IMPACTO VISUAL DE PARQUES EÓLICOS MARINOS DENTRO DE UN SISTEMA DE SOPORTE A LA TOMA DE DECISIONES

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VISUAL IMPACT ASSESSMENT OF OFFSHORE WIND FARMS IN A DECISION SUPPORT SYSTEM

ABSTRACT:

Onshore or offshore renewable energy helps to obtain energy in a sustainable manner. However, the deployment of both alternatives can damage the environment with different kind of impacts. For this reason, the place to construct these infrastructures must take into account all related impacts. In this way, Decision Support Systems (DSS) are useful tools. In this paper, a methodology to introduce a visual impact indicator into a DSS for the Environmental Impact Assessment of Offshore Renewable Energy (AMBEMAR) is shown. This DSS is also described. This methodology is adjusted to DSS requirements and flexible to any study case. The result is one visual impact index calculated through a multicriteria analysis that can be used to compare different cases. This methodology is applied to a study case located in the coast in front of Cantabria region (Spain). Two hypothesis of wind farms and other two possible locations for its electric transforming substations are analysed from visual impact point of view. The method shows that furthest wind farm has the lowest impact but indices have a slight variation in both cases.

Keywords: DSS, visual impact, Spanish method, offshore wind farms, VIA, wind energy

RESUMEN:

Las energías renovables ayudan a obtener energía de forma sostenible, pero su emplazamiento también implica riesgos e impactos de diversa índole sobre el medioambiente, tanto en el ámbito marítimo como en el terrestre. Por ello, se deben tomar decisiones que tengan en cuenta estos tipos de impacto. Para facilitar este laborioso trabajo son útiles los Sistemas de Soporte a la toma de Decisiones (DSS). En este artículo se presenta el módulo para la valoración del impacto visual incluido en un DSS para la Evaluación de Impacto Ambiental de las Energías Renovables Marinas AMBEMAR-DSS. El índice de impacto visual que se presenta es aplicable a las características geográficas de cualquier área de estudio, y puede ser empleado dentro de los requisitos establecidos por el DSS. La metodología se sintetiza mediante un análisis multicriterio para obtener un único índice que permita comparar entre varias alternativas. Ésta es aplicada a dos hipótesis de parques eólicos situados a distintas distancias de la costa frente a la región de Cantabria (España); además, se analizan dos posibles ubicaciones de la subestación de transformación eléctrica desde el punto de vista del impacto visual. Con ello se obtiene que el parque eólico más lejano obtiene un menor impacto visual, aunque la variación de los índices es baja.

Palabras clave: DSS, impacto visual, Spanish method, parques eólicos marinos, VIA, energía eólica

1.- INTRODUCTION

Renewable energy helps to reduce CO2 emissions and to generate energy in a sustainable way. This kind of generation has advantages respect to traditional ones, which are based on fossil fuels consumption. However, they also produce environmental impacts [1]. Nowadays, offshore wind energy is becoming more common in Europe and decreasing the difference with the onshore development [2]. Part of this change is because environmental impacts create social opposition. Among these conflicts, the most important ones are related to visual impact [3][4], although there are others that influence in people perception, as analysed by Klain [5]. Visual impacts can be reduced, and even cancelled, if they are placed far enough from the coast, but the energy price would increase due to different aspects [6]. In order to avoid this economic increment, their locations must be near the coast, which produces changes in environmental affections and involved stakeholders [7].

Environmental effects of offshore wind farms are numerous. A Decision Support System (DSS), which takes into account all kinds of impacts, helps designers to choose the best location [8]. There already exist some DSS, or multicriteria systems that can be applied to DSS, in onshore wind energy [9][10][11]. However, there is a lack of them in offshore. Some of these systems use visual impact as a design factor [10], while in others it is not considered, as in the study carried out by Van Haaren [12]. He suggests that wind farms have better public opinion once they are built.

Visual impact depends on different variables such as distance, contrast or landscape value [13]. Nowadays, there is a variety of methodologies developed to evaluate it. Some of them utilize surveys to identify population preferences [14]. Others quantify economically the impact [15] or create restriction maps [16]. Some other methodologies use indices or indicators based on geometrical operations such as MVE [17], the method developed by Torres-Sibille [18], or the Spanish Method (SPM) [19], which was reviewed as SPM2 by Manchado et al. [20] and validated by Tsoutsos [21]. Furthermore, there are indices specifically developed for its use in DSS or multicriteria systems [22][23].

The inclusion of SPM coefficients in a DSS system has also other advantage. It allows the inclusion of visual impact assessment (VIA) of wind farms in the design stage. In this way, the designer can carry out a transversal analysis. This paper describes the methodology to include SPM-SPM2 coefficients in the new software AMBEMAR-DSS.

The paper follows the next structure: section 2 describes AMBEMAR-DSS; section 3 describes the methodology to calculate the visual impact; section 4 shows the study case; section 5 exposes the results; and finally, section 6 exposes the conclusions.

2.- AMBEMAR-DSS

AMBEMAR-DSS is a DSS that evaluates diverse project hypotheses related to offshore renewable energy allowing their comparison [24][25]. This software has been developed as a QGIS plugin, which gets all the advantages of this GIS open source [26]. Furthermore, AMBEMAR-DSS has a user-friendly interface to facilitate its use.

The main objective of this system is the analysis of offshore renewable energy project impacts during its life cycle. This kind of energy production can have negative effects on environmental and socio-economical aspects in every project stage: construction, operation and decommissioning (demolition and dismantling). A simplified matrix of impacts can be obtained from all these impacts as can be seen in fig. *1*.

The main environmental factors evaluated in this DSS are: hydrodynamic and sediment transport, water quality, natural habitats and bentonitic species, ichthyofauna, marine mammals, marine birds, bats, and terrestrial habitats and species. Regarding socio-economical factors: marine resources, maritime traffic, tourism and leisure, protected natural spaces and restricted areas for diverse uses. All of them are grouped in 6 categories: noise, terrestrial and marine occupation, electromagnetism, rotor action, onshore and offshore structures affection and visibility.

Three teams of experts in different areas developed the previous environmental factors, which were divided in modules as follows:

- Habitats and species module: flora and fauna of study area was evaluated. In this way, boolean criteria was stablished whether there are protected species, and fuzzy logic criteria whether they have some importance.
- Hydrodynamic and sediment impact module: a set of functions was defined to evaluate the impact in the seabed. They are based on water depth and surface affected by scouring.
- Visual impact module: the impact in seascapes based on Spanish Method (SPM-SPM2) was evaluated. This module is the main scope of this paper.

The teams developed this DSS through an iterative process. First, requirement analysis (RA) was carried out to evaluate the system characteristics, setting a framework for the software development. Then, they defined the software specifications (SS) based on the RA, so the activities duplication and possible inconsistences did not happen. The third step was to develop a first version of the DSS based on the latter characteristics. The last phase of this iterative cycle was bug tracking and feedback (FB). The latter results are the inputs for RA in the second cycle [27].

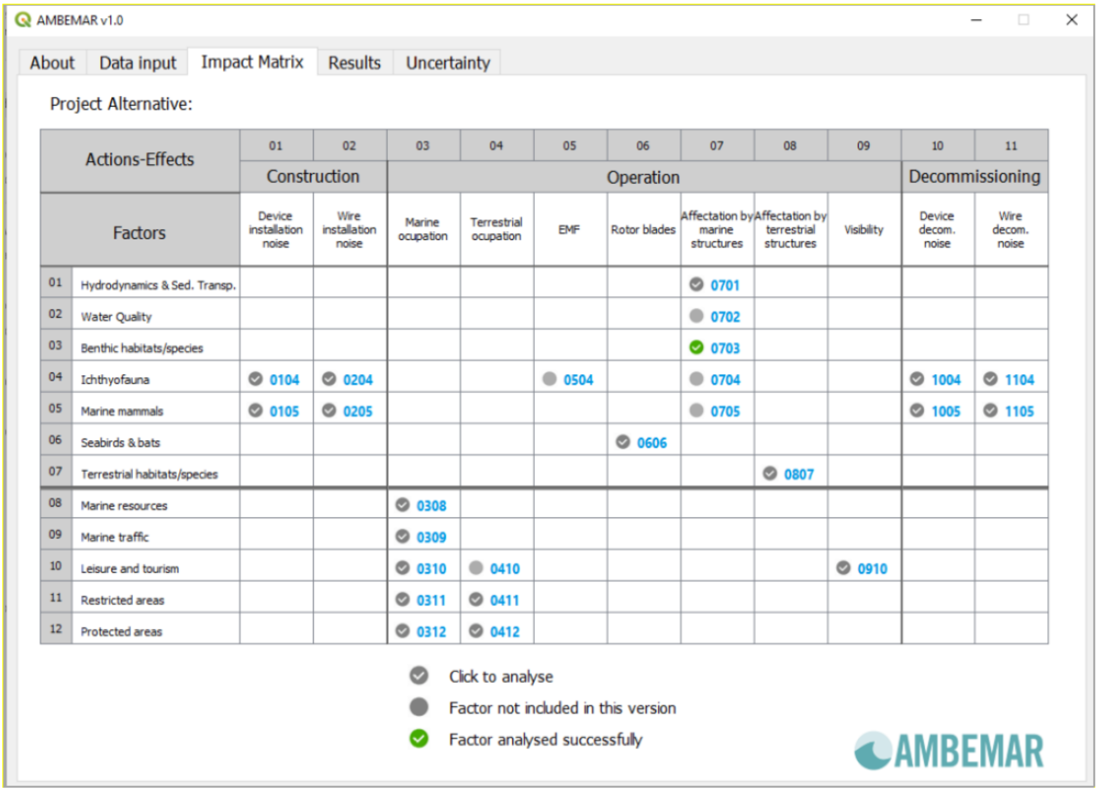

Fig. 1. – Interface and matrix of impacts of AMBEMAR-DSS v1.0.

An impact matrix was established from all impacts previously shown. This matrix evaluates them between 1 (maximum positive impact) and -1 (maximum negative impact). Four possible scenarios are specified:

- Worst Case Impact: defined by the maximum negative impact.
- 3 Worst Environmental Impacts Average: the mean of the 3 worst environmental impacts.
- 3 Worst Socio-Economic Impacts Average: the mean of the 3 worst socio-economic impacts.
- Global Average: the mean of all impacts in the matrix.

3.- METHODOLOGY: VISUAL IMPACT MODULE

This section explains the methodology to integrate the Spanish Method (SPM – SPM2) inside the DSS. To get this integration, the process shown in the fig. 2 is divided in the next steps: Elaboration of the visual inventory (i.e. the cartographic data in which the visual impact indicator will be calculated, as described in section 3.1); visibility calculation from the viewshed; and estimation of indicators for every visual inventory layer and its combination in a unique index.

3.1.- Visual inventory

It is composed of all those cartography layers with relevant information from a landscape or land use point of view, e.g. touristic places, nuclei of population, etc. Everyone is composed by one or more entities distributed in the study area. This inventory defines the territorial characteristics of the areas where population is living and, therefore, is susceptible to have a visual impact.

The visual inventory has been categorised following three criteria (see table 1):

- Urban criteria: any area with anthropic incidence or those areas frequented by local population or tourists.
- Landscape criteria: any natural area with some landscape value.
- Routes criteria: any route, road or railway used by the population as a means of transport.

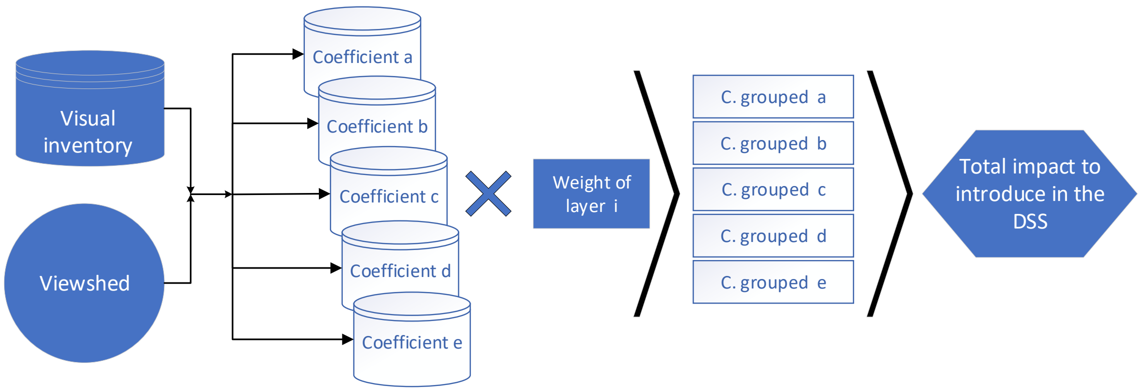

Fig. 2. Flow diagram of the methodology developed. Once the visual inventory and viewshed are obtained, coefficients are calculated. Finally, all coefficients are grouped in a unique index using weights for layers and coefficients. It is introduced in the DSS.

Urban Criterion	Landscape Criterion	Routes Criterion
• Nuclei of population • Population • Beaches • Cultural heritage (CH) • Viewpoints • Historical towns	• Landscape Importance Areas (LIA) • Sites of Community Importance (SIC) • Important Bird and Biodiversity Areas (IBAs) • Natural Parks (NP) • Special Protected Areas for Birds (SPAB) • Sites of Geological Interest (SGI) • RAMSAR sites	• Roads • Greats Littoral Routes (GLR) • Small Littoral Routes (SLR) • Railway • Way of St. James

Table 1. Layer distribution of the visual inventory for this study case following the criteria.

3.2.- Visibility

The visual impact is based on the viewshed [28]. The sum of all viewsheds for every turbine is calculated resulting in a visibility map for the wind farm. MOYSES® software [29] has been used to calculate them. It requires as data inputs the digital elevation model, coordinates and heights of the turbines and distance of visibility influence.

3.3.- SPM-SPM2 impact coefficients

The previously calculated visibility is spatially intersected with the visual inventory. The SPM-SPM2, which evaluates the visual impact, is composed by 5 coefficients that range from 0 (null impact) to -1 (maximum negative impact). They define the following properties of a specific visual intrusion:

- Coefficient a: average of turbines seen from a visual inventory layer.
- Coefficient b: visibility of a visual inventory layer from the wind farm.
- Coefficient c: combined effect of number of turbines and visual amplitude.
- Coefficient d: visual effect dependent on the distance.
- Coefficient e: visual effect dependent on the affected population.

Coefficients are calculated for every entity of a visual inventory layer. The considered entities could be partially or totally inside the area of influence. Then, the coefficient average of all entities is calculated. In this way, only one value is obtained for each coefficient.

The terminology is detailed in order to clarify it: coefficients are the partial results of SPM2 (a, b, c, d and e) applied to one visual inventory layer; indicator is the combination of a specific coefficient for all visual inventory; and index is the combination of all indicators. Next section details them deeper.

3.4.- Combination of indicators

The application of the methodology to visual inventory results in five coefficients for each layer, i.e. coefficients a, b, c, d, and e are calculated for every layer of visual inventory C_i. A weight P_i between 0 and 1 is assigned to every layer. This allows summarising each coefficient in its respective indicator summing each coefficient of C_i multiplied by its P_i. It results in five indicators I_{sum} for every C_i as is shown in (eq. 1). The sum of weights ΣP_i must be 1.

$$I^N{}_{sum} = \sum_{i=1}^{i=N^{o}\ total\ layers} P_i * C_i \qquad N \in (a, b, c, d, e) \qquad \text{(eq. 1)}$$

These five indicators are combined in a unique index (I_{total}) for one selected hypothesis. To carry out this combination the indicators $I^N{}_{sum}$ (only those obtained from coefficients a, b, c, and e) are multiplied by its weight $P^N{}_i$ between 0 and 1. The sum of weights $\Sigma P^N{}_i$ must be 1. Then, these are added and multiplied by the indicator obtained from the coefficient d resulting in I_{total} (eq. 2).

In the expression proposed in eq. 2, the coefficient d multiplies the result of other coefficients. It assigns to this coefficient a relevant importance as is usually shown in scientific literature [13][22][23].

$$I_{total} = \left(\sum_{i=a}^{i=K} P^K{}_i * I^K{}_{sum} \right) * I^d{}_{sum} \qquad K \in (a, b, c, e) \qquad \text{(eq. 2)}$$

Weights P_i can be assigned in diverse ways, e.g. surveying stakeholders for a social analysis. These weights could also be assigned by field experts and/or planning designers.

4.- Study case

The study area is located on the Northern coast of Spain. It is near Santander, capital of Cantabria, and in front of an area with high landscape value known as Costa Quebrada.

Figure 3 shows the two possible wind farm placements and the two possible electric substation locations. One of the wind farms is located at 3 km from the shoreline and it would be built with ground base foundation (GBF), whereas the second one is located at 8 km from the shoreline and it would be built with floating foundation (FF). Regarding electric substations, one is located in La Maruca quarter (LM), whereas the other one is on the cape Punta de San Juan de la Canal (SJ).

GBF wind farm consists of 5 turbines with a height of 150 m from base to blade tip. The distance among them is 750 m. FF wind farm consists of 5 turbines with a height of 200 m from base to blade tip. The separation among turbines is 1 km. Figure 4 shows the area of influence for both wind farms, which have a radius of 35 km following the recommendations of the Sustainable Plan for Energy in Cantabria [30]. The digital elevation model has a resolution of 25 meters.

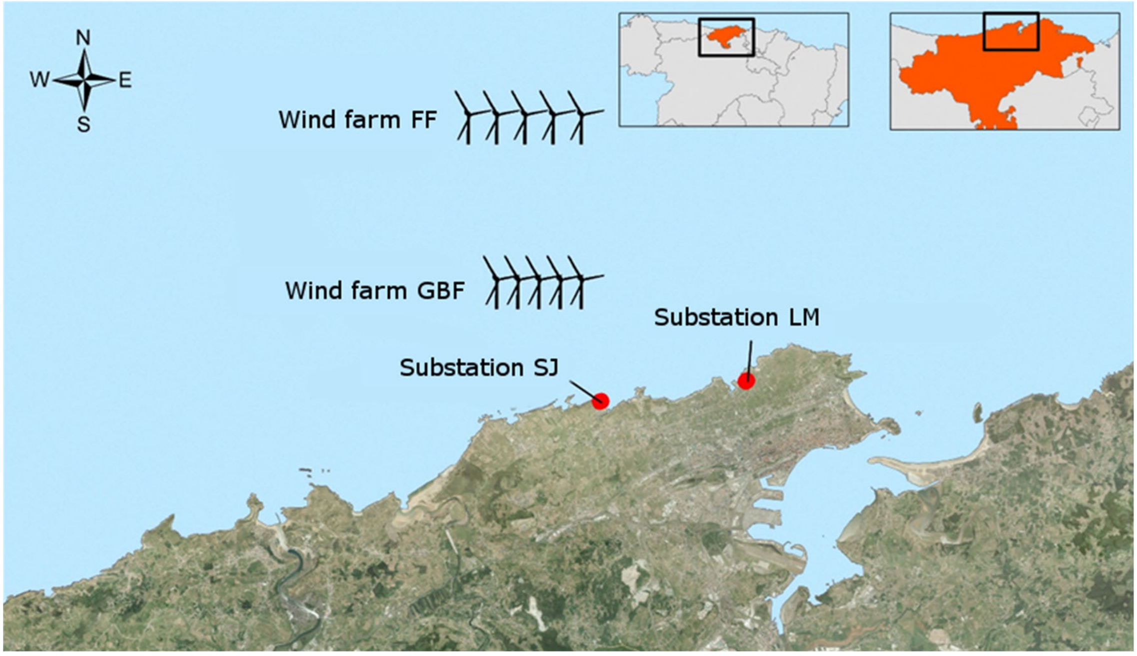

Fig. 3. Study hypothesis locations chosen during AMBEMAR-DSS development.

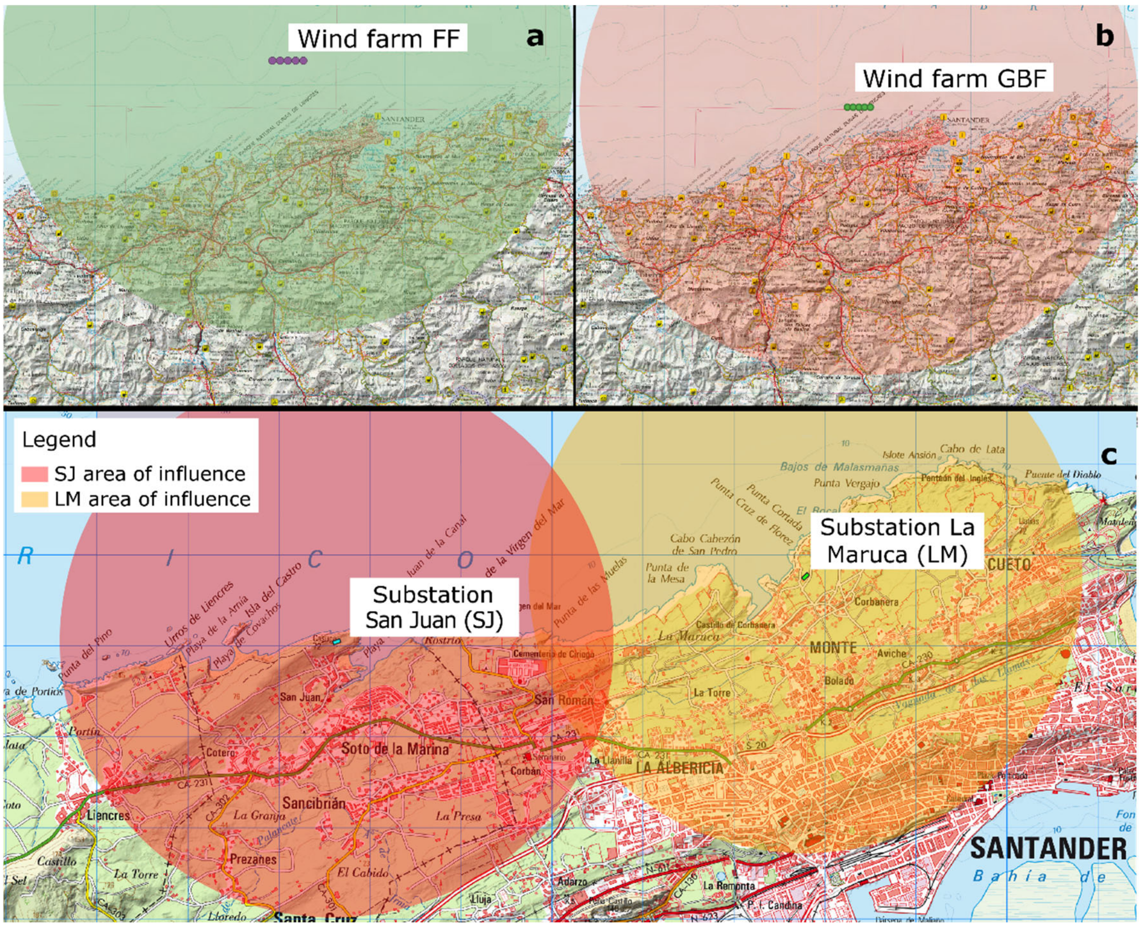

Fig. 4. (a) FF turbines location; (b) GBF turbines location; (c) both electric substations location. Each one has its own area of influence represented.

Both substations, whose dimensions are 40 x 80 m, are discretised in 14 points. The maximum height of the substation, 20 m, has been assigned to all points. In both cases, the radius of influence is 3 km (figure 4) following a currently active Spanish regional landscape normative [31]. The digital elevation model has a resolution of 5 meters because the area of influence is lower and the computational time allows to carry out the calculations in a reasonable time.

5.- Results

5.1.- Electric substations

Both substations have affection over diverse visual inventory layers (see table 2). When a layer has impact 0 in its five coefficients for one hypothesis, it indicates that layer does not have visibility for that case. The number of layers affected is lower than those detailed in table 1 because all of them are not in its area of influence.

As some layers are more relevant than others, their weight in the multicriteria system is different. In this study case, the visual affection in the population has been considered as the most important one. Following this consideration, the weight is 0.5 for urban criterion, 0.3 for landscape criteria and 0.2 for routes. The sum of all of them is 1. Weights assigned to each criterion and layers of visual inventory are only indicative. All of them would need social engagement to choose which the most important criteria are because visual impact is inherent to population. For this reason, the entities with population use have more preponderance in this paper.

The index I_{sum} (table 2) shows the sum, for each coefficient, of the impact value of all layers multiplied by its corresponding weight (as indicated in section 3.4). I_{sum} for coefficient b is the only one that indicates lower impact in LM location than in SJ (table 2 and figure 5), i.e. LM has lower average visibility in the visual inventory. Part of this is because of the minor number of layers affected. In addition, LM has higher visual impact in those layers from which it is visible. Coefficients show impacts more shared between all layers in SJ location than in LM. Regarding visible surface, LM is visible from 5.95 km^2 while SJ is from 9.33 km^2.

				San Juan (SJ)					La Maruca (LM)				
				a	b	c	d	e	a	b	c	d	e
Crit.	W	Layer	W	0.25	0.25	0.25	-	0.25	0.25	0.25	0.25	-	0.25
Urban	0.5	Nuclei	0.15	-0.549	-0.563	-0.046	-0.349	-1	-0.473	-0.055	-0.055	-0.466	-1
		Population	0.15	-0.52	-0.536	-0.053	-1	-0.892	-0.192	-0.202	-0.037	-1	-0.971
		Beaches	0.1	-0.199	-0.235	-0.072	-0.633	0	-0.713	-0.771	-0.170	-0.992	0
		CH sites	0.1	0	0	0	0	0	-0.286	-0.333	-0.013	-0.363	0
Landscape	0.3	LIA	0.2	-0.002	-0.019	-0.01	-0.457	0	0	0	0	0	0
		SIC	0.05	-0.032	-0.035	-0.16	-0.1	0	0	0	0	0	0
		IBAs	0.05	-0.014	-0.057	-0.06	-0.159	0	0	0	0	0	0
Routes	0.2	Roads	0.1	-0.303	-0.308	-0.035	-0.131	0	0	0	0	0	0
		GLR	0.05	-0.326	-0.380	-0.165	-0.590	0	-0.701	-0.706	-0.108	-0.788	0
		SLR	0.05	0	0	0	0	0	-0.657	-0.695	-0.104	-0.702	0
			I_{sum}	-0.229	-0.246	-0.047	-0.412	-0.283	-0.267	-0.219	-0.043	-0.430	-0.295

Tabla 1. Impacts for each layer and for both electric substations. Weights (W) are also specified. The last row shows the result of applying (eq. 1).

In this case, the weights assigned to each coefficient a, b, c and e are 0.25, based on the original SPM. It considers the same importance to all coefficients. The sum of them, multiplied by its corresponding weight, is multiplied by coefficient d (see expression 2 in section 3.4). It results that SJ substation has a total visual impact $I_{total} = -0.083$, whereas in LM is -0.089. LM has more affection in SLR, GLR, beaches and CH sites than SJ. Instead, LM has lower impact in nuclei of population and population layers, and null in roads.

In conclusion, if only the visual effect and I_{total} are considered, the best substation location would be SJ. LM affects to lower number of layers, but it is higher in layers with touristic sense such as beaches and routes.

5.2.- Wind farms

Both wind farms affect same visual inventory layers (table 3). Weights are distributed following the same criteria used in the last section, i.e. layers with population data have more weight. For this reason, urban criteria is the most relevant.

The same happens with coefficients: weights assigned to them are the same as in the substation case. The value of each one is 0.25 and the sum of them, multiplied by its corresponding weight, is multiplied by coefficient d (see expression (eq. 2) in section 3.4). This results in the total impact $I_{total} = -0.043$ for GBF wind farm case and $I_{total} = -0.034$ for FF.

				Ground base (GBF)					Floating (FF)				
				a	b	c	d	e	a	b	c	d	e
Crit.	W	Layers	W	0.25	0.25	0.25	-	0.25	0.25	0.25	0.25	-	0.25
Urban	0.5	Nuclei	0.1	-0.069	-0.094	-0.022	-0.218	-0.814	-0.092	-0.119	-0.03	-0.154	-0.838
		Population	0.1	-0.136	-0.173	-0.094	-0.189	-0.747	-0.136	-0.172	-0.094	-0.189	-0.747
		Beaches	0.08	-0.186	-0.236	-0.059	-0.551	0	-0.204	-0.254	-0.049	-0.393	0
		CH sites	0.07	-0.08	-0.097	-0.005	-0.239	0	-0.134	-0.172	-0.009	-0.176	0
		Viewpoints	0.1	-0.167	-0.167	-0.013	-0.195	0	-0.04	-0.2	-0.001	-0.134	0
		H. Towns	0.05	-0.047	-0.078	-0.014	-0.121	-0.975	-0.167	-0.218	-0.026	-0.1	-0.971
Landscape	0.3	LIA	0.1	-0.293	-0.324	-0.186	-0.482	0	-0.309	-0.339	-0.143	-0.345	0
		SIC	0.03	-0.071	-0.081	-0.047	-0.214	0	-0.104	-0.12	-0.054	-0.192	0
		IBAs	0.03	-0.158	-0.172	-0.123	-0.343	0	-0.182	-0.204	-0.096	-0.305	0
		PN	0.06	-0.14	-0.165	-0.095	-0.325	0	-0.184	-0.204	-0.12	-0.327	0
		SPAB	0.02	-0.003	-0.004	-0.01	-0.1	0	-0.006	-0.009	-0.03	-0.1	0
		SGI	0.03	-0.291	-0.364	-0.045	-0.385	0	-0.467	-0.556	-0.057	-0.353	0
		RAMSAR	0.03	-0.002	-0.003	-0.005	-0.1	0	-0.003	-0.005	-0.015	-0.1	0
Routes	0.2	Roads	0.04	-0.068	-0.087	-0.028	-0.245	0	-0.087	-0.114	-0.037	-0.162	0
		GLR	0.04	-0.214	-0.265	-0.048	-0.459	0	-0.26	-0.303	-0.058	-0.273	0
		PLR	0.04	-0.308	-0.349	-0.07	-0.487	0	-0.308	-0.362	-0.065	-0.25	0
		Railway	0.04	-0.013	-0.018	-0.087	-0.265	0	-0.012	-0.037	-0.037	-0.137	0
		W. St. James	0.04	-0.106	-0.142	-0.054	-0.259	0	-0.118	-0.147	-0.064	-0.162	0
			I_{sum}	-0.142	-0.168	-0.061	-0.297	-0.205	-0.157	-0.204	-0.057	-0.220	-0.207

Tabla 2. Impacts for each layer and both wind farms. Weights (W) are also specified. The last row shows the result of applying (eq. 1).

I_{sum} for coefficients a and b is larger (in absolute numbers) in FF installation than in GBF (table 3 and figure 5). This shows that the average visibility from visual inventory is higher when the wind farm is far from the shoreline. This is mainly because of the topography of this area. FF is visible from valleys that do not have visibility to GBF. This effect is important in historic towns and SGI, but the opposite effect happens in viewpoints layers. The latter has the coefficient a highly lower in FF than in GBF. Regarding I_{sum} for coefficients c and d, they logically decrease when distance increases. Besides, visible surface is higher in GBF wind farm than in FF. GBF is visible from 254.48 km^2 whereas FF is visible from 242.2 km^2.

In conclusion, in this study case FF has lower visual impact because its I_{total} is lower than in GBF case. If only both wind farms are compared, the impact reduction is 21%. However, the variation between both hypotheses is 0.009 in absolute numbers, i.e. 0.9%.

6.- CONCLUSIONS

This paper proposes a method to introduce an index that measures diverse visual impact characteristics in an environmental DSS for offshore renewable energy. AMBEMAR-DSS can combine the so-obtained indices along with the results obtained from other kinds of impacts to get a transversal solution.

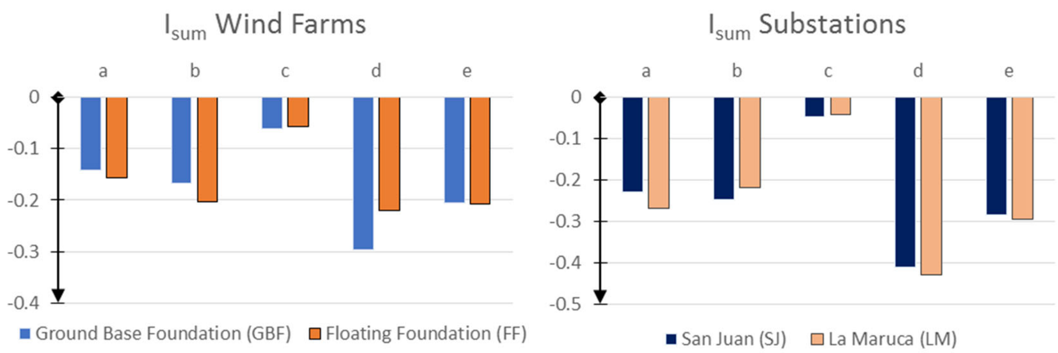

Fig. 5. Left graph shows I_{sum} for both wind farms. Right graph shows I_{sum} for both electric substations.

This method allows comparing various wind farms from a visual impact point of view taking into consideration the territorial characteristics of the study area. One of its main limitations, but at the same time also a strength, is the possibility of introducing different social sensibilities when weights are assigned. It could generate different results when the same wind farm is studied depending on social factors. Furthermore, it allows adapting the system to the society interests where the project is being carried out.

In conclusion, the aggregation method developed in this paper can also be used to evaluate visual impact affections during the design stage.

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