs, particularly those related to feeding, are lowered. In addition to the favourable climate, the European Union has contributed to the development of the sector through the provision of subsidies. These incentives have made it possible to invest in new technologies and infrastructure, encouraging modernisation and increasing production capacity. [7].

However, the effect of aquaculture on the environment has been the focus of attention in recent years, particularly in intensive offshore fish farms. The main environmental issues related to aquaculture include:Pollution from unconsumed feed and excrement as some of the feed given to fish is not ingested and, together with animal excrement, can contribute to water eutrophication.

In addition, the use of chemicals such as antibiotics, pesticides and other products in aquaculture can have a negative impact on the marine environment. [5]

III. WIND ENERGY

The Canary Islands, located in the Atlantic Ocean off the northwest coast of Africa, are characterised by a persistent wind regime that makes them an ideal area for the exploitation of wind energy [8],[9]. This regime is determined by a combination of factors, including:

- Azores anticyclone: This semi-permanent high-pressure system located in the North Atlantic influences the airflow towards the Canary Islands, generating trade winds from the northeast (Santana et al., 2016).

- Orographic effect: Lemon Mountains that characterise the landscape of the islands channel the winds, increasing their intensity in specific areas [10].

- Canary Current: This cold current flowing along the western coast of the archipelago contributes to creating a pressure gradient that favours wind formation [11].

In this study, we aim to examine the specific wind potential of the north-eastern area of Gran Canaria, focusing on wind intensity and its implications for renewable energy production. Through a detailed analysis of wind intensity data in this area, we will estimate the amount of wind energy that can potentially be generated. This estimate will allow us to assess the feasibility of installing wind farms, quantifying their potential environmental and economic benefits.

We will use historical data from meteorological stations located in the north-eastern area of Gran Canaria (fig.4), managed by PLOCAN (https://plocan.eu/en). PLOCAN is a multi-purpose scientific and technical service infrastructure that provides support for research, technological development and innovation in the marine and maritime sectors (https://plocan.eu/en).

PLOCAN stations are equipped with high-quality sensors for measuring meteorological parameters such as wind speed, wind direction, temperature, atmospheric pressure and humidity.

In addition to the data measured directly by PLOCAN stations, we will also consider simulated data from the SIMAR set operated by Puertos del Estado (https://www.puertos.es/es-). The SIMAR set comprises time series of wind and wave parameters obtained from advanced numerical models.

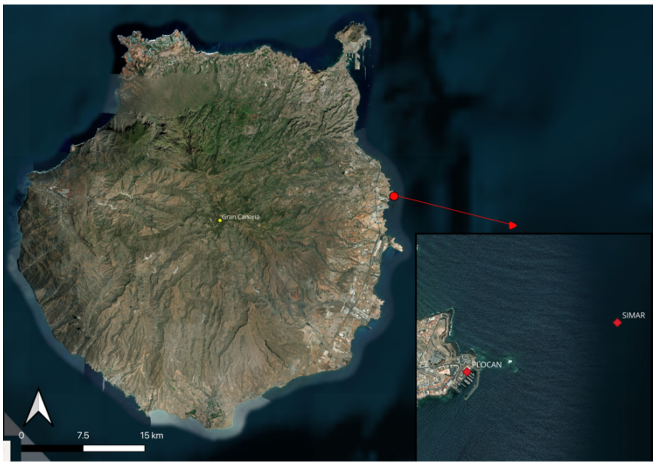

Fig. 4. Location of weather station 502 operated by PLOCAN and location of point 4038009 of SIMAR set operated by Puertos del Estado.

These simulated data provide a wider spatial and temporal coverage than measured data, allowing wind potential to be assessed in a more comprehensive context. The SIMAR set covers both the Mediterranean Sea and the Atlantic Ocean, both in open waters and on the coast. This makes it possible to assess wind potential in different geographical areas and to identify the most promising sites for the installation of wind farms.

Point 4038009 (*fig.4*) was considered.

A. Directional wind distribution (on-site data and model data)

Through the processing of on-site data, it was possible to assess the directional distribution of wind speeds for the north-eastern area of Gran Canaria (meteorological station 502). These are shown in the figure (*Fig.5-a*) during the entire reference period (December 2017 - November 2021). The meteorological station provides data every 15 minutes, which is useful for understanding the prevailing wind direction in that area. The same was done for the SIMAR model data. Figure 5-b shows the directional distribution of wind speeds for point 4038009 located near meteorological station 502. The same period (December 2017 - November 2021) was taken as a reference and the data are provided hourly. To compare the two scenarios, the on-site data were averaged (*Fig. 5*).

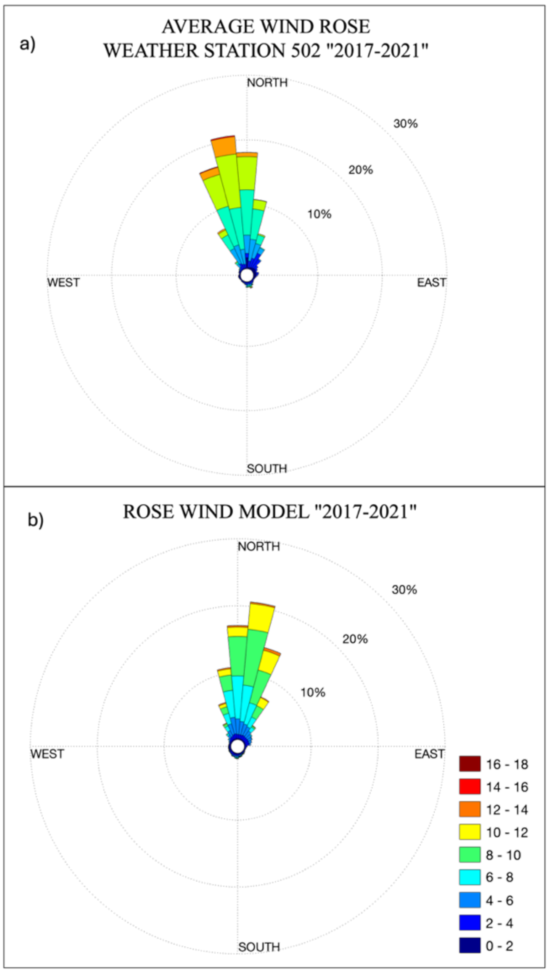

Fig. 5. Wind speed direction from December 2017 to November 2021. a) recorded by weather station 502. b) recorded by SIMAR model data the point 4038009.

Figure 5-a shows that the wind has a predominantly north-west directional distribution, while Figure 5-b shows that the wind has a predominantly north-east directional distribution. This discrepancy is since the on-site station is installed on a building in the harbour of Talliate and therefore the data are influenced by the orography, whereas the data from SIMAR point 4038009, are recorded offshore the coast.

B. Integration of Wind Energy and Aquaculture in the Canary Islands.

The presented work aims to explore potential synergies between aquaculture and wind power plants. Specifically, it focuses on identifying optimal sites for the installation of wind turbines near existing fish farms in the north-eastern part of the island. To pursue this objective, additional SIMAR (Integrated Environmental and Resource Monitoring System) points were selected from the existing network in the area. These points were chosen based on their proximity to active aquaculture facilities. Subsequently, for each selected SIMAR point, the extractable wind power was assessed. Finally, an index was developed that integrates the information on extractable wind power with other relevant factors, such as the distance to aquaculture sites and the availability of electricity grid infrastructure. This index makes it possible to identify the sites with the most favourable combination for the installation of a wind power system in synergy with existing aquaculture facilities.

IV. Materials and Methods

For the evaluation of wind power, data from the SIMAR point shown in the figure 6. Wind power was assessed at a height of 15 metres, using a vertical axis micro wind turbine DS3000 with a rated power of 3kW. As the wind speeds provided were calculated at a height of 10 metres, it was necessary to evaluate this figure at a height of 13 metres, as the turbine will be installed on a pole with a maximum height of 8 m, using Naegeli's formula (1954):

$$V_h=V_{10}*[0.233+0.656\log(h+4.75)] \qquad (1)$$

Next, the power generated by the turbine (*fig 7*) was evaluated for the different points (*fig 6*) considering a power coefficient of 0.28 using the following formula:

$$P = \frac{1}{2}\,Cp\,\rho\,A\,v^3 \qquad (2)$$

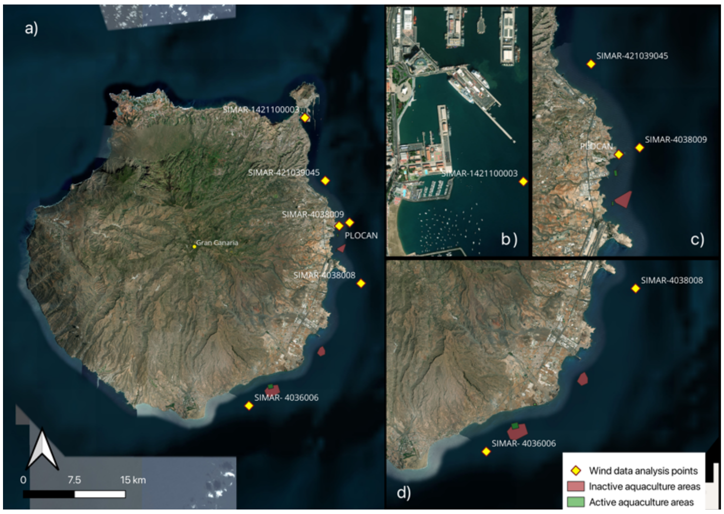

Fig. 6. Location of SIMAR set points operated by Puertos del Estado along the east coast of the island of Gran Canaria.

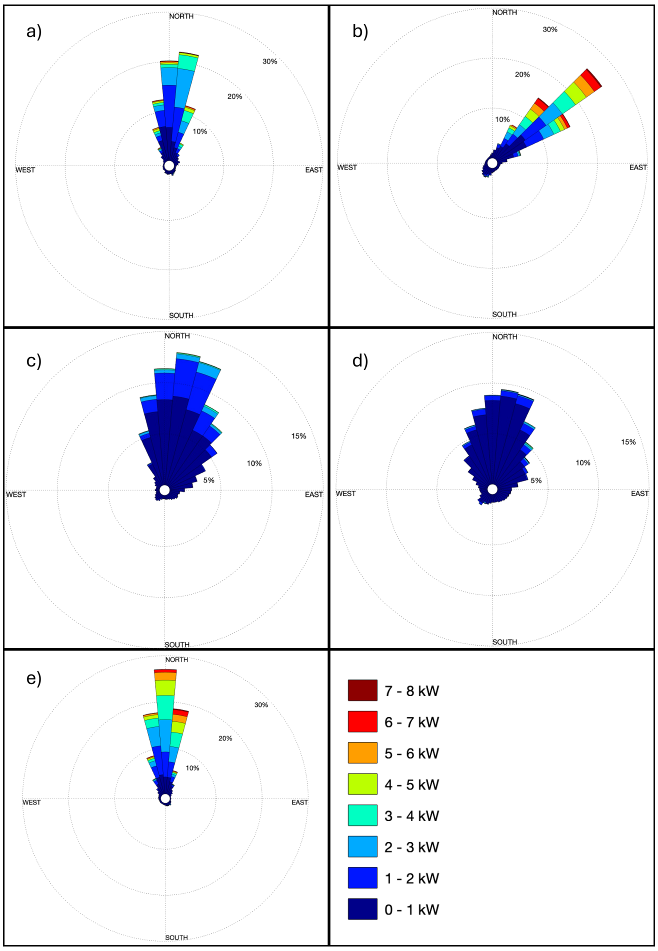

Fig. 7. Power rose generated by the wind in a typical year. a) power of the SIMAR-4038009 point. b) power of the SIMAR-4036006 point. c) power of the SIMAR-421039045 point. d) power of the SIMAR-1421100003 point. e) power of the SIMAR-4038008 point.

In order to assess the optimal site for the installation of an offshore wind farm, a 'typical year' was considered to estimate the amount of energy that could be extracted from each site using the selected turbine model, taking into account that the latter has a blocking speed of 15 m/s.
Table II shows the variables that were used to calculate the sustainability index (SI). The first two take into account the depth of the seabed and the wind power [13], while the last MVI [14]used to quantify the stability of wind resources. This factor can be calculated as follows:

$$MVI = \frac{\max(WPD_m)-\min(WPD_m)}{WPD_a} \qquad (3)$$

where $WPDm$ represents monthly average WPD;$WPD\alpha$ denotes annual average WPD; max(•) and min(•) are maximum operator and mini- mum operator, respectively.

We defined the Sustainability Index (SI) as the geometric mean of all environmental indexes relevant to our study.
The environmental index was based on the values of wind power, water depth, and MVI. These values were then modified by their Parameter Specific Sustainability Functions, that is:

$$\mathrm{SI} = \prod_{i=1}^{n} PSSF_i \qquad (4)$$

Were the $PSSF_i$ were defined on an arbitrary scale between 0 and 1, where 0 indicates a non-suitable value and 1 represents the most suitable.

TABLE II. RANKING OF SUSTAINABILITY INDEX (SI) VARIABLES.

Ranking of SI	1	2	3	4
Wind Power ($x10^3$)	<1	1-1.5	1.5-2	>2.0
Water depth	>50	30-50	10-30	<10
MVI	>28	25-28	20-25	<20

TABLE III. ENERGY PRODUCED IN A TYPICAL YEAR USING A MINI-WIND TURBINE MODEL DS3000.

Site	Coordinates	Bathymetry [m]	Energy [kWh]	SI1	SI2	SI3	SI
SIMAR-4038009	15.33°W; 28.00°N	30 - 50	12398.58	0.50	0.50	0.75	0.19
SIMAR-4036006	15.50°W; 27.74°N	>50	25002.41	0.25	1.00	0.25	0.06
SIMAR-421039045	15.30°W; 28.10°N	30 - 50	7012.4	0.50	0.25	0.75	0.09
SIMAR-1421100003	15.42°W; 28.13°N	< 10	4164.4	1.00	0.25	0.50	0.13
SIMAR-4038008	15.33° W; 27.92° N	>50	17837.29	0.25	0.75	1.00	0.19

As shown in Table III, two sites SIMAR-4038009 and SIMAR-4038008 are observed to have a significantly high sustainability index, mainly attributable to favourable wind conditions. These areas are characterised by high and constant average speeds, making them particularly suitable for the installation of wind turbines. These conditions make the sites ideal for the implementation of a hybrid plant integrating aquaculture and wind turbines.

V. RESULTS AND DISCUSSION

In this study, we analysed the energy potential of several sites for the installation of offshore wind turbines, with a focus on the possibility of supplementing existing aquaculture systems with mini-wind turbines. The results show that sites SIMAR-4038009 and SIMAR-4038008, located in the south-eastern part of the island, have a significantly high sustainability index, mainly attributable to favourable wind conditions. The areas are in fact characterised by high and constant average speeds, making them particularly suitable for the installation of wind turbines.

The area is already occupied by active aquaculture facilities, making it possible to design a mixed system combining aquaculture cages and mini-wind turbines. This innovative solution optimises the use of marine space, allowing the coexistence of two complementary infrastructures with reduced environmental impact and more efficient resource management. Preliminary results indicate that the adoption of mixed facilities could be a sustainable and beneficial strategy for the development of local energy and food resources.

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