Economic and financial evaluation of a floating wind project in the Northwest of the Iberian Peninsula

Teresa Cardoso[1], Regina Salvador[2]

[1]PhD student at NOVA-FCSH, a2023106842@campus.fcsh.unl.pt

[2]Coordinator Jean Monnet Centre of Excellence on 'Sustainable Blue Europe'; Ph.D. Professor at Universidade NOVA de Lisboa, regina.salvador@fcsh.unl.pt

Abstract

The acceleration of energy consumption has been subject of special attention from both the political class and the scientific community. There is a need to take measures aiming to reduce the use, or even non-use, of fossil fuels. On one hand, to combat climate change, and on the other, to ensure countries' energy independence. In this context, targets have been set for the incorporation of renewable energies into gross final consumption, especially with the use of floating offshore wind energy, due to technology's development. In addition, floating wind energy will contribute to achieve the Sustainable Development Goals (SDGs) set out in the United Nations 2030 Agenda. Portugal is no exception. In fact, its geographical location gives it a significant advantage when it comes to utilising this renewable resource. Mainland Portugal's maritime space, under national sovereignty or jurisdiction, extends over 591.502 km^2. If, on one hand, the ocean's tridimensionality poses challenges in terms of governance and maritime spatial planning, on the other hand, it allows for various human activities and use. This work presents a case study, the implementation of two offshore floating wind farms in two areas in the northwest of the Iberian Peninsula (Viana do Castelo), with a capacity of 1.98GW. The exclusion criteria, among other things, for geo-referencing the areas were analysed. Different scenarios were created using the OffshorePlan platform and the economic and financial viability of the project was assessed by analysing the sensitivity of the Net Present Value, Internal Rate of Return and the Payback Period indicators. The variations between the probable values imposed by potential shareholders - NPV (2.5 M€), IRR (10%), and Payback Period (10 years), and those obtained - NPV (3 M€), IRR (13.18%), and Payback Period (9.3 years) - were exceeded by 22%, 31.8%, and 7.5%, respectively.

These results support the decision to approve investment in the hypothetical economic operator's project. The values obtained for the Levelised Cost of Electricity are also considered acceptable.

Keywords: Floating wind energy; economic-financial feasibility; geographical location

1. Introduction

The acceleration of energy consumption has been subject of special attention from both the political class and the scientific community. There is a need to take measures aiming to reduce the use, or even non-use, of fossil fuels. On one hand, to combat climate change, and on the other, to ensure countries' energy independence. In this context, targets have been set for the incorporation of renewable energies into final consumption, especially with the use of floating offshore wind energy, due to technology's development. In addition, floating wind energy will contribute to achieve the Sustainable Development Goals (SDGs) set out in the United Nations 2030 Agenda. Portugal is no exception. In fact, its geographical location gives it a significant advantage when it comes to utilising this renewable resource. Mainland Portugal's maritime space, under national sovereignty or jurisdiction, extends over 591,502 km^2. If, on one hand, the ocean's tridimensionality poses challenges in terms of governance and maritime spatial planning, on the other hand, it allows for various human activities and use.

2. Case Study

This work presents a case study of a hypothetical company, 'Vento no Mar', which intends to invest in two floating offshore wind farms in two areas in the Northwest of the Iberian Peninsula (Viana do Castelo). The study was divided into two phases. The first relates to maritime spatial planning to select the location to ensure a balance between the private use of maritime space, and the common use and freedom of movement in the oceans. For this purpose, exclusion criteria were imposed: after being analysed, the areas were geo-referenced in the MT and EEZ.

2.1 Marine Spatial Planning

According to Thenen et al. (2021, p.1) "Maritime spatial planning (MSP) aims to analyse and allocate the use of maritime areas to minimise conflicts between human activities and maximise benefits, while ensuring the resilience of marine ecosystems. It therefore requires multisectoral spatial planning to allocate maritime space to different maritime activities over time and must be integrated into the context of broader environmental management to address the spatial and temporal environmental effects of activities. Furthermore, it must consider a multidimensional environment in which human activities can take place on the seabed, in the water column, on the surface or above it, and that marine resources are variably distributed in space and time."

From an economic perspective, we can infer that MSP allows for a reduction in uncertainty/risk for investors in projects in the maritime space, by ensuring: (i) greater legal certainty for all stakeholders; (ii) cross-border cooperation, where applicable; (iii) coherence with other planning systems; and (iv) better coordination and simplified decision-making processes (Gustavsson et al., 2019). In Portugal, the Bases of the National Maritime Spatial Planning and Management Policy are set out in Law no. 17/2014, of 10 April, developed by Decree-Law no. 38/2015. It should also be noted that the Maritime Spatial Planning Situation Plan (PSOEM), approved by Council of Ministers Resolution (RCM) No. 203-A/2019 of 30 December, only includes spaces for the development of pilot projects for renewable energies. Thus, as mentioned, the process for the Allocation Plan for Offshore Renewable Energies is underway. This plan, once approved by RCM, will automatically become part of the PSOEM.

In the wake of the above and bearing in mind that the case study is the investment project for two offshore floating wind farms in the mainland subdivision, specifically off the coast of Viana do Castelo, we began this process by analysing the exclusion criteria, which are shown in Table 1.

Table 1 - Exclusion criteria considered when selecting the two study areas

Criteria	Exclusion	Source
Horizontal wind speed (m/s)	< 8,0	DGRM, 2023
Number of production hours at full capacity (NEPs) (h/year)	< 4000	DGRM, 2023
Bathymetry (m)	< 70 e > 500	DGRM, 2023
Slopes (º) and (%)	> 2º / > 10%	DGRM, 2023
Distance to coastline (km)	> 35 km	DGRM, 2023
Seabed	> % of rocky bottoms	DGRM, 2023
Tectonic faults	Overlap without monitoring and reports from Windfloat Atlantic	DGRM, 2023
Windfloat Atlantic area	Overlap	DGRM, 2023
Viana do Castelo LZ area	Overlap	DGRM, 2023
Coastal protection strip	Overlap	DGRM, 2023
Natura 2000 network	Overlap	DGRM, 2023
Location of shipwrecks and sinkings	Overlap	DGRM, 2023
Underwater cultural heritage	Overlap	DGRM, 2023
Metallic natural resources	Overlap	DGRM, 2023
Reef complexes	Overlap	DGRM, 2023
National defence	Overlap	DGRM, 2023
Existing submarine telecommunications cables	Overlap	DGRM, 2023
Submarine emissaries	Overlap	DGRM, 2023
Harbour navigation / approach cones	Overlap	DGRM, 2023
Maritime traffic separators	Overlap	DGRM, 2023
Buoys and maritime signalling	Overlap	DGRM, 2023
Water intake zones	Overlap	DGRM, 2023
Dredging and coastal drift	Overlap	DGRM, 2023
Scientific research	No measures to mitigate conflicts	DGRM, 2023
Fishing	No conflict mitigation measures	DGRM, 2023
Recreation, sport and to	No conflict mitigation measures	DGRM, 2023

Source: Elaborated by the author, 2023

After analysing the exclusions and based on the platform mentioned, we obtained the number of wind turbines - 66 - to be installed in each area, considering the project's installed power of 1 GW.

Next, we calculated the technical area corresponding to the occupation of a wind turbine, without interfering with neighbouring wind turbines, based on the inter-wind turbine distance shown in Table 2 and the number of wind turbines required for the project's installed power. An area of 3.9 km^2 per wind turbine was obtained.

Table 2 - Assumptions for the selection of each area

Assumptions	Source
Project location: Subdivision of mainland Portugal	DGRM, 2023
Project installed capacity: 1 GW	Author, 2023
Equal number of wind turbines	
Wind (h = 200 m)	Information provided by LNEG, 2023
Inter-wind turbine distance corresponding to 7D in the direction parallel to the prevailing wind and 10D in the direction perpendicular to the prevailing wind, where D is the turbine diameter	
Positioning orientation: predominant directions:	
NW to N - 330° to 360°	
Wind rose for the centre point of each area	

Source: Elaborated by the author, 2023

The area to be occupied by the 66 wind turbines was then calculated: 257.32 km2. It should be noted that the northern area includes the areas of Windfloat Atlantic (11.25 km^2) and the recent Technology Free Zone (ZLT) (7.63 km^2) corresponding to a total of 18.88 km^2 (Ministerial Order 298/2023). The calculation was carried out using Microsoft© Excel software and allowed the areas to be geo-referenced, which are shown in Table 3 with their coordinates and in Table 4 with their dimensions.

Table 3 - Coordinates of Viana do Castelo selected areas

Vertices		LAT	LONG
North Area	1	41° 49' 16,26'' N	9º 01' 55,71'' W
	2	41° 40' 22,63'' N	9º 01' 56,74'' W
	3	41° 38' 39,24'' N	9º 15' 50,01'' W
	4	41° 44' 36,24'' N	9º 18' 29,87'' W
South Area	5	41° 34' 01,44'' N	9º 00' 48,74'' W
	6	41° 24' 05,47'' N	9º 00' 40,68'' W
	7	41° 19' 46,18'' N	9º 09' 03,51'' W
	8	41° 30' 50,11'' N	9º 12' 47,71'' W
Coordinate System: GCS WGS84			

Source: DGRM, 2023

Table 4 - Size of Viana do Castelo selected areas

Areas	(Km^2)
Total	**607**
North	313
South	294

Source: DGRM, 2023

From 607 km^2, around 215.3 km^2 is in MT and around 391.7 km^2 in the EEZ, corresponding to around 35% and 65% of these maritime zones, respectively. Figures 1 to 3 show the maps on a macro scale to give a more detailed view of the criteria under study.

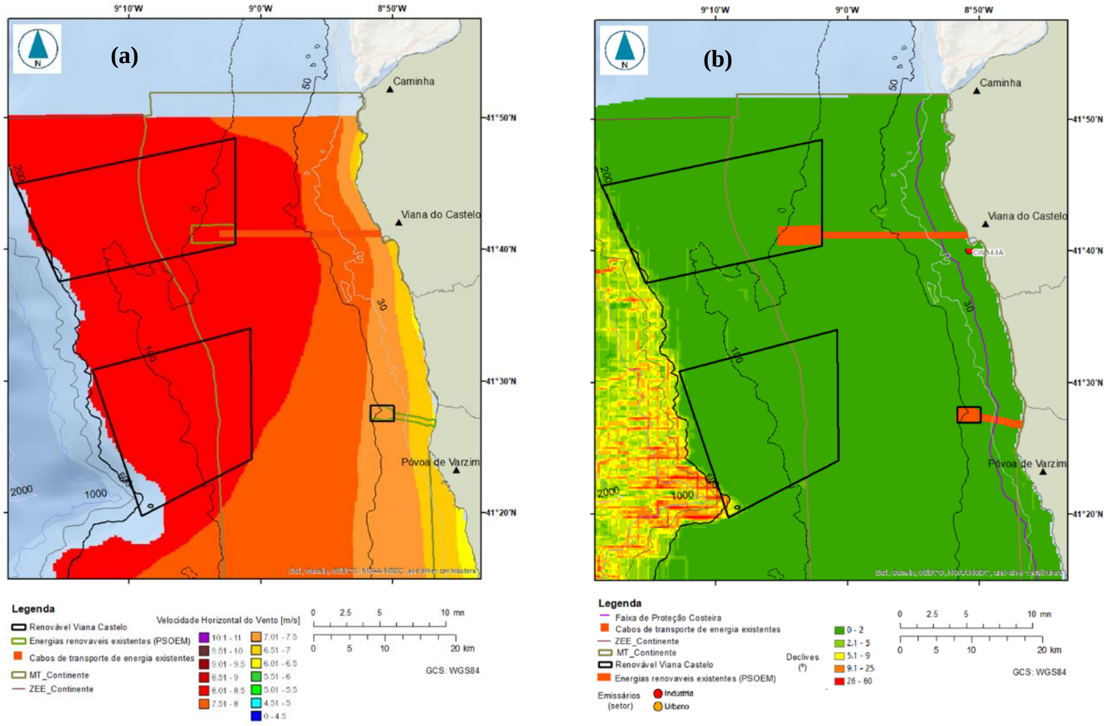

Figure 1 - (a) Horizontal wind speed map (b) Slopes and submarine emissaries' map. Source: DGRM, 2023

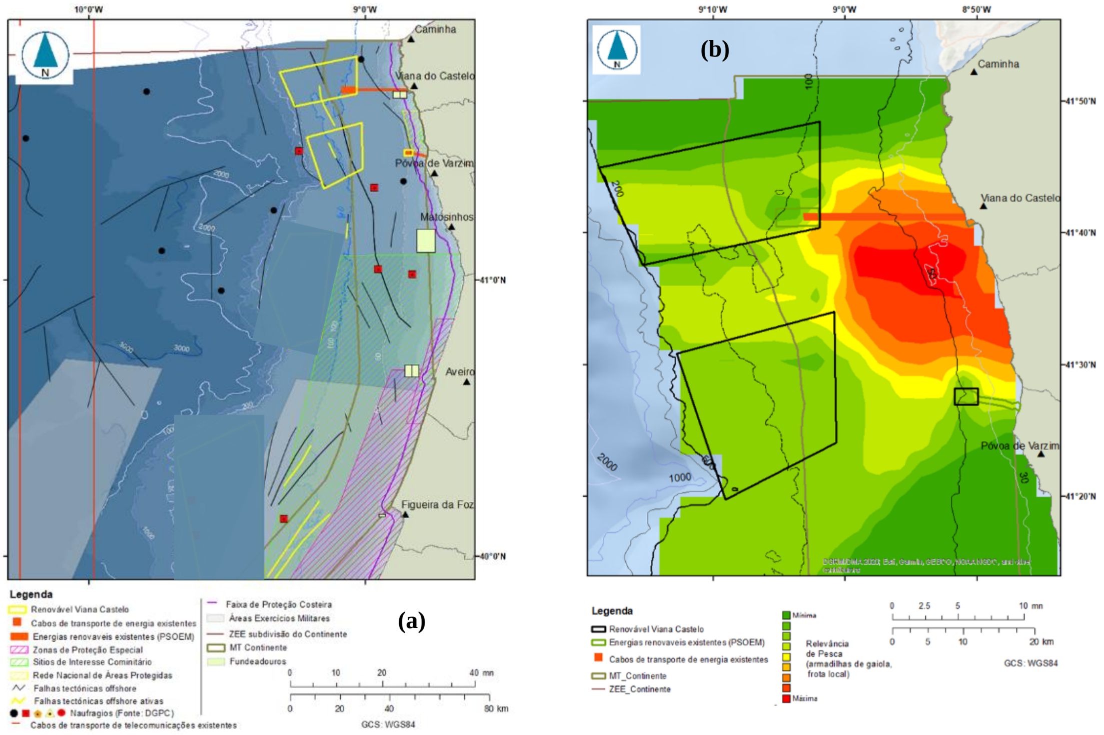

Figure 2 - (a) Several exclusions map (b) Cage trap fishing - local fleet map. Source: DGRM, 2023

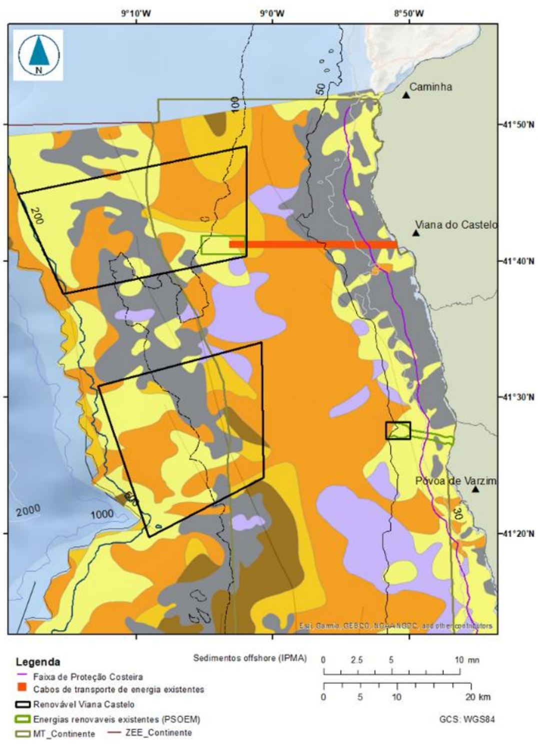

Figure 3 - Seabed composition map. Source: DGRM, 2023

Table 5 - Seabed composition of Viana do Castelo areas

North Area	Area (km^2)	South Area	Area (km^2)
Sand	112	Muddy sand	106
Muddy sand	102	Sand	89
Rocks and boulders	58	Rocks and boulders	51
Sandy mud	41	Sandy mud	31
Mixed sediment	0,10	Mud	8,8
		Mixed sediment	8,3

Source: DGRM, 2023

3.2 Economic and Financial Feasibility

The ‘Spot Economic Analysis’ module of the OffshorePlan – Planning the Installation of Offshore Renewable Energy Systems in Portugal, developed by LNEG, was used for economic and financial feasibility analysis.

3.2.1 Inputs in the 'Spot Economic Analysis' Module

This section presents the assumptions and input data for each area under study. Table 6 reflects the assumptions for this modelling.

Table 6 - Economic and financial analysis assumptions

Assumptions
The hypothetical company 'Vento no Mar' has equity of around €50,000,000.00.
The investment project consists of a floating wind farm in each selected area.
To safeguard the risk, the shareholders of the company 'Vento no Mar' impose that the decision to invest is conditional on the values obtained for the useful life of the wind farms, 30 years: IRR ≥ 10%; NPV ≥ 2,500,000.00 € and Payback Period ≤ 10 years.
Bank credits were considered the source of debt financing.
The onshore electricity network with no need for investment.
The interconnection network not included in the 'One-off Economic Analysis' model.
Wind turbines and platforms produced at the shipyard located in Viana do Castelo port.
Production and installation of wind turbines and platforms carried out for one year.
Existence of vessels to transport the infrastructure and workers for wind farm maintenance operations.
The initial investment (CAPEX) value was from Kost et al. (2021).
The LCOE calculation did not consider the costs associated with electricity interconnection.
The subsidised tariff and its time were obtained from internal LNEG data.
The market tariff was obtained based on Portuguese electricity market prices from OMIE (2023). To calculate the average annual value of the market tariff, we considered the period from July 2022 to June 2023 and obtained a value of 110.30 €/MWh. For the calculation, we used Microsoft© Excel software.
The inflation rate projected by the IMF for June/2025 (CFP, 2023).
The June/2023 interest rate applied in the Eurozone was considered (BdP, 2023)
Decommissioning will be in the year following the period of lifetime of the wind farms.

Source: Elaborated by the author, 2023

Table 7 shows the data that remains fixed regardless of the funding sources.

Table 7 - Fixed data, regardless of the source of funding and its sources

	Data	Source
Resource utilisation and technology		
Floating offshore wind	V236	Vestas, 2023
Unit power of the system (power of each wind turbine) (MW)	15	
Number of production hours at full capacity (NEPs) (h/year)	4000	OffshorePlan - LNEG, 2020
Project dimensioning		
Project installed power (MW)	1000	See Table 2
Project lifespan (years)	30	Vestas, 2023
Energy losses		
Annual equipment degradation (%)	1	Information provided by LNEG, 2023
Plant wake effects (%)	5	
Electrical interconnection network (%)	2	
Other factors (%)	1	
Distance travelled by vessels		
System Transport and Operation and Maintenance North Area (km) South Area (km)	28 33	DGRM, 2023
Project Costs		
Investment Cost (€/MW)	4000000	See Table 6
Power and Distance - Fixed Term (€/MW)	90,500	
Power and Distance - Variable Term (€/MW/km)	21	
Decommissioning Costs - % of Initial Investment	5	Martinez *et al.*, 2022
Economic Parameters - Remuneration		
Subsidised rate - Average annual value (€/MWh)	147,00	Information provided by LNEG, 2023
Time (years)	15	
Market rate - Average annual value (€/MWh)	110,30	See Table 6
Economic Parameters - Fees and Taxes		
Average annual discount rate (%)	5; 7,5; 10	Castro-Santos et al., 2013
Inflation (%)	2,4	IMF June in CFP, 2023
Corporate Income Tax (%)	21	EPortugal, 2023

Source: Elaborated by the author, 2023

3.3 Financing Scenarios

3.3.1 Equity capital

The equity financing scenarios were created by using the data in Table 7, varying the average annual discount rate. It is assumed that the investment is made during 2024 (1 January to 31 December) and that operations start on 1 January 2025.

3.3.2 Own and debt capital

Table 8 shows the financing conditions with equity and debt (bank credit) and their respective sources. The scenarios were created using the data in Tables 7 and 8, varying the equity/ debt ratio and the average annual discount rate.

Table 8 - Input data for the equity and debt financing scenarios

	Year - 2025	Source
Economic Parameters - Investment Financing		
Bank credit - Financed portion (%)	25*; 70**	*Author; **Casto-Santos, 2013b
Payment period (years)	25	Author
Interest rate (%)	4,67	BdP, 2023

Source: Elaborated by the author, 2023

4. Results and Discussion

This section presents the results obtained based on the methodologies explained above, followed by some considerations on the economic and financial viability of the investment project for a floating wind farm in each of the selected areas.

4.1 Marine Spatial Planning

The selection of the areas considered the exclusion criteria in Table 2, in compliance with the provisions of the 'Law of the Sea', specifically regarding administrative easements, the protection and preservation of the marine environment and the mitigation of conflicts between common and private uses.

4.1.1 Wind Speed Average

The two selected areas were georeferenced over zones where the estimated wind speed average is 8.50 m/s, Figure 1a, considering a height above mean sea level (h) of 200 m (DGRM, 2023).

4.1.2 Number of production hours at full capacity (NEPs)

The selection of the two areas considered the zone where the NEPs would be highest, in this case with a value of 4000 h/year (DGRM, 2023).

4.1.3 Bathymetry and Slopes

Given that bathymetry and slopes are factors that significantly affect the location of floating wind farms, the two areas were georeferenced between 75 m and 200 m deep with slopes of less than 10%, to minimise the difficulties of fixing this type of platform, Figure 2a, (DGRM, 2023). Bathymetry is essential for identifying the suitability of installing and maintaining floating wind farms. The value of the water depth is crucial due to the cost associated with mooring and cabling systems. The installation procedure also depends on variations in water depth (Díaz et al., 2020).

4.1.4 Distance to the Coastline and the Port of Viana do Castelo

The distances used are the averages calculated based on the minimum and maximum distance of each polygon. The distance between the offshore wind farms and the coastline is reflected in the electricity grid to be developed offshore and onshore. Thus, the two areas were georeferenced to ensure the smallest distance (North area: 25 km and South area: 33 km), considering the minimisation of conflicts of common uses, which are practised closer to the coast, and the change in the natural landscape (DGRM, 2023).

The distance from the coast and the port, where the shipyard that will produce the wind turbines and platforms is located, will influence the costs of transporting and installing the infrastructure in the wind farms (Díaz et al., 2020).

In the case under study, we can see that the difference between the two selected areas is not significant, considering the values of the economic indicators obtained, such as IRR, NPV, Payback Period and LCOE (see Table 11, 15, and 16).

4.1.5 Seabed

The two areas were georeferenced predominantly over sandy bottoms, Figure 3, due to the impact these have on the economic viability of floating offshore wind farms. However, it was not possible to exclude all rocky bottoms, which account for 18% of the total in the two areas (19% in the northern area and 17% in the southern area).

The rocky bottoms do not prevent the establishment of these parks, although it must be borne in mind that these are important areas for commercial fishing, trawling, in particular, which will create a situation of conflict with fishermen with licences for this fishing gear (DGRM, 2023). This issue will be developed further in the 'Fishing' criterion.

4.1.6 Tectonic Faults

Identifying the existence of active tectonic faults is essential for locating and assessing the risks of wind farms. However, the two areas under study overlap two active tectonic faults (Figure 2a), so this should be considered in the Environmental Impact Assessment of each of the projects, by analysing the influence of the Richter points on the wave height, in order to safeguard the infrastructure. There are no reports of the influence of these faults on the Windfloat Atlantic floating wind farm (DGRM, 2023).

4.1.7 Natura 2000 Network

The Natura 2000 Network includes marine and coastal Special Protection Areas (SPAs) and marine and coastal Sites of Community Importance (SCIs), which are regulated by special legislation (DGRM, 2023). That said, the areas under study were georeferenced so as not to overlap with the SPAs and SCIs (Figure 2a).

4.1.8 National Defence

In this context, the area relating to National Defence is understood as the area of military exercises. Although it is a large area, the selected areas do not overlap with it (Figure 2a).

4.1.9 Port Navigation and Approach Cones

The selected areas do not overlap with the easement zones for anchorages and anchorages, buoys and maritime signalling systems, and the maritime traffic separation system, Figure 2a. However, a distance of 5 km has been established, thus safeguarding the approach to the port of Viana do Castelo, ensuring that wind farms remain outside the mandatory pilotage areas, and ensuring the safety of navigation (DGRM, 2023).

It is also important that the electromagnetic fields created by wind turbine rotors do not affect ships' radars and Vessel Traffic Services (VTS) (Díaz et al., 2020).

4.1.10 Underwater Cultural Heritage

The map in Figure 2a was drawn up at a different scale to the rest so that you can see the underwater archaeological sites whose exact location cannot be disclosed for the safety of this heritage (DGRM, 2023). The selected areas do not overlap with the areas of underwater heritage interest, Figure 2a.

4.1.11 Water Intake Zones

The two selected areas do not overlap with water intake zones, an activity carried out by aircraft as part of rural firefighting (DGRM, 2023).

4.1.12 Aeronautical Easements

In the radar system, aircraft are recognised and located through the change in frequency of the return signal, the so-called ‘Doppler effect’. The rotation of wind turbine blades causes this ‘Doppler effect’, interfering with tracking, which disrupts the identification of an aeroplane (Díaz et al., 2020). The two areas were georeferenced in zones that do not constitute a constraint on aeronautical easement zones (DGRM, 2023).

4.1.13 Submarine Telecommunications Cables

Submarine cables can be affected by wind farms, as they can hinder or even prevent the movement of ships for the repair or installation of submarine telecommunications cables (Díaz et al., 2020). For this reason, it is not recommended that wind farms be located close to access to submarine cable mooring stations. However, the georeferenced areas do not overlap with areas where this type of submarine cable exists (Figure 2a), although, like underwater cultural heritage, their exact location cannot be disclosed for safety reasons (DGRM, 2023).

It should be noted that the model used did not include interconnection to the electricity grid, including offshore submarine cables, as we did not have access to this information.

4.1.14 Dredging

Dredged spoil is immersed in the coastal drift. However, we did not want to lose sight of this exclusion criterion, demonstrating that the two areas selected are outside the coastal drift. The floating wind farms installation does not constitute an easement for this use (DGRM, 2023).

4.1.15 Scientific Research

Scientific research activities may be restricted if there is a need to use aerial means to fly over the wind farms (cetacean surveys, for example). Research cruises taking place in wind farm areas will also be affected, as the circulation of vessels will be subject to specific constraints (DGRM, 2023).

4.1.16 Recreation and Tourism

Recreational and tourism activities are carried out almost exclusively along the coastline, in tourist areas, bathing areas, diving areas, water sports, etc (Díaz et al., 2020). Regarding that, the north and south areas are 28 and 33 km from the coastline, respectively, and at a depth of between 75 and 200 m, we believe there are no significant constraints on these activities (DGRM, 2023).

4.1.17 Fishing

The areas selected represent constraints on commercial fishing activity, especially bottom trawling or driftnetting since the likelihood of these colliding with wind turbine structures is high. The fact that these farms restrict the use of the fishing gear should be considered a measure that will contribute to the protection of marine ecosystems and maximum sustainable yield (DGRM, 2023).

However, it is considered that the installation of the two floating wind farms in the selected areas does not constitute a full easement, Figure 2b, which would prevent fishing activity. Fishing will therefore have to be organised locally, within the perimeter of the farms, to maintain the integrity of the power generation structures and maritime safety (DGRM, 2023).

The possibility of installing artificial reefs should be considered to create conditions that boost biological productivity (DGRM, 2023).

4.1.18 Aquaculture

The compatibility of aquaculture with commercial floating wind farms is an expectation that has been developing. Aquaculture is the activity that could benefit most from the creation of floating offshore wind farms. These farms are large and resistant to sea waves, which could make it possible to set up production units, especially for shellfish and algae (DGRM, 2023).

If aquaculture is integrated into floating offshore platforms, fishermen who originally worked in the maritime zone will be able to dedicate themselves to aquaculture in cages, which will avoid affecting fishermen's livelihoods and will fully utilise the offshore wind farm area (Huang et al., 2022).

4.1.19 Nature Conservation

The most worrying situation about offshore wind farms is the negative impact of wind turbines on seabird populations. To this end, the areas selected were geo-referenced to ensure their distance from coastal zones, since the main migratory corridors for seabirds are located close to these areas.

It is important to note the regular sightings of numerous cetaceans near the Windfloat Atlantic wind turbines, especially the common dolphin, the harbour porpoise, and the minke whale, which do not show stress behaviours.

As far as biodiversity is concerned, the Windfloat Atlantic wind turbines are proof that these structures do not have a negative impact on biodiversity since they are densely colonised by organisms typical of rocky substrates, namely mussels and laminaria (DGRM, 2023).

It is also important to emphasise that the wind turbines and platforms will be produced in Viana do Castelo shipyards, which will prevent the platforms from being populated by exotic species, as is the case at Windfloat Atlantic.

However, the application of the exclusion criteria doesn't remove the obligation for the company to proceed by Regulation (EU) 2020/852 of the European Parliament and the Council - Climate Taxonomy, and paragraphs 4.3 - "Production of electricity from wind energy" of Annexes I and II of Commission Delegated Regulation (EU) 2021/2139. These criteria determine under what conditions the economic activity - floating offshore wind farms - is qualified to make a substantial contribution to mitigating or adapting to climate change and, also, to establish whether this economic activity does not significantly jeopardise the fulfilment of the environmental objectives of descriptors 1 (biodiversity), 6 (seabed integrity) and 11 (noise/energy) set out in the Marine Strategy Framework Directive (MSFD).

Figure 4 shows the geometry of the selected areas, orientated according to the dominant wind direction. These areas cover a total of 607 km^2: 313 km^2 in the northern area and 294 km^2 in the southern area.

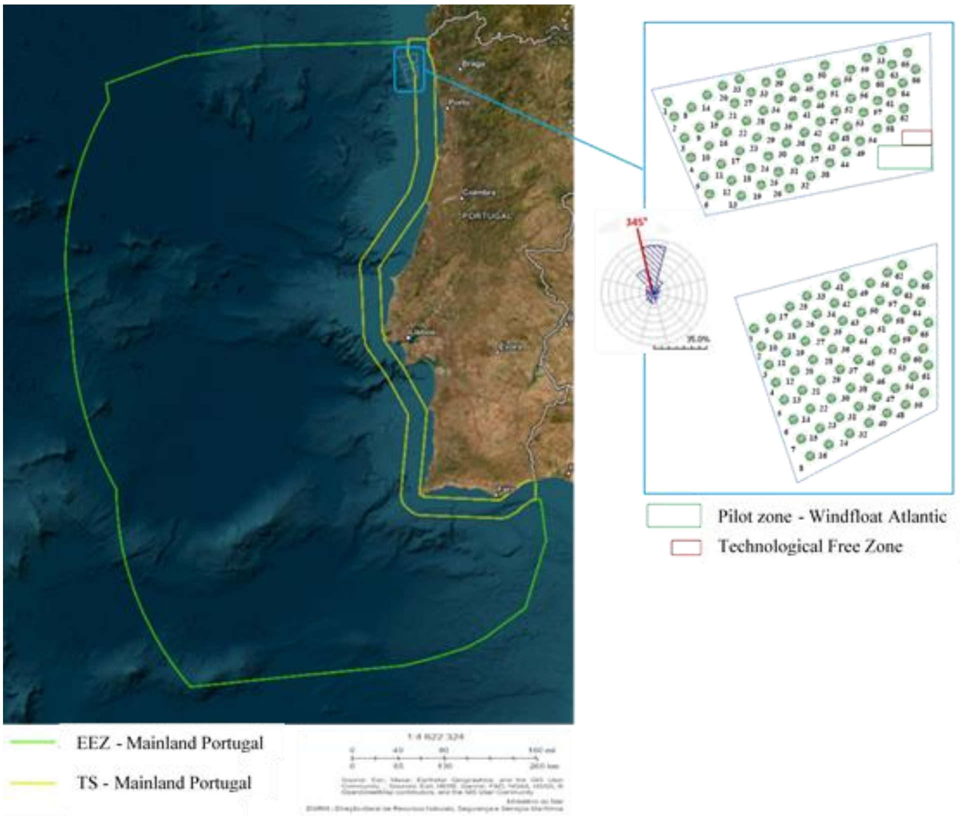

Figure 4 - Geo-spatialisation of the areas north and south of Viana do Castelo with wind turbines. Source: Elaborated by the author, 2023

In each zone, we designed 66 wind turbines, a figure obtained from the 'Point Economic Analysis'. Installing 1 GW in each of them gives an exact power of 0.990 GW per zone, totalling 1.98 GW.

4.2. Economic and Financial Feasibility

Below are the results obtained based on the methodology presented in the previous chapter for the two areas under study. These results relate to the entire useful life of the project, which in this case is 30 years.

4.2.1 Results Not Dependent on Financing Source

Table 9 shows the costs of initial investment (CAPEX), operation and maintenance over the lifetime of the project (OPEX), and the removal of wind farm infrastructure (DECEX).

Table 9 - Distribution of project costs in the two areas

	North Area			South Area		
	CAPEX (€/MW)	**OPEX** (€/MW)	**DECEX** (€/MW)	**CAPEX** (€/MW)	**OPEX** (€/MW)	**DECEX** (€/MW)
Year 0 - 01/Jan to 31/Dec 2024	4.000.000	-	-	4.000.000	-	-
Years 1 to 30 - 2025 to 2054	-	2.732.640	-	-	2.735.790.00	-
Year 31 - 2055	-	-	200.000	-	-	200.000

Source: Elaborated by the author, 2023

The variation in OPEX between the two selected areas is 0.12 percent, which is not considered significant.

In the last year of the wind farms' useful life, the company must allocate the amount corresponding to DECEX to ensure the amount needed to decommission the farms the following year.

Table 10 shows the periods of entry into force and the respective time of the Remuneration parameters.

Table 10 - Subsidised tariff and market tariff

	(€)	**Input/Time**
Subsidised tariff for 15 years	147,00	1st to 15th year
Market tariff	110,30	16th to 30th year

Source: Elaborated by the author, 2023

Table 11 shows the Levelised Cost of Energy (LCOE) values obtained, regardless of the financing source, as it is not sensitive to it.

Table 11 - Economic indicator - LCOE

	Discount rate (%)	**5**	**7,5**	**10**
North Area	**LCOE** (€/MWh)	118,08	138,28	160,66
South Area	**LCOE** (€/MWh)	118,13	138,32	160,70

Source: Elaborated by the author, 2023

The results obtained for the LCOE show that this economic indicator, which, according to Castro-Santos (2013, p.2) "evaluates the economic cost of an energy production system throughout its life cycle" in addition to the costs during the useful life of the project, is sensitive to the discount rate considered and the distance from the coastline/port (North and South areas). With a 5% discount rate was obtained, the lowest LCOE value (118€/MWh).

Table 12 shows the energy indicators calculated using Microsoft© Excel software.

Table 12 - Wind project performance indicator - Capacity Factor

	Exact Installed Power (MW)	Net Annual Energy Produced (Net AEP) (MWh)
	990	3129468
CF	**36%**	

Source: Elaborated by the author, 2023

Usually, the CF of wind farms is between 20 and 40% (Díaz et al., 2023). Considering that the CF obtained is 36%, above the average for that range, the availability of wind in the selected areas is considered acceptable.

Table 13 shows the number of jobs (direct and indirect) created and the number of housings supplied with electricity from the two wind farms, calculated based on Díaz et al. (2020).

Table 13 - Socio-economic indicators - Jobs and housing

Employment	North Area	South Area
Number of direct jobs (ED/MW)	9108	9108
Subtotal of direct jobs (ED/MW)	**18.216**	
Number of indirect jobs (EI/MW)	7425	7425
Subtotal of indirect jobs (EI/MW)	**14.850**	
Jobs per selected area (EArea/MW)	**16533**	**16533**
Total jobs (ET/MW)	**33.066**	
Housing	**North Area**	**South Area**
Number of housings per area (H/MW)	707157	707157
Total number of housing (HT/MW)	**1.414.314**	

Source: Elaborated by the author, 2023

The results in Table 13 lead us to conclude that the implementation of the project in the two selected areas will contribute significantly to the growth of the sustainable blue economy on a local and regional scale, creating 18,216 direct jobs and 14,850 indirect jobs. This positive result is mainly due to wind turbines and platforms production at Viana do Castelo shipyards.

Concerning electricity, the two wind farms will supply 1,414,314 family homes, covering 75% of the total 1,894,933 homes in the NUT II - Norte region (INE, 2023).

Table 14 shows the results of the environmental indicators.

Table 14 - Environmental indicators

	(tons/year)
CO_2 emissions	1.417.086
SO_2 emissions	32.967

Source: Elaborated by the author, 2023

These two wind farms will reduce CO_2 and SO_2 emissions, which will help mitigate the effects of these pollutants.

Regarding Climate Taxonomy, the company will have to ensure that the economic activity - 'Production of electricity from wind energy' will not significantly jeopardise compliance with the environmental objectives of descriptors 1 (biodiversity), 6 (seabed integrity) and 11 (noise/energy) laid down in the MSFD, as provided for in paragraphs 4.3 of Annexes I and II of Delegated Regulation (EU) 2021/2139.

The economic and financial viability of the project was estimated, with the intent to decide on it. To this end, different scenarios were constructed and the respective Internal Rate of Return (IRR), Net Present Value (NPV), Payback Period, and Levelised Cost of Energy (LCOE) were estimated. Three alternative discount rates (5%, 7.5% and 10%) and two possible equity/debt financing combinations (25% and 70%) were also considered as hypotheses.

4.2.2 Results of the Equity Financing Scenarios

Table 15 summarises the economic results of the equity financing scenarios. These results relate to the project's lifetime - 30 years.

Table 15 - Economic indicators resulting from equity financing

Discount rate (%)	North Area			South Area		
	5	**7,5**	**10**	**5**	**7,5**	**10**
NPV (M€)	2,104	0,728	-0,205	2,102	0,727	-0,206
IRR (%)	9,37	9,37	9,37	9,36	9,36	9,36
Payback Period (years)	13,4	18,2	>30	13,4	18,2	>30

Source: Elaborated by the author, 2023

From the agent's economic rationality perspective (the 'Vento no Mar' company), the benefits generated by the investment must be greater than the cost of implementing it. Thus, the fulfilment of NPV>0 is the criterion to consider when implementing the investment (Soares et al., 2015).

As seen (Table 15), as the discount rate increases, the NPV decreases, becoming negative for the rate of 10 per cent. Therefore, according to the economic logic of 'opportunity cost', the higher this rate, the more difficult it becomes to accept the investment (Soares et al., 2015).

Figure 5 shows the curves representing the NPV profiles, which relate the surpluses generated to the respective discount rates (Soares et al., 2015) of 5%, 7.5%, and 10% (Castro-Santos et al., 2013).

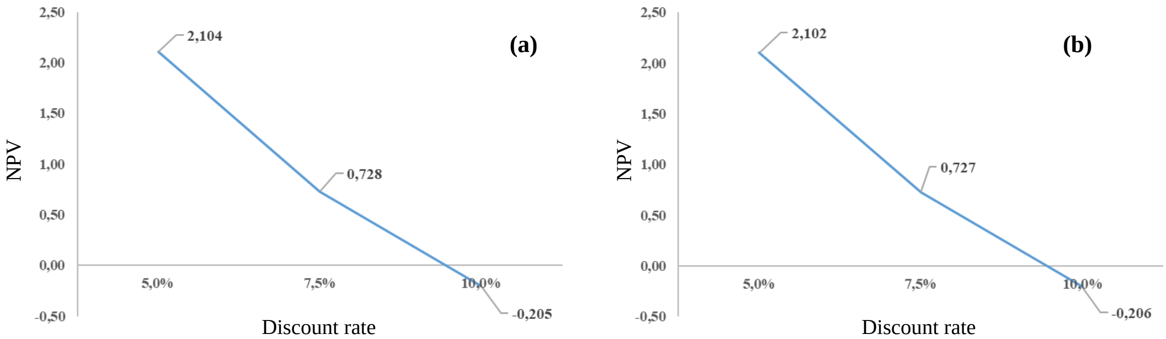

Figure 5 - NPV evolution as a function of the update rate (a) North area; (b) South area. Source: Elaborated by the author, 2023

The graphs (Figure 5) show that the lower the slope of the curve, the lower the sensitivity of the NPV to the discount rate (Soares et al., 2015).

The IRR results indicate that for discount rates below 9.37% (North area) and 9.36% (South area) the decision will be to accept the investment. Above these rates, the decision will be to reject (Soares et al., 2015). In other words, the project is economically viable for discount rates of 5% and 7.5% (IRR > discount rate) (Castro-Santos et al., 2013).

Figure 6 shows the equivalence of NPV and IRR in investment selection for the two areas under study.

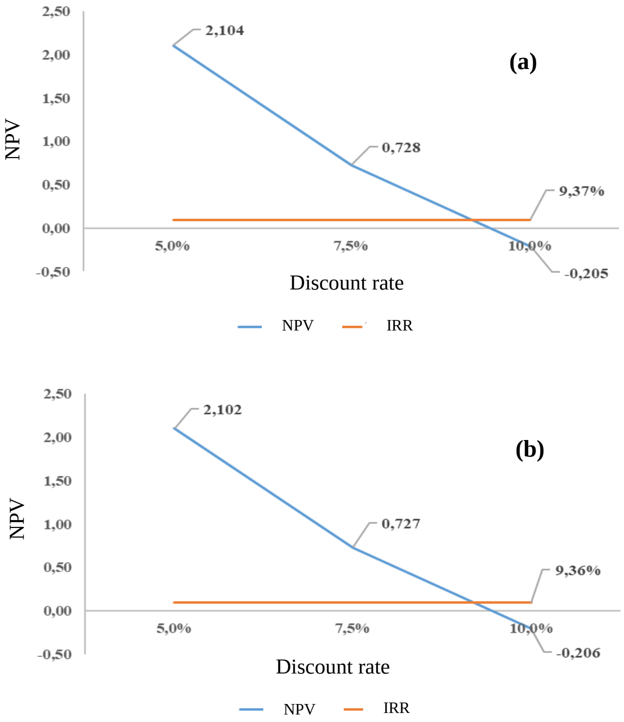

Figure 6 - NPV and IRR equivalence: (a) North area; (b) South area. Source: Elaborated by the author, 2023

On one hand, positive NPV values for discount rates (5% and 7.5%) means that they are lower than the IRR. On the other hand, if the NPV is negative, the IRR is lower than the discount rate.

Regarding the Payback Period for both areas, except for when the 10% discount rate is applied, the results are always lower than the project's useful life, 30 years. This indicates that the investment is acceptable.

4.2.3 Results of the Equity and Debt Financing Scenarios

Table 16 summarises the economic indicators of the equity and debt financing scenarios (bank credit - 25% and 70% financed instalments), with a 25-year repayment term and an interest rate of 4.67%.

Table 16 - Economic indicators resulting from equity and debt financing investment

Financed portion: 25%	Discount rate (%)					
	North Area			South Area		
	5	7,5	10	5	7,5	10
NPV (M€)	1,340	0,124	-0,697	1,338	0,122	-0,698
IRR (%)	7,82	7,82	7,82	7,82	7,82	7,82
Payback Period (years)	16,7	26,9	<30	16,7	27	>30
Financed portion: 70%	**Discount rate (%)**					
	North Area			South Area		
	5	7,5	10	5	7,5	10
NPV (M€)	-0,051	-0,974	-1,589	-0,053	-0,975	-1,590
IRR (%)	4,89	4,89	4,89	4,88	4,88	4,88
Payback Period (years)	>30	>30	>30	>30	>30	>30

Source: Elaborated by the author, 2023

As can be seen (Table 16), as the discount rate increases the NPV decreases, becoming negative for the 10% rate and with the 25% financed portion (bank credit). In the scenarios with the 70% financed portion (bank credit), the NPVs obtained are negative, regardless of the discount rate. In this scenario, equity assures the investment.

Figure 7 shows the curves representing the NPV profiles (bank credit of 25% and 70% of the total investment, respectively), which relate the surpluses generated to the respective discount rates (Soares et al., 2015) of 5%, 7.5% and 10% (Castro-Santos et al., 2013).

The graphs (Figure 7) show that the NPV is sensitive to the cost of capital. In the scenarios with a 25% source of equity and debt financing (bank credit), the Payback Period is less than the project's useful life (30 years). When the 10% discount rate is applied, the project is not economically viable.

If the share of external financing is 70% of the total investment, regardless of the discount rate applied, the project is not economically viable. The IRR is lower than the discount rate, the NPV < 0 and the Payback Period > 30 years.

The payback period is the time it takes for the project to pay off the cost of the investment and start making a profit. It can be inferred from this that the longer this period, the greater the risks. This period must always be shorter than the useful life of the project, otherwise the company should not make the decision to invest.

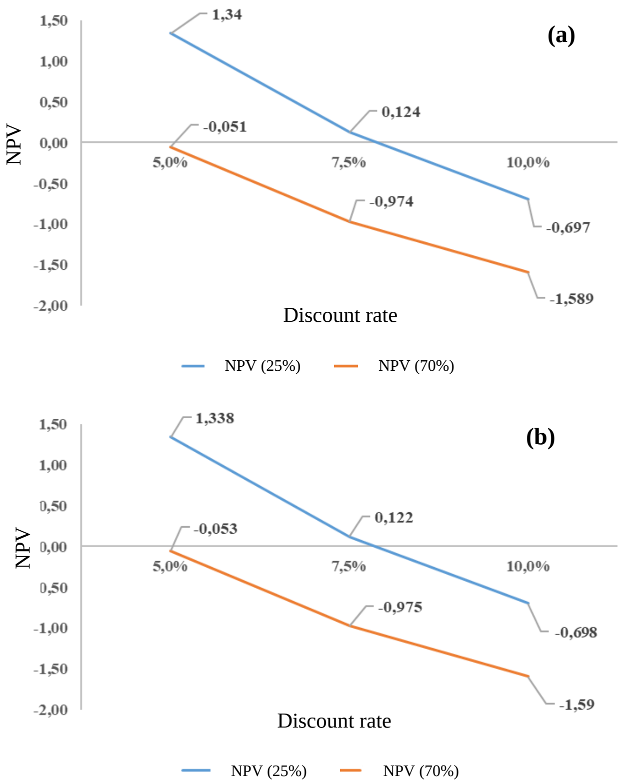

Figure 7 - NPV evolution as a function of the update rate (a) North area; (b) South area. Source: Elaborated by the author, 2023

5. Conclusions

The sensitivity analysis showed that the project's critical variable is the discount rate, which has a decisive influence on the NPV. The conclusion is that the project is economically and financially viable for the scenarios with an equity financing source and discount rates of 5% and 7.5%. This result is considered positive for the realisation of the investment, considering the interest rates currently charged on the financial markets. With a source of funding from own and debt party capital, the project is only viable in the scenario with a 25% financed portion and discount rates of 5% and 7.5%. It can also be concluded that the NPV (≥2.5 M€), IRR (≥10%) and Payback Period (≤10 years) defined as profitability limits by the shareholders were exceeded by 22% by the NPV (3 M€), 31.8% by the IRR (13.18%) and 7.5% by the Payback Period (9.3 years) in the scenario with a 5% discount rate and equity financing source. It can therefore be concluded that these criteria support the approval of the project. The values obtained for the LCOE are considered acceptable, as they are within the ranges of other studies presented by Martinez et al. (2022). The capacity factor obtained (36%) is above the average capacity factor for wind farms (20-40%). Regarding the 'Employment' indicator, it can be concluded that the project will make a positive contribution to the local and regional economy. The large number of homes that will benefit from the energy produced by the two wind farms will help mitigate climate change and achieve the decarbonisation targets set for 2050. About environmental indicators, it can be concluded that the implementation of the two wind farms will significantly reduce CO_2 and SO_2 emissions. The operation of these wind farms will also contribute to the realisation of the SDGs, as shown in Table 17.

Table 17 - Contributions of the Investment Project to the United Nations SDGs

SDG	Contribution of offshore floating wind farms
3 SAÚDE DE QUALIDADE	Minimising the effects of climate change on human health by reducing greenhouse gas emissions.
7 ENERGIAS RENOVÁVEIS E ACESSÍVEIS	Producing electricity from a renewable energy source, wind, which is considered more sustainable and less polluting than fossil fuels such as coal and oil. By providing clean electricity, they will contribute to reducing greenhouse gas emissions and combating climate change, which is a key goal of this objective.
8 TRABALHO DIGNO E CRESCIMENTO ECONÓMICO	Creation of 33,066 jobs, with 100% of the work carried out by companies based in Portugal.
9 INDÚSTRIA, INOVAÇÃO E INFRAESTRUTURAS	Promotion of the development of the floating offshore wind industry in Portugal.
13 AÇÃO CLIMÁTICA	Reduction of more than 1.4 million tonnes of CO_2 emissions per year, which will contribute significantly to climate action.
14 PROTEGER A VIDA MARINHA	Producing electricity from a renewable energy source, wind, which is considered more sustainable and less polluting than fossil fuels such as coal and oil, will reduce greenhouse gas emissions, which will promote the mitigation of the impacts of climate change on the oceans, which is a major threat to marine life.
15 PROTEGER A VIDA TERRESTRE	Mitigating the effects of climate change on terrestrial ecosystems and biodiversity by reducing greenhouse gas emissions. These ecosystems and species are in danger due to rising temperatures, extreme weather events and other effects of climate change. In addition, the development of offshore wind energy will help reduce the demand for fossil fuels and help reduce the negative impacts of the extraction and use of these fuels on terrestrial ecosystems.

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