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AMBEMAR-DSS: A DECISION SUPPORT SYSTEM FOR THE ENVIRONMENTAL IMPACT ASSESSMENT OF MARINE RENEWABLE ENERGIES

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ABSTRACT

The high energy demand and the threat of climate change have led to a remarkable development of renewable energies, initially through technologies applied to the terrestrial environment and, recently, through the awakening of marine renewable energies. However, the development of these types of projects is often hampered by failure to pass the corresponding environmental impact assessment process.

The complexity of working in the marine environment and the uncertainties associated with assessing the impacts of such projects make it difficult to carry out objective and precise environmental impact assessments.

AMBEMAR-DSS seeks to establish a basis for understanding and agreement between the different stakeholders (project developers, public administrations, environmental organizations and the public in general), in order to find solutions that allow the development of marine renewable energies, minimizing their environmental cost. For this purpose, a DSS is proposed which, based on cartographic information and using objective and quantifiable criteria, allows comparative assessments and analyses between different project alternatives. The analytical procedures used by the system include, among others, hydrodynamic modeling tools and visual impact simulators. In addition, impacts on marine species are assessed taking into account intrinsic ecological and biological aspects. The magnitude of the impacts is quantified by means of fuzzy logic operations and the integration of all the elements is carried out by an interactive multi-criteria analysis. The results are shown in tables, graphs and figures of easy interpretation and can be also visualized geographically by means of a cartographic viewer.

The system identifies the main impacts generated in the different phases of the project and allows establishing adequate mitigation measures in search of optimized solutions. The establishment of the assessment criteria has been based on the abundant, but dispersed, scientific literature on the various elements of the system and having the opinion of experts in the various fields. Nevertheless, the DSS developed constitutes a preliminary basis on which to build and improve a system with the input of researchers, promoters and experts from different disciplines.

Keywords
Environmental Impact Assessment, Marine Renewable Energy, Decision Support System, Geographic Information Systems.

INTRODUCTION

The Environmental Impact Assessment (EIA) is a necessary process for the assessment of projects whose execution can produce significant impacts on the environment.

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Since its inception in the United States during the 70s (NEPA, January 1, 1970), the EIA has spread around the world, evolving and developing new methodologies and procedures (e.g. see a full review and classification made by Conesa, 2009). The EIA was initially applied to land projects and progressively extended to the marine environment, initially applied to oil and gas industry projects (Budd, 1999, Glasson et al., 1994). With the boom of the marine renewable energies (MREs) a new stage was started. The necessary requirements for their implementation have led to a growing interest in the possible impacts produced by these types of facilities on the different elements of the system (e.g. Frid et al., 2012; GMI, 2010a; Hiscock et al., 2002; Huddleston et al., 2010). Thus, the precise knowledge of these interactions is a fundamental element for the decision making about the feasibility of their development.

However, the high costs and difficulties of working in the marine environment make the available knowledge about it limited, which produces high uncertainties. Thus, the knowledge gaps relating the environmental factors and their responses to the different actions of the projects, can lead to assessments with a high degree of subjectivity. This subjectivity can make the acceptance or rejection of the projects more dependent on the social or political responses (e.g. Bell et al., 2005), than on their real impacts or benefits.

Recently, the development of new techniques for prospecting the marine environment and the advance in scientific knowledge have contributed to notably reduce the uncertainties associated with the development of MERs. In parallel, there has also been a great development in specific software applications, which has allowed a qualitative leap in the possibilities of executing complex calculations and making quicker and more accurate assessments. In this sense, the numerical modeling tools, such as the hydromorphodynamic model Delft3D (Roelvink et al., 1994), has allowed analyzing the hydrodynamic and sedimentary transport impacts produced as a consequence of the alteration of wave and current regimes (García-Alba et al., 2017). Current programs, such as Moyses (Manchado et al. 2013) or MarRojo, allow to evaluate the visual impacts produced by the presence of the devices in the environment and the consequent alteration of the landscape quality according to human perception. Potential habitat models, such as MAXENT (Phillips, et al., 2006; 2017), ENFA (Hirzel et al., 2002), SDM (Naimi & Araujo, 2016) or BIOMOD (Thuiller et al., 2009), allow mapping of virtual habitats and predicting the possible presence of certain species depending on the physical characteristics of the environment, thus reducing the marine surveys costs.

The advance of information technologies has led to the development of different types of EIA applications, in most cases focused on the evaluation of terrestrial projects, such as EIA09 (Cruz et al., 2009), TDEIA (Duarte, 2000) or ENVIGO (Eon +)). One of the more recent applications is "TheNewEIS" of Royal HaskoningDHV, which incorporates visual and interactive procedures for the EIA of marine projects. Finally, the use of Geographic Information Systems (GIS) for decision making on MREs has been applied by Aguilar (2013). Related to these applications, the use of Decision Support Tools for marine spatial planning has been thoroughly reviewed by Pinarbasi et al., (2017).

Therefore, it could be said that there is a growing need to carry out environmental impact studies applicable to marine projects. These studies should contemplate the complex interactions existing in this medium and evaluate the possible consequences of executing the projects. The improvement of scientific knowledge and the availability of computer programs with innumerable applications give us the opportunity to develop EIA tools capable of integrating the different elements of the system and of carrying out accurate, objective and standardized assessments, quickly and efficiently. Therefore, the objective of this paper is to present the AMBEMAR Decision Support System for the EIA of MREs, as well as the results of its application to a proposed offshore wind farm.

METHODOLOGY

Description of the AMBEMAR system

AMBEMAR is a Decision Support System (DSS) based on Geographic Information Systems and designed for the environmental impact assessment of marine renewable energy projects. It is a QGIS plugin, developed in Python, with a user interface designed in Qt.

The application structure of the DSS is carried out following the general guidelines of the environmental impact studies. The first step is to define the characteristics of the project and its alternatives. Then, the actions and effects that occur during the different phases of the project (preconstruction, construction, operation and decommissioning), as well as the environmental factors that could be affected, are defined. The interaction between these two elements are used to generate an impact matrix (see Figure 4 in the results). In this version of the DSS, only the most significant impacts of MREs have been included in the matrix.

The different interactions of the matrix are codified individually to assess their impacts. Valuations are made in objective and quantitative terms, applying Boolean or fuzzy logic criteria. The rating scale is standardized and restricted to a range of continuous values between +1 (very positive impacts) and -1 (very negative impacts). The valuation procedures are carried out by crossing GIS layers of project effects and environmental factors. All the assessment procedures and criteria applied in AMBEMAR-DSS are described in detail in the complementary information document included in the AMBEMAR web page (http://ambemar.ihcantabria.es).

The results of the impact assessments obtained at each element of the matrix are classified into 5 categories according to the following scale of values; positive impact (for values between +1 and 0), compatible (between 0 and -0.2), moderate (between -0.2 and -0.6), severe (between -0.6 and -0.8) and critical (between -0.8 and -1). The final evaluation of the project is carried out through four different procedures. The first one consists in the application of the "worst case" criteria and its value will correspond to that obtained by the element with the lowest score. The next two procedures result from the averaging, separately, the impacts corresponding to the 3 worst impact values of the environmental and socioeconomic factors, respectively. The last procedure consists on the averaging of the two previous results and would represent the global impact of the project. In the event that the proposed project presents, globally or punctually, any significant negative impact (moderate, severe or critical), mitigation measures should be adopted.

In order to analyze the confidence level of the assessments, the system includes a simple method to estimate the uncertainty. The procedure is based on the quantity and quality of the information used in the evaluation. To assess the quantity factor, the percentage of items covered in the evaluation is estimated. To assess the quality factor, the reliability of the information used in the analysis is considered. Thus, the use of official information and legally established criteria are given a value of 1. While the use of unofficial layers of information and subjective criteria are given a minimum value of 0.6. As an intermediate point, if the assessments are made using technical information and criteria established by prestigious institutions, the quality value given is 0.8. Then, the global quality factor is obtained by averaging the values corresponding to all the elements of the matrix. Finally, the overall confidence level of the assessment is obtained through the product of the values obtained in the quantity and the quality factors.

Case study

To test the suitability of the AMBEMAR-DSS, a simplified case study has been proposed on the coast of the Cantabrian Sea (North Spain). To this end, two alternative offshore wind farms, installed at 3 km and 9 km from the coast respectively, have been evaluated. The first alternative consists of 5 wind turbines of 5MW each (150 m of total height), anchored by Gravity Base Foundations (GBFs) at 60 m depth. The second alternative consists of 5 floating wind turbines of 8 MW each (200 m of total height), moored by a triple anchoring system at 150 m depth. The selection of this technology is due to the fact that it produces high impacts on certain elements (e.g. visual and seabirds). In addition, the park has been designed in an area with several environmental constraints (e.g. fishing grounds, marine protected areas, colonies of protected birds, shipping routes, macroalgae exploitation zones, special areas of conservation, densely populated areas and important leisure and tourism zones).

The GIS layers of environmental factors have been obtained mainly from official sources, such as the Spanish Government or the regional government of Cantabria, as well as from diverse free access sources, such as the data repository from Halpern et al., (2008) or technical reports from specialized organizations (e.g. seabird colonies from SEO/Birdlife, 2016; Álvarez and Velando, 2007). Additional information layers have also been generated following different procedures, such as visual impact modeling or scouring calculations, both aspects dealt with specifically in the subsequent sections of this document. Figure 1 shows the location of the proposed project alternatives on the Cantabrian coast, along with various GIS layers of information related to environmental factors, actions and effects coexisting in the study area.

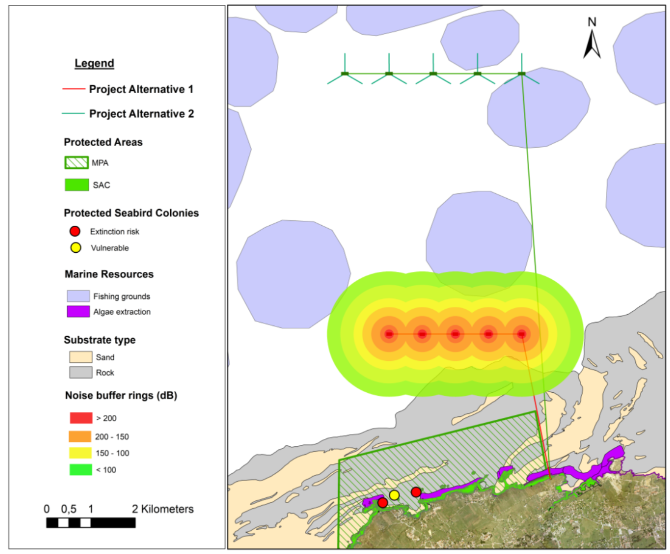


Figure 1: Location of the study area with several GIS layers related to different actions and effects of the project and their interaction with environmental factors (e.g. location of the devices, type of substrate, fishing grounds, algal resources, MPAs, SACs, noise, protected seabird colonies...).

Visual impact module

MarRojo visual impact module included in AMBEMAR-DSS allows to characterize the visual effects generated by marine renewable infrastructures and assess theirs impact magnitude in a quantitative and standardized way. This is done by means of quantitative indicators based on parameters such as the visual affected area or length, the affected population or the vision angle among others. Scientific literature includes several types of indicators based on visibility, distance, population, horizontal and vertical sight angle, visual acuity, contrast, etc. (Manchado et al., 2013, 2015; Depellegrin, 2016; Tsoutsos et al., 2015; Bishop and Miller, 2007; Kokologos et al., 2014; Wrozynbski et al., 2016). AMBEMAR-DSS includes two main indicators: the SPM2, composed by several partial indicators as mentioned in the Spanish Method (Manchado et al., 2015) and the MVE (Magnitude of Visual Effects) (Otero et al., 2012) explicitly mentioned in the regional legislation of Cantabria (Gobierno de Cantabria, 2014).

The assessment starts with the definition of the study area and the generation of a node grid (WT grid) equally distributed along the marine domain. The WT grid shapes the set of points for the calculation. The input data used to perform the calculation includes a digital terrain model (DTM), view shed for each node, population nuclei, roads, heritage or archaeological elements, protected zones, natural parks, vantage points, landscape itineraries, etc. All of them represented by means of GIS layers. Also, it is necessary to determine a set of adjustment parameters directly involved in the calculation, as the number of turbines for the proposed wind farm, device height, WT grid density, presence of vegetation and the indicators to be generated.

The first result provided by MarRojo consist on the values of the specified indicators for each node of the WT grid, thus obtaining a preliminary discrete assessment of the visual impact. Then, different interpolation techniques are applied in order to characterize the complete maritime domain in a continuous way (Figure 2). Thus, it is possible to assess the visual impact produced by the wind farm in any point of the domain. The result is transferred to the impact matrix, estimating in an standardized and objective way the visual impacts of different project alternatives.

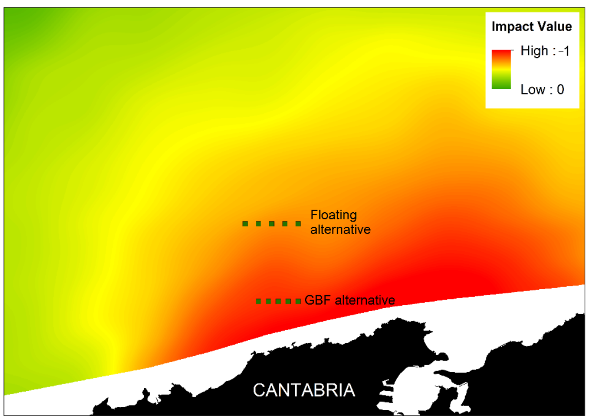


Figure 2. Standardized assessment of the visual impact of the project, regarding the affected area indicator for population nuclei indicator, in the maritime domain evaluated. Wind turbines are represented by rectangles.

Hydrodynamic impact module

Similar to the visual impact module, AMBEMAR-DSS incorporates a specific module for the assessment of the hydrodynamic impact. The module allows studying the scouring processes produced by infrastructures in the seabed and evaluates the magnitude of this impact in quantitative, objective and standardized terms.

Based on the work carried out by García-Alba et al. (2017), the hydrodynamic impact module allows quantifying the impact produced by different types of mooring structures (monopile, GBF, jacket, floating) on the seabed using a machine learning system (Bárcena et al., 2015). This system is powered by a set data obtained by numerical modelling using the hydromorphodynamic model Delft3D (Roelvink et al., 1994).

These aforementioned previous simulations have been chosen by the combination of tidal conditions and average currents in the study area obtained from the IH-Data database (Cid et al., 2014), 50th percentile of the swell in the study area (Perez et al., 2017), bathymetry, granulometry, sediment density and grain size disposal on the study site. The application of this module provides for each case study the affection on the seabed in plant (surface) and profile (depth of sediment) (Figure 3). This condition is standardized using transformation functions that quantify the impact on a scale from 0 (no impact) to -0.5 (maximum impact value considered for this factor) based on the values of the affected area and profile. The hydrodynamic impact value for each structure is incorporated into the AMBEMAR-DSS impact matrix and the cartographic layer of the scouring area is then used to assess the impact on benthic communities.

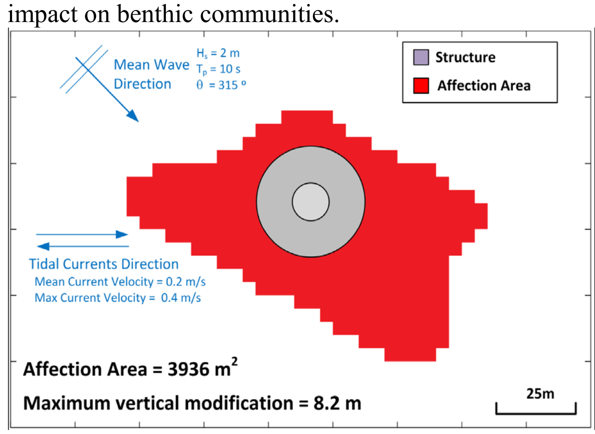
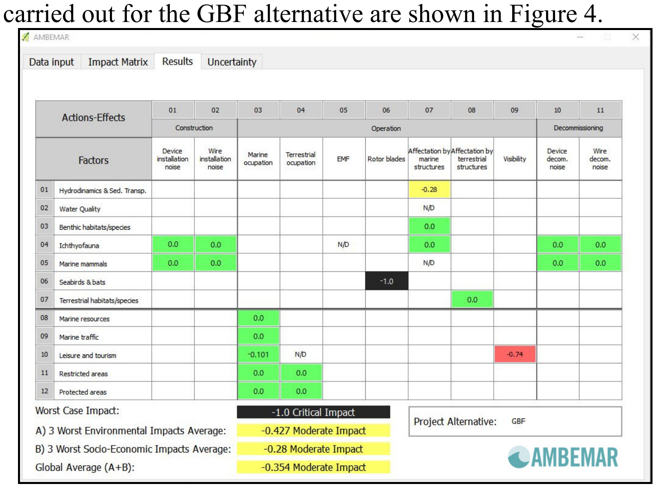


Figure 3. Result of the worst scouring case scenary, corresponding to a GBF located at 30 m depth in an area with predominance of fine and very fine sands.

RESULTS

The results of the Environmental Impact Assessments carried out for the GBF alternative are shown in Figure 4.



Actions-Effects / Factors	01 Construction: Device installation noise	02 Construction: Wire installation noise	03 Operation: Marine ocupation	04 Operation: Terrestrial ocupation	05 Operation: EMF	06 Operation: Rotor blades	07 Operation: Affectation by marine structures	08 Operation: Affectation by terrestrial structures	09 Operation: Visibility	10 Decommissioning: Device decom. noise	11 Decommissioning: Wire decom. noise
01 Hydrodinamics & Sed. Transp.							-0.28				
02 Water Quality							N/D				
03 Benthic habitats/species							0.0				
04 Ichthyofauna	0.0	0.0			N/D		0.0			0.0	0.0
05 Marine mammals	0.0	0.0					N/D			0.0	0.0
06 Seabirds & bats						-1.0					
07 Terrestrial habitats/species								0.0			
08 Marine resources			0.0								
09 Marine traffic			0.0								
10 Leisure and tourism			-0.101	N/D					-0.74		
11 Restricted areas			0.0	0.0							
12 Protected areas			0.0	0.0							

Figure 4. Results of the Environmental Impact Assessment corresponding to the GBF alternative of the project. The Impact Matrix reflects the elements evaluated (Actions-Effects vs. Factors interactions) and the colors correspond to the different impact categories (Black: Critical, Red: Severe, Yellow: Moderate, Green: Compatible, Blue: Positive). N/D: Not Data for that element.

As it can be seen, the impact of rotor blades on seabirds during the operation phase constitutes the most significant negative impact of the GBF alternative (-1; critical impact). This impact is lower in the floating alternative, which obtains an impact value of -0.77 (severe impact) for this element. Similarly, the visual impact of the GBF alternative is notably higher (-0.74) than that of the floating alternative (-0.55). In both cases, the shorter distance to the coast of the GBF alternative (3100 m vs. 8900 m of the floating alternative) has a great influence in the results obtained due to the proximity to seabird colonies and population.

The hydrodynamic and scouring effects produced around the structures have given a moderate impact for the GBF alternative (-0.28 value) and a compatible impact for the floating one (-0.024 value). In this case, the distance to the coast influences indirectly in the obtained results because the higher depth of the floating alternative reduces the scouring effect. Additionally, the larger surface of the GBF mooring constitutes an important factor in the high scouring produced by this alternative.

Another factor affected by the project alternatives is that corresponding to the leisure and tourism. The marine occupation by the windfarm prevents the access to the restricted area, thus limiting the marine space available for its use. In this sense, the proximity to important marinas near the project area has produced slight impacts in both alternatives. In this case, the higher restricted area of the floating windfarm produces a higher impact (-0.121) than the GBF windfarm (-0.101).

Globally, the floating alternative has obtained a smaller impact value (-0.244) than the GBF alternative (-0.354), but both of them are classified as moderate. In addition, both alternatives show severe or critical impacts as worst cases, therefore, both of them should be modified by the adoption of mitigation measures in order to reduce those impacts. In both alternatives the environmental factors have obtained higher impact values than the socioeconomic factors.

The uncertainty analysis has given a global confidence level of 66.4%. This result, corresponding to a 88% of items assessed with a quality factor of 0.755 on average, represents a high degree of uncertainty in the global EIA process.

DISCUSSION

In this work the usefulness of AMBEMAR DSS has been shown through the application to an offshore wind case study. Despite being an initial version, the DSS has allowed to assess quantitatively and objectively the main impacts of MRE projects.

In view of the results obtained, the impacts on seabirds constituted the most limiting element in the case study. The presence of protected seabird colonies (*Hydrobates pelagicus* and *Phalacrocorax aristotelis*) near the project areas has been the main cause of this impact. In this sense, the accuracy of the assessment could be further improved by introducing correction factors that take into account habits related to different species, such as the main migratory routes, the height of flight or the dispersion ranges of the colonies (Atienza et al., 2011; Mateos-Rodríguez et al., 2012; GMI, 2010b). In this sense, Garthe and Hüppop (2004) developed a species-specific sensitivity index based on their vulnerability to wind farms.

The impacts on marine mammals, mainly associated with noise levels (GMI, 2010c, Reeves, 1992, Thomsen et al., 2006) or collisions (Laist et al., 2001), constitute also key aspects in the impact assessments of MRE projects. In order to assess these impacts accurately, it is necessary to have detailed information on the distribution and behavior of the different species, as well as on the acoustic levels that produce alterations or damage to them (Nedwell and Howell, 2004; Nedwell et al., 2004, 2007). However, despite the numerous initiatives and agreements that express the need to regulate the impact of underwater noise (e.g. ACCOBAMS, ASCOBANS, OSPAR, etc) there are few works trying to fill this gap (e.g. Anderson et al., 2017). Another source of uncertainty is the lack of information regarding the distribution of marine mammals in the area. In this sense, although the Bay of Biscay is an area with a high presence of cetaceans (Castro et al., 2004, Kiszka et al., 2007), there is no precise information available about their distribution and abundance patterns. As a result, the presence criteria applied has been very conservative, considering the presence of cetaceans at a distance of 750 m in order to apply the criteria established in Anderson et al., (2017). On the other hand, noise levels also affect fish and sea turtles, although studies related to these organisms are much scarcer (e.g. Popper et al., 2014; Viada et al., 2008). In this case, the absence of pile driving, dredging, drilling or other type of noisy actions has resulted in low impact values for this element. Otherwise, the establishment of mitigation measures aimed at avoiding or minimizing noise impacts would have been required. Among the main preventive measures to adopt, there would be; (i) the programming of activities avoiding sensitive areas and periods, (ii) the establishment of exclusion zones (or "safety zones") around the emission source, (iii) the cessation of activity if the presence of animals is detected and (iv) the implementation of operational procedures like ramp-up at the start of the activity (Anderson et al., 2017; Weir and Dolman, 2007). Additionally, it is also possible to apply engineering solutions, such as bubble curtains, isolation casings or cofferdams, for the reduction of noise levels in the vicinity of the emission source (Würsig et al., 2000; Nehls et al., 2007; Thomsen, 2012), or the use of acoustic deterrent devices to keep animals away (Gordon et al., 2007).

It is widely accepted that the generation of electromagnetic fields (EMF) are among the major environmental issues related to the deployment of marine renewable energy devices (GMI, 2010a). However, despite the great attention given to this subject, there are few studies assessing the real magnitude of the EMF impacts based on empirical data (e.g. see review by Fisher and Slater, 2010). In general, the studies carried out in this sense have not shown significant impacts of EMF within the range of submerged power cables (e.g. Kavet et al., 2016; Woodruff et al., 2013; Bergström et al., 2014). Moreover, the extent and effects of EMF could be reasonably mitigated by adequate cable design (BERR, 2008), which allows reducing the potential impact of this factor.

According to several authors, alterations to hydrodynamic and sedimentary regimes produced by MRE devices could extent at distances of kilometers away from the arrays (Neill et al. 2009, 2012; Rees et al., 2006). The hydrodynamic impact module included in AMBEMAR-DSS has allowed to estimate, in a fast, precise and effective way, the scouring produced by different types of devices under different environmental conditions. The results obtained in the present study suggest that the affection produced by this phenomenon on the seabed is limited to a few tens of meters in the worst case considered. Although the importance of this impact may seem trivial, the need to assess the scouring acquires a crucial importance in those areas where protected or commercially important habitats and species may be affected (Miller et al., 2013). In addition to the scouring, the occupation of the seabed by the structures and the abrasive effects of the dragging by catenaries and seafloor wiring also cause impacts on benthic communities Krivtsov and Linfoot (2012). The installation of submarine wiring would produce additional spatial alterations (BERR, 2008). On the other hand, the presence of the structures would act as artificial reefs, contributing with both positive (e.g. creation of new habitats) and negative (e.g. dispersion of invasive species) impacts to marine ecosystems (Langhamer, 12, Langhamer et al., 2009).

The visual impacts are among the main concerns of wind energy. The decrease in visual quality and the consequent perception of loss of property value (among other aspects), generate opposition on part of the society (Bell et al., 2005, Rand and Hoen, 2017, Abbott, 2010). This rejection has sometimes been described as the "not in my backyard" (NIMBY) syndrome. However, the NIMBY concept has been discredited as simplistic, pejorative and unhelpful to find solutions, adding that efforts should be oriented to propose attractive strategies instead of overcoming the opposition (Rand and Hoen, 2017, Petrova, 2013). To deal with this aspect, the visual impact module included in AMBEMAR DSS has allowed to obtain an objective and standardized estimation of the visual impacts produced by MRE developments. The output of this module is a series of maps that offer the value of different visual or visibility indicators, extended to the territorial domain selected by stakeholders. These maps will be included in the AMBEMAR DSS, whatever the stage of design in which the system is being used.

Other socioeconomic affections would be associated to the occupation of the maritime space and the consequent restrictions of uses in the area. In this sense, the two proposed alternatives directly affect the exploitation of marine resources, since they overlap with fishing grounds and with macroalgae extraction areas. However, the percentage of the area affected with respect to the total of the region is so low (<0.1%) that the impact generated is practically negligible. Furthermore, these restricted areas would act as marine reserves due to fisheries exclusion, which could suppose, in absolute terms, a positive impact given their potential for the maintenance of exploited populations (Bergström et al., 2014; Langhamer, 2012; Wilhelmsson and Langhamer, 2014).

The use of maritime space for leisure and tourism would be slightly affected in our case study. In this sense, the use of the distance and the size of the marinas located near the energy farm have demonstrated to be effective indicators in order to assess the impact of the restricted maritime space on users. Contrary to what it would be expected, the GBF alternative, which is located closest to the coast (and therefore to the main marinas) has shown a smaller impact than the floating alternative. The reason for this apparent inconsistency is because the GBF windfarm generates a smaller restricted surface into the area of influence of the same marinas. Regarding maritime traffic, this study has proposed a useful procedure to identify, delimit and characterize the shipping routes present in coastal areas, using the shipping routes raster layer created by Halpern et al., (2008) as a base. However, given that the main shipping routes were located outside the study area, the resulting impact for this element was zero.

Regarding the assessment of the impact on marine and terrestrial protected areas, it will depend fundamentally on the uses and activities allowed in their corresponding management plans. However, in the absence of specific mention in this regard, it has been established an exclusion criterion for the development of marine renewable energy farms within the protected areas. In the event that the activity does not cause alterations on the conservation objectives of the protected area, the assessment of the impact is made based on the percentage of the area affected and its location (zone of influence or nucleus). This criteria would penalize those activities causing alterations on the more sensitive zones of the protected areas.

According to the analysis carried by Rand and Hoen (2017), socioeconomic factors seem to be more relevant than environmental concerns in the acceptance of wind farms. Olson-Hazboun et al., (2016) go further and state that framing of renewable energy as an environmental issue could have adverse effects in certain contexts. Slattery et al., (2012) found that when the development of wind energy is based on potential economic opportunities, even environmentally less concerned people would support it. In view of these results, it seems logical to think that, in anthropized environments, socioeconomic factors should have a greater weight than environmental ones, while, in natural environments, the environmental factors should be more relevant. The different impact assessment procedures included in AMBEMAR-DSS allow to adapt the assessments to the type of environment and the social context of the project.

The preliminary nature of the present study is evidenced by the uncertainties calculation procedure incorporated in the DSS. The low confidence level obtained in the general assessment (66.4%), suggest that both, the number of items and the quality of their assessment procedures, should be improved. In this sense, the number of items covered should reach 100%, since the lack of information should never lead to approve a project. This method could be further improved by introducing a weighting factor that assigns different weights to the items according to their relative importance (e.g. the assessment of impacts on phytoplankton would be apparently less crucial than the assessment of seabird impacts in the case of an OWF located near a protected seabird colony). In any case, this procedure has allowed to carry out an objective and quantitative estimate of the confidence level of the assessment results, providing the application with an effective tool to test their reliability.

Conclusions

As long as we need to consume energy and natural resources, there will be impacts on nature. The question is how to minimize those impacts in order to achieve a sustainable development. With the threat of climate change on the doorstep, the world needs low-carbon energy sources, such as the marine renewable energies. It is undeniable that they produce impacts on the environment, but they need to be balanced against their potential to deliver significant amounts of low carbon energy. If we focus on identifying and characterizing the impacts in objective and quantifiable terms (and try to minimize them), this activity can contribute enormously to reduce the consumption of fossil fuels and the threat of climate change.

For that, it is essential to establish objective and standardized criteria to assess the environmental impacts of MRE developments in a comparable way. This is a hard and complex work that should be carried out with the effort and the consensus of researchers, industry promoters, government bodies, ecologists, social representatives and experts from different disciplines.

AMBEMAR-DSS seeks to establish a basis for understanding and agreement between the different stakeholders, in order to find solutions that allow the development of marine renewable energies minimizing their environmental cost. AMBEMAR-DSS provides a quick overview of the potential impacts of certain marine renewable energy projects as part of the screening process. The results of this study do not reflect the real impacts of an existing project, so they should only be taken as a guide. The study proposes a methodological approach that should be further improved and adjusted with the contribution of the different stakeholders.

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