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Towards the Sustainable Decommissioning of Fixed Platforms by Aligning Ecosystem Services and Wind Generation: A Brazilian Case

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ABSTRACT

Brazilian legislation, as well as others around the world, determines that oil platforms, mainly fixed, must be decommissioned at the end of the feasibility of exploring the oil field, however, it is not common to consider the loss of ecosystem services that sustain life, the biodiversity and make resources available to humans. Considering the importance of the ecosystems that developed in the substructures of platforms, this work proposes a solution to maintain ecosystem services together with the development of clean, economically viable wind energy generation. For this, a proposal is built based on climatological, geographic, and wind power generation market data that seeks to demonstrate the financial viability of the specific case of the Robalo 1 Platform, which is located about 50 km from other platforms to be decommissioned, in the Sergipe-Alagoas Basin, Brazil. It was found that when minimally valuing ecosystem services such as artificial reefs and integrating wind generation for the non-decommissioning of the fixed platform substructure, from the point of view of net present value, the project proves to be viable.

Keywords: Descommissioning, Offshore Wind Energy, Environmental Services, Oil Platform, Reuse, Sustainable Technologies
JEL Classifications: A120, D4, L11, M110

1. INTRODUCTION

According to the Brazilian Ministry of the Environment - MMA (2020), ecosystem services are about the benefits that nature brings to people, being vital for human well-being and economic activities. Thus, they can be classified into ecosystem services of provision, regulation, cultural and support. Decommissioning is the final phase of the life cycle of an offshore oil and gas exploration structure, when it is no longer viable to continue exploring, so all wells are plugged and abandoned (Kaiser and Liu 2014).

For Sommer et al. (2019), the knowledge regarding the environmental impacts with the strategies used in the decommissioning of platforms is still incomplete, since the simple removal of structures that have already been installed for decades, integrates the habitat of marine life and its total removal means the almost complete loss of associated biota.

Thus, it is necessary that decommissioning be planned within an ecosystem approach, and the valuation of ecosystem services considering the permanence of oil platforms is considerably relevant to demonstrate its importance.

This work aims to test the applicability of an ecosystem services approach for the project of non-decommissioning of fixed platforms' substructure, considering the insertion of wind turbines that still allow energy production, partially taking advantage of these structures.

For the methodological development of this work, in addition to an in-depth bibliographic review, data are also collected from a climatological database and a geographic database, which allowed defining the allocation for the case study and the technical, financial and environmental analyzes to test the proposal from a commercial wind turbine model.

2. THEORETICAL SUPPORT

2.1. Offshore Wind Energy

Raimundo and Santos (2015) say that wind energy comes from the air masses that are used due to their movement to rotate the blades of a wind turbine, converting the kinetic energy of the winds into mechanical energy in the blades, which will travel through a multiplier, within the structure of the wind turbine, increasing the speed of rotation and transmitting the energy to a generator, which will transform it into electricity, which will be distributed to the grid.

Offshore wind energy is the use of equipment to capture the potential of air masses at sea, and although the operation of this system is similar to that described above, there are some particularities related to treatments due to the corrosive environment, installation costs, costs operation and maintenance, among others. Compared to onshore wind energy, offshore wind generation allows to produce more electricity, as the winds tend to flow at higher speeds than the winds on land, and large investments in offshore plants are expected in the coming decades, still considering the scarcity of land for onshore generation (Bilgili et al., 2011).

Cavazzi and Dutton (2016) state that in terms of structural reliability, it is recommended that for generation in shallow water (up to 30 m depth) the foundation is of the single-pillar type; for intermediate waters (between 30 and 60 m) of the jacket type; and for deep water (deeper than 60 m), the ideal are floating structures.

According to Christófaro et al. (2013) the jackets that wind turbines can be installed on are lattice structures similar to a high voltage electrical tower, which has four piles to commonly attach to sandy ocean floors, such a structure is similar to that used in fixed jacket oil platforms.

According to Krohn et al. (2009), wind conditions at sea have less turbulence than on land, and offshore installations are certified to operate between 25 and 30 years. In view of substantially higher installation costs at sea, service life extension is a possibility, but there are still no significant discussions on the topic.

Although there is great expectation regarding the exploration of offshore wind potential in Brazil, and some projects have already applied for Environmental licensing to operationalize, the Regulatory Framework to regulate the granting of authorizations for the use of offshore energy potential is still in the form of the legislative bill 576, of 2021 and awaits approval (Brazil, 2021). The current text does not present restrictions on the reuse of jacket structures from the decommissioning of oil exploration to achieve exploration of wind potential.

2.2. Ecosystem Services in Artificial Reefs

Unlike what happens in Brazil, Suzdaleva and Beznosov (2021) argue that the legs of offshore platforms can be used as artificial reefs to maintain the quality of the environment, bio productivity, and biodiversity of marine ecosystems.

According to the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA, 2020) in its normative instruction nº 28 November 2020, an artificial reef is understood as a submerged structure, deliberately built or placed on the seabed to emulate the ecosystem functions of reefs and other natural substrates, such as protection of biodiversity, regeneration of degraded habitats, enhancement of marine biological resources and others.

Considering that emulating can be understood as the act of doing one's best to equal or exceed something (Cambridge Dictionary, 2022), we can assume that the ecosystem services provided by an artificial reef are of equal value to those offered by a natural reef.

Blount et al. (2021) show that by creating artificial reefs as new habitats, the expectation is that fish assemblages will settle there and that, at least, they will become similar to natural reefs, if not more diverse and abundant.

As exposed by Hylkema et al. (2021) when studying artificial reefs in the Caribbean, the main reasons for creating such structures are to create new dive sites, develop research, and support the restoration of ecosystems that encourage diversity. However, it must be considered that, regardless of its purposes, this new location must not negatively affect the surrounding habitat.

2.3. Legal Basis of Decommissioning

The first provisions that dealt with technical guidelines for the decommissioning of oil platforms in Brazil were resolutions of the National Agency of Petroleum, Natural Gas and Biofuels (ANP), which is responsible for regulating the sector, and therefore published Ordinance No. 25 of 2002 that "Approves the Regulation for Abandonment of Wells drilled with a view to the exploration or production of oil and/or gas" (ANP, 2002) and Resolution No. 27 of 2006 that "Approves the Technical Regulation that defines the procedures to be adopted in the Deactivation of Installations and specifies conditions for the Return of Concession Areas in the Production Phase" (ANP, 2006). However, without any mention of the environmental dimensions.

Ordinance No. 25 was revoked by ANP (2016) Resolution No. 46 OF 11/01/2016, which "approves the Operational Safety Regime for the Integrity of Oil and Natural Gas Wells", and No. 27 was revoked by ANP Resolution No. 817 DE 24/04/2020 which "provides for the decommissioning of oil and natural gas exploration and production facilities, the inclusion of land area under contract in the bidding process, the disposal and reversal of assets, the fulfillment of remaining obligations, the return of the area and other measures" (ANP, 2020). There is also Resolution No. 41/2015 that guides the decommissioning of pipelines and subsea systems (ANP, 2015).

Resolution No. 817 defines the decommissioning of facilities as the "set of activities associated with the definitive interruption of the operation of the facilities, the permanent abandonment and razing of wells, the removal of facilities, the proper disposal of materials, residues and tailing and the environmental recovery of the area“, that is, there is some concern with environmental preservation. The same resolution considers environmental recovery as “interventions that aim to restore its natural characteristics to the environment, such as the stability and balance of the processes originally operating in it or their suitability for the planned use of the degraded area“.

Following the technical regulation for the decommissioning of exploration and production facilities set out in Annex I of Res. No. 817, the facilities removed from operation, the equipment necessary to carry out the decommissioning, and the area where the facilities are located must be maintained by the contractor in safety conditions, to mitigate the risks to human life, environment, and other users, until the decommissioning process is completed.

Thus, it allows offshore platforms to be maintained as long as they are duly justified and meet applicable regulations, enabling the comparison of decommissioning alternatives, whose analyzes must adopt, at least, the technical, environmental, social, safety, and economic criteria.

Another point is that the installations that are partially removed or that remain *in situ* must not interfere with navigation, the marine environment, and other users of sea resources, and the person in charge of the Production Unit must present a semi-annual report and letter of the flag that the unit is in satisfactory condition.

Resolution No. 854 published in September 2021, which “regulates the procedures for presenting financial guarantees and terms that ensure the financial resources for the decommissioning of production facilities in the oil and natural gas fields“, establishes that the parties involved in the process of decommissioning comply with and ensure compliance with the National Policy on the Environment and Environmental Crimes, being responsible for complying with the applicable environmental and socio-environmental protection legislation, including concerning its employees (ANP, 2021).

The National Environmental Policy (PNMA), established by Law No. 6938, of August 31, 1981, and regulated by Decree No. 99,274/90, was constituted, among others, of the following instruments: environmental quality standards, zoning, environmental impact assessment, and environmental licensing. IBAMA was established, as an autonomous entity linked to the Ministry of the Environment, the executive body of the National Environmental Policy, with the main attribution of the execution of the policy of preservation, conservation, and sustainable use of natural resources, is responsible for conducting the processes environmental licensing at the federal level (Brazil, 1981).

IBAMA requires, as a condition of the environmental license (Operation License) of an oil field, the delivery of a Deactivation Project as one of the environmental projects that make up the Environmental Impact Study (EIA) (Teixeira and Machado 2012).

According to Luczynski (2002) the legislation on abandonment should contemplate, at least, the following aspects:

a. Protection of marine fauna throughout the process
b. In case of transformation of the structure into a reef, define its depth, as well as the continuity and safety of navigation in the surroundings
c. Ensuring monitoring, by a multidisciplinary team, of the deactivation process and maintenance of habitat conditions.

In Brazil, decommissioning activities are subject to the requirements of Resolution No. 001/86 of the National Environmental Council - CONAMA/IBAMA, which regulate the environmental impact analysis and the licensing process by the agency, and Law 12,305/2010 that governs the National Solid Waste Policy. By these regulations, IBAMA prohibits the on-site abandonment of subsea platform structures and equipment, in addition to launching into deeper waters and removal and disposal on land, requiring that such waste have an appropriate destination.

The main option to be considered for the decommissioning of platforms in Brazil contemplates the evaluation of the complete removal of the entire structure of oil production, however, the analysis of alternatives and comparative evaluation are contemplated by IBAMA, and options that prove to be superior considering criteria may be accepted. environmental, social and economic, however alternatives to total removal have not yet been employed (Oliveira, 2017).

3. RESEARCH METHODOLOGY

For the economic valuation of the ecosystem services of the platform facilities, the values of the hectare per year of conservation in 1994 were used as a reference based on Costanza et al., (1997), this value was corrected to July 2022 through the inflation simulator available from the US government at U.S. bureau of labor statistics (2022).

In this way, the addition of annual recurring revenue (ARR) from ecosystem services should be applied:

$$ARR = Area \times Service\ value$$

3.1. Study Area

The Sergipe-Alagoas Basin was selected to develop a specific case because, according to Barboza et al. (2020), when compared to other offshore oil basins, has better characteristics to enable the installation of a wind farm. It could take advantage of the infrastructure of oil platforms, as it has a set of oil fields and exploratory blocks close to the coast, and a percentage of fixed oil platforms higher than other basins with offshore wind attractiveness. Such structures have low water depths and are permanently connected to the mainland by a duct (production flow pipe).

Within the Sergipe-Alagoas Basin, the Robalo Platform 1 (PRB-1) was selected, which had its decommissioning and request for the decommissioning process in 2021, located at latitude -10.65353 and longitude -36.63528, With a water depth of approximately 12 m. It is further away from the other platforms in this Basin, according to the Nautica Charter 22300 of the Brazilian Navy

(Marinha do Brasil, 2021), and which could make its allocation in a joint wind farm with the other platforms to be decommissioned in this Basin unfeasible.

This platform is located 4.7 km from the coast of the Santa Isabel Biological Reserve, between the Sergipe municipalities of Pacatuba and Pirambu, as can be seen in Figure 1.

3.2. Wind Turbine Selection

For this scenario, was chosen the machine V164-8.0 MW, produced by Vestas Offshore, because it is one of the largest turbines in terms of generation commercially installed in the world and with a consolidated position, having obtained representative expression in European facilities since 2016. This is also the turbine considered by Barboza et al. (2020) which presents the worst scenario to enable the insertion of wind turbines as an alternative to the decommissioning of fixed oil platforms in Brazil.

The power curve of this turbine that operates with a cube at 118 m high, represented in Figure 2, was used to obtain the values related to power and energy generation with the implementation of this equipment in the study area selected for offshore wind exploration.

3.3. Determination of Wind Potential

For characterization and assessment of wind intensity in the selected study area, the average wind speed for the period from 1981 to 2010 was considered, using data from the Reanalysis Project, a comprehensive database with a vast period of information collected from radiosonde, buoys, ships, aircraft, satellites, and meteorological stations, with data compiled and that went through a quality control process, generating a preliminary product with input data for the data assimilation model (Jenne et al., 1993).

With the data obtained with the help of the GrADS software, considering the Law of the Wall, the interpolation was performed, changing the height *(z)* according to the height of the selected wind turbine hub. The average value of surface friction velocity (u_τ) obtained by the program was used, the von Kármán constant approximating to 0.4 and the estimated roughness length value (z_0) was 0.0002 meters, as it is considered a typical roughness value for calm seas (Picolo et al., 2014). For this purpose, the following equation was used:

$$u_{(z)} = \frac{u_\tau}{k}\ln\left(\frac{z}{z_0}\right) \tag{1}$$

To determine the production profile throughout the year, the Weibull distribution was adopted for the application of the probability density function *(f(u))*, which demonstrate the fraction of time that the wind is at certain speeds from the following equation (Mathew, 2006):

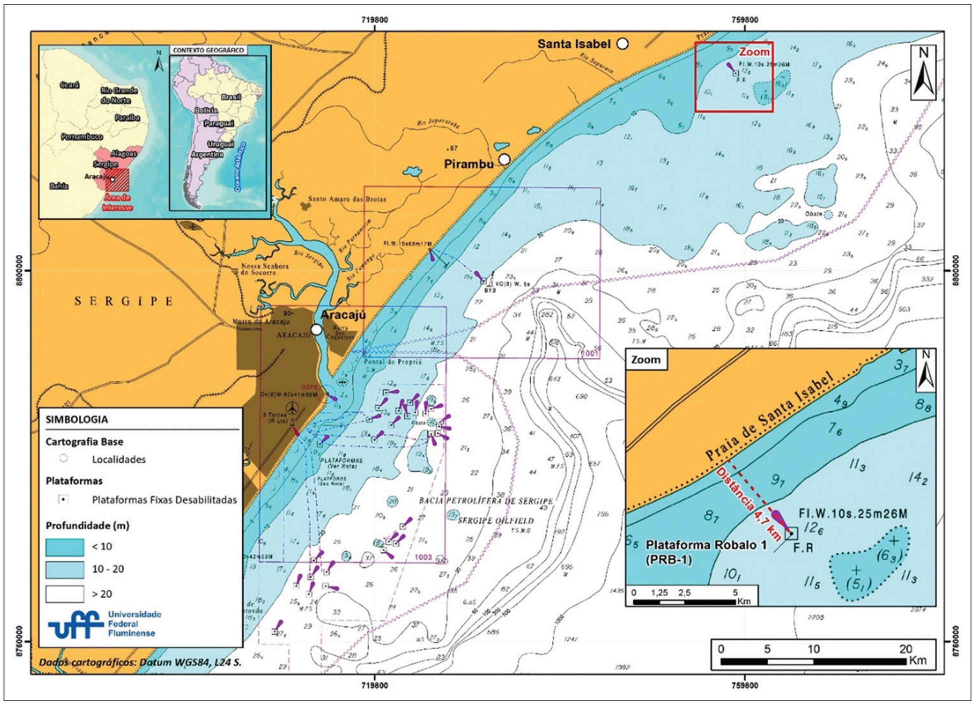
$$f(u) = \frac{k}{c}\ln\left(\frac{u}{c}\right)^{k-1} e^{-\left(\frac{u}{c}\right)^{k}} \tag{2}$$

Based on UNIDO (2015), the form factor *(k)* was defined with a value equal to 4, the scale factor (c) was determined by dividing the annual average wind by 0.89, and also considering the amount of wind and its probability *(u)*.

Associating the wind turbine power curve *(P(u))* with the probability density function *(f(u))* obtained by the operating time *(t)* it became possible to determine the Annual Average Energy Production *(E)* (Ko et al., 2015):

$$E = \sum (P(u)xf(u)) * t \tag{3}$$

Figure 1: Location of the Robalo 1 platform, in relation to the coast of the State of Sergipe and in relation to the other platforms to be decommissioned



Source: Authors' elaboration

At the end of this step, the capacity factor *(Cp)* of the selected wind turbine was calculated, which is the ratio between the energy effectively generated *(E)* for the selected location and the nominal energy *(En)* da of the turbine that would be produced if it operated at its power 100% of the time:

$$Cp = \frac{E}{En} * 100 \tag{4}$$

3.4. Financial Viability

The methodology used to determine the economic analysis takes into account the average price of the A-4 new energy auction of 2022, as well as the exchange rate was considered at 5.1961 using the reference date of August 19, 2022, obtained from the Brazilian central bank (BACEN, 2022) and the US 10 year treasure rate with reference in the same date define the Minimum Rate of Attractiveness (MRA). These values were defined as they refer to the date of the most recent new energy auction in Brazil on the date of submission of this work.

In order to calculate the net monetary gain, discounting all expected future inflows and disbursements for the present date, and consequently assess the feasibility of the project considering a 25-year cash flow, the calculation of the Net Present Value was performed, which is mathematically expressed by (Horngren et al. 2000):

$$PV = \sum_{t=0}^{n} \frac{F_t}{(1+i)^t} \tag{5}$$

The *NPV* calculation made it possible, through the knowledge of the expected flow of future benefits *(Ft)*, the period *(t)* in years and the defined minimum rate of attractiveness *(i)*, to determine the Internal Rate of Return by equating the NPV to zero.

4. ANALYSIS AND DISCUSSION OF RESULTS

The basic technical characteristics of this wind turbine are shown in Table 1.

The average annual wind speed at 118 meters, considering the cube height of the turbine, is 6.07 m/s, but another relevant point is the low variability in wind averages throughout the year, as can be seen in Figure 3.

The lower variability in wind speeds compared to winds in other oil basins, as can be seen in Barboza et al. (2020), can ensure better forecasts in the allocation of resources and guarantee of generation throughout the year, avoiding the underutilization of resources.

Table 1: Technical characteristics of the V164-8.0 MW wind turbine (Vestas, n.d.)

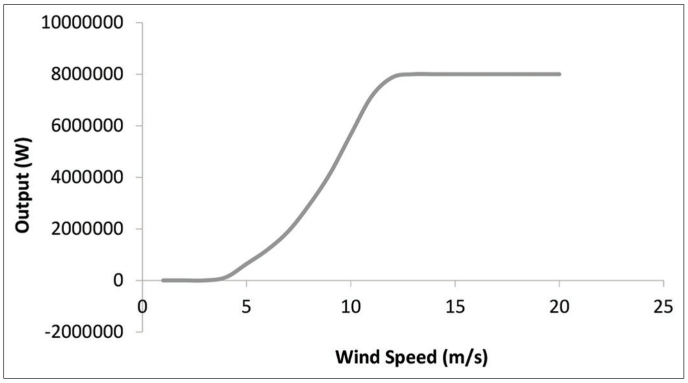
Item	Value	Units
Rated power	8000	kW
Rated wind speed	13	m/s
Cut-in wind speed	4	m/s
Cut-out wind speed	25	m/s
Rotor diameter	164	m
Hub height	118	m
Swept area	21,164	m²

Source: Vestas, n.d.

After calculating the average wind speeds at a height of 118 meters, the Weibull distribution was performed to estimate the probability of occurrence at a given wind speed in the area of the platform. The variations in wind speed used in the probability density function *(f(u))*, indicated that the portion of time that the wind is at a speed between 6 and 7 m/s is the highest, as can be seen in the Figure 4.

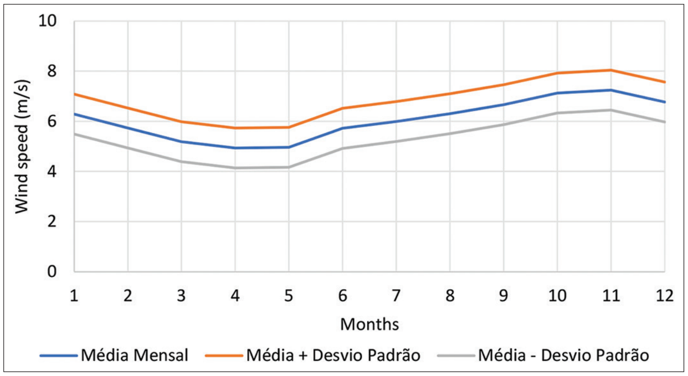
By considering the average monthly wind speeds and the wind probability with the Weibull distribution, it was possible to calculate the potential energy production for each month, over

Figure 2: V164/8.0 MW power curve



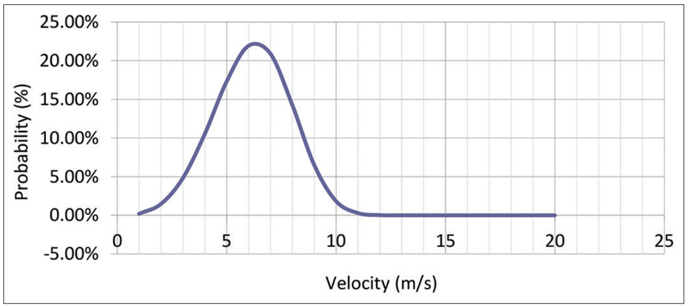
Source: Adapted from Pandit and Kolios, 2020

Figure 3: Monthly wind speed behavior at 118 m height



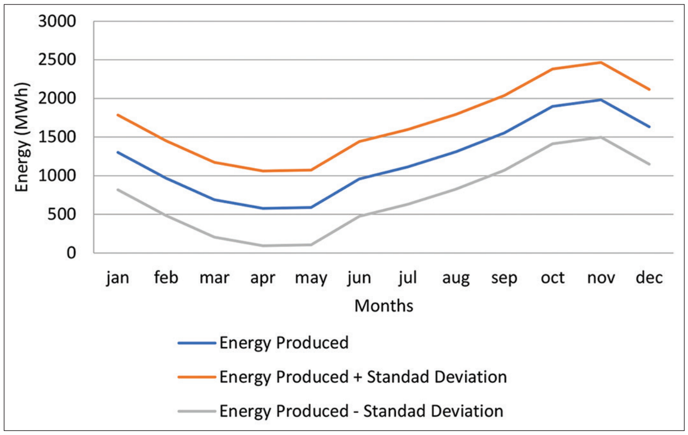
Source: Authors' elaboration

Figure 4: Weibull distribution for mean annual wind speed at 118 m height



Source: Authors' elaboration

Figure 5: Power potential to be produced with the V164-8.0 MW at 118 m



Source: Authors' elaboration

which the positive and negative standard deviation was considered, as can be seen in Figure 5.

It is noticed that the months in which there is a greater possibility of generating energy are October and November, with an average of 1895 MWh and 1982 MWh, respectively, while the months with the lowest potential are the months of April and May with a monthly average of 577 and 587 MWh, respectively.

According to Banigo (2010) typical dimensions of the marine surface area occupied by the oil platform jackets are 400 by 500 feet, that is, approximately 18581 square meters or 1.8581 hectares. Considering that the artificial reefs that are already found in these structures and restricting ecosystem services only to these areas, although according to Costanza (2020) they are broader, the ARR for this space would be US$ 22875.18 in July 2022.

To estimate Capital Expenditure (CAPEX) and Operational Expenditure (OPEX), the technical report produced by Valpy et al. (2017), considering an installation that is <40 km from the coast, a depth of <25 m and with an 8 MW wind turbine, so these values are presented in Table 2 in euros and converted to dollars.

Support substructure and commissioning costs were disregarded, due to the proposal to reuse the facilities already used for oil production. The average price of the 2022 A-4 new energy auction was R$ 258.16, or through conversion on August 19, 2022, US$ 49.68.

In Table 3 it is possible to observe the most relevant results, which demonstrate the viability of this model of this model of "non-decommissioning" of oil platforms.

When analyzing the table, it is possible to see that the NPV is positive, representing that the investment in this project returns higher revenues than the expenses, and therefore, it would be feasible, however, the IRR is lower than the MRA, indicating that, under the assumptions of this case, the rate of return obtained would be lower than the minimum rate considered attractive by the investor, however, it is necessary to test other alternatives and point out that the gain with intangible assets, such as the image of the organizations involved before stakeholders, was not considered.

Table 2: Expenditures by the comparative approach (adapted from Valpy et al., 2017)

Parameter	€/MW	US$/MW	Total (US$)
CAPEX			
Development	92,000	99,016	9,858,544
Turbine	1,003,000	1,079,489	
Array electrical	50,000	53,813	
OPEX			
Operations and planned maintenance	33,000	35,517	81796
Unplanned service and other OPEX	43,000	46,279	

Source: Author's elaboration. OPEX: Operational expenditure, CAPEX: Capital expenditure

Table 3: Summary of scenario results

Power generation	14004	MWh/year
Maximum power	0.42	MW
Average power obtained	1.60	MW
Annual average capacity factor	20.0	Percentage
ARR ecosystem services	22 875.18	US$/year
Income	695 766.33	US$/MWh/year
NPV	1 508 446.42	US$
IRR	2.846	Percentage

Source: Author's elaboration. ARR: Annual recurring revenue

The generated energy is also attractive to collaborate with the mix of renewable energies in the Brazilian national energy matrix, although it was calculated only for a single wind turbine.

5. CONCLUSION

The meteorological data used indicate that the offshore wind generation, 118 m from the surface, has adequate speed for the operation of wind turbines, so even for a c wind turbine, in terms of energy generation, the use of wind turbines as an alternative to decommissioning of platforms proves to be viable, as it allows reducing dependence on other energy sources, especially if we think of a distribution structure for the municipalities of Pacatuba and Pirambu, which are very close to the lease and could benefit directly from the public energy network.

It should be remembered that the premises tested here assess the generation of a single isolated platform, and the financial additional for ecosystem services was restricted only to the artificial reef in the dimensions of the Platform, without considering the adjacent areas that integrate the coastal ecosystem services and that, if the extraction of the Platform occurs, its biological relationships may have a negative impact. Even so, without considering image gains, the permanence of the structure proved to be economically viable, since from an economic point of view, it is necessary to consider more than the positive NPV, but also the social and environmental impacts.

As this work presents some restrictions, it is expected that in future works, the analysis of a wind farm will be developed that integrates the platforms that are close in the Sergipe-Alagoas Basin, that the technical, economic and environmental viability will be tested, that others aspects will be evaluated of ecosystem services and that a more detailed cash flow is developed by proposing a minimum value for offshore wind auctions observing the model of other countries.

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