Managing the oceans: Site selection of a floating offshore wind farm based on GIS spatial analysis

Laura Castro-Santos[a,*], María Isabel Lamas-Galdo[b], Almudena Filgueira-Vizoso[c]

a Universidade da Coruña, Departamento de Enxeñnaría Naval e Industrial, Escola Politéecnica Superior, Esteiro, 15471, Ferrol, Spain

b Universidade da Coruñaa, Departamento de Ciencias da Navegación e Enxeñnaría Mariñna, Escola Politéecnica Superior, Esteiro, 15471, Ferrol, Spain

c Universidade da Coruña, Departamento de Química, Escola Politécnica Superior, Esteiro, 15471, Ferrol, Spain

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ABSTRACT

The aim of this study is to develop a methodology for using Geographic Information Systems (GIS) spatial analysis in the development of a floating offshore wind farm. When you plan a floating offshore wind farm it is very important to determine the areas where wind resource is high, which will produce good economic results in terms of the feasibility of the farm. However, the present paper analyses how some restrictions (environmental areas, navigation restricted areas, depth, ports, shipyards, etc.) affect to the floating offshore wind farm. The tool developed allows increasing the quantity of these restrictions as the user needs. The procedure has been considered for the Galician area (North-West of Spain), a region that has experience in onshore wind. Therefore, the GIS tool analyses the site selection for a floating offshore wind farm.

1. INTRODUCTION

Geographic Information Systems (GIS) have been used for a wide variety of applications: economic feasibility of floating offshore wind farms [1,2] and wave farms [3,4], wind potential of offshore wind farms [5–7], potential of small-scale renewable energy systems of rural livelihoods needs [8], evaluating rainwater harvesting potential [9], identifying the potential sites for the location of biogas plants considering environmental, socio-economic [10] and geographical aspects [11], etc.

Moreover, when all the onshore sites for wind farms are occupied two options can be developed: repowering the onshore wind farms [12] or developed new wind farms in offshore locations [13]. In this context, the renewable energy sector has been changed its current onshore location to offshore areas. In fact, wind energy is the most important renewable energy in Europe with 12.5 GW of gross additional wind capacity installed in 2016 [14], being its global installed capacity is 153.7 GW [14]. However, the country with more capacity installed of wind energy is China [15]. In this context, the marine policies [16], maritime spatial planning [17] and the global governance of the sea [18] are very important in order to select the best place to install a marine energy farm.

Regarding offshore wind energy, the world's capacity has increased from 2134 MW in 2009 to 23,356 MW in 2018 [19]. The European Union is the world leader in offshore wind with 18,519 MW of capacity in 2018, followed by Asia (4806 MW), China (4588 MW), Viet Nam (99 MW) and Japan (65 MW) [19].

When a floating offshore wind farm is planned, it is important to know the type of floating offshore wind platform: Tensioned Leg Platform (TLP) [20], spar [21] or semisubmersible; and the layout of the farm [22–24] and their influence on costs [25]. Serrano Gonzalez et al. [26] analyse the importance of sharing the electrical cables among several offshore wind projects. However, it also is important to recognize where it can be installed because there are areas where the offshore wind resource is very good, but where the farm cannot be installed for several reasons: legal aspects, navigation areas, environmental protected regions, visual impact [27], etc. Therefore, the establishment of a tool that can manage these issues has a great importance. There are some studies related to the offshore wind zoning [28] and the flow of coastal ecosystems [29] in China. On the other hand, other authors explain the importance of the stakeholders of the offshore wind farms [30] and the influence that they generate in society regarding the installation of offshore wind farms [31].

The aim of this paper is to develop a method for planning a floating offshore wind farm using Geographic Information Systems (GIS). It uses several restrictions such as the environmental protected areas, navigation corridors, bathymetry, seismic fault lines, ports, shipyards or seabed conditions. The Galician area (North-West of Spain) has been selected to analyse the methodology. The results obtained are the economic maps of the location selected with all the restrictions introduced.

2. METHOD

2.1. General Methodology

One of most important issues regarding floating offshore wind farms is their economic feasibility, which depends on aspects such as the location and its offshore wind resource, the electric tariff for these types of technologies, the distance from farm to shore, depth, among others. All these aspects will determine if a floating offshore wind farm is or not economically feasible in terms of its levelized cost of energy, internal rate of return or net present value.

However, a floating offshore wind farm can be very feasible in economic terms because the location where the farm is installed has a great offshore wind resource, but maybe the farm can be installed in this area for several reasons. Therefore, the aim of this work is to develop a method for planning the location of a floating offshore wind farm using Geographic Information Systems (GIS). Several restrictions will be involved for this purpose: environmental protected regions, bathymetry, navigation corridors, seismic fault lines, shipyards, ports or seabed characteristics.

The method proposed is composed of two tools (see Fig. 1):

- **TGR (Tool for general restrictions)**: it calculates the non-restricted area and it introduces the economic maps for a particular case of a number of offshore wind turbines previously defined and constant for all the areas.

- TRPS (Tool for restrictions of ports and shipyards): it introduces the restrictions of ports and shipyards considering as input variables the output of the TGR and given as result the economic maps with all the restrictions (general, ports and shipyards).

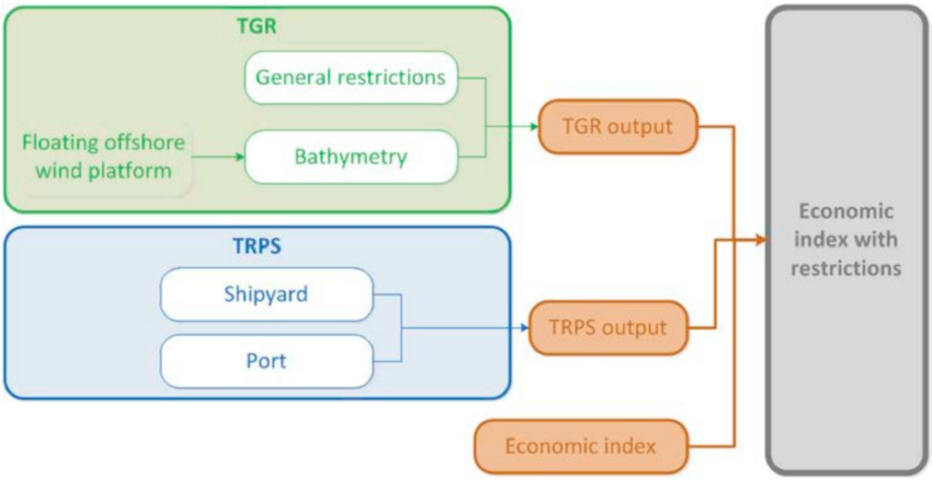

Fig. 1. Method proposed.

2.2. TGR

The Tool for general restrictions (TGR) creates a map that considers the restrictions previously selected given an initial view of the areas where a floating offshore wind farm can be installed. It has not taken into account the economic indexes, which will be introduced later.

Firstly, the map with all the selected restrictions is calculated. The user selects the number of restrictions introduced. In this case, the restrictions introduced are: fishes, navigation areas, seismic fault lines, environmental protected areas, restrictions of the Spanish strategic study for offshore wind farms and rocks.

Secondly, the map with the restriction of the bathymetry is introduced. This restriction is dependent on the type of floating offshore wind substructure considered. For instance, there are floating platforms such as the spar whose draft is higher than the semisubmersible platforms. Therefore, this aspect is taken into consideration in the method proposed.

The display of the software allows the user to select the restrictions that he wanted and reclass the bathymetry considering the kind of floating platform.

2.3. TRPS

The Tool for restrictions of ports and shipyards (TRPS) introduces the restrictions of ports and shipyards considering the results obtained of the TGR. Although in this study only local ports and shipyards have been considered, the tool allows to introduce the port or shipyard that the user wants if he has their main characteristics.

Firstly, several parameters such as the tons supported by the crane, the draft of the port and the draft of the shipyard are reclassified. Then, a buffer or an area of influence centred in the port or the shipyard and with a specific radio will be developed. It will determine the final location where a floating offshore wind farm can be installed.

The user can select the characteristic of the port or shipyard and reclass its value using the display of the TRPS. In addition, the maximum distance from the port or shipyard to the floating offshore wind farm can also be introduced.

Finally, all the calculated restrictions (the general ones and the bathymetry) are joined and the economic index selected (internal rate of return, levelized cost of energy, net present value, discounted pay-back period or other) is introduced. The results of this operation are the economic maps restricted for the economic index selected.

3. CASE OF STUDY

The floating offshore wind farm considered is composed of 21 offshore wind turbines of 5.075 MW of 126 m of rotor diameter and 90 m of height tower. Therefore, the total power of the farm is 107 MW. The platform selected is a floating offshore semisubmersible platform with three columns, 76 m of length and 12 m of draft, being the wind turbine located in the centre of the platform. However, the user can change the size of the farm as he wants. On the other side, the grid size of results always will depend on the grid size of the inputs. Therefore, it can be changed by user depending on the restriction inputs.

The proposed method has been applied to the region of Galicia, located in the North-West of Spain (see Fig. 2).

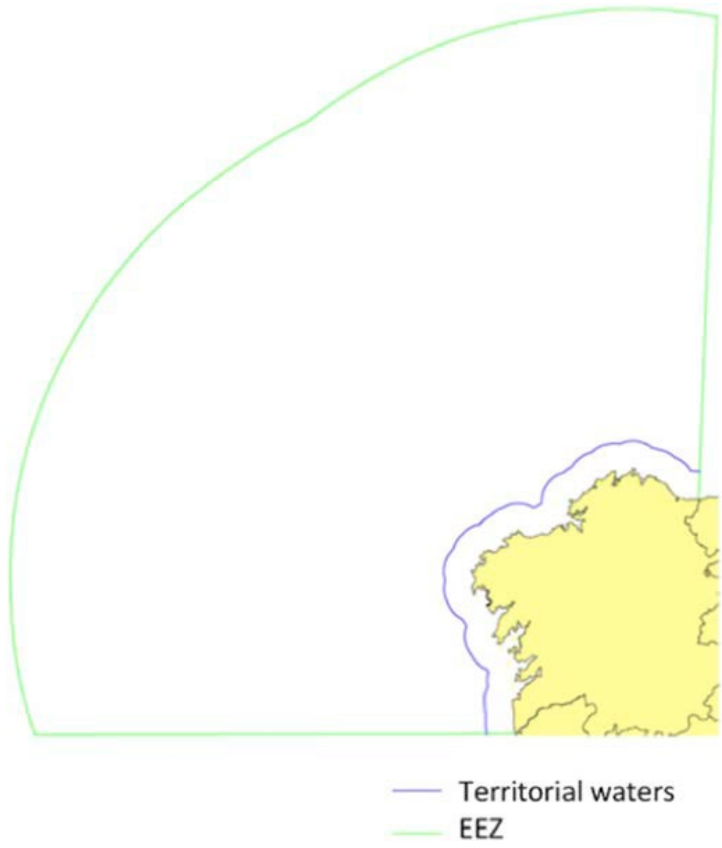

Fig. 2. Territorial waters and Exclusive Economic Zone (EEZ) in the Galician region.

In this context, several restrictions have been considered. Firstly, the "environmental strategic study of the Spanish shore for installing offshore wind farms" [32] is a Spanish normative that defines three different areas, as shown Fig. 3:

- Suitable areas (green).

- Suitable areas, but with environmental conditioners (yellow).

- Unsuitable areas (red).

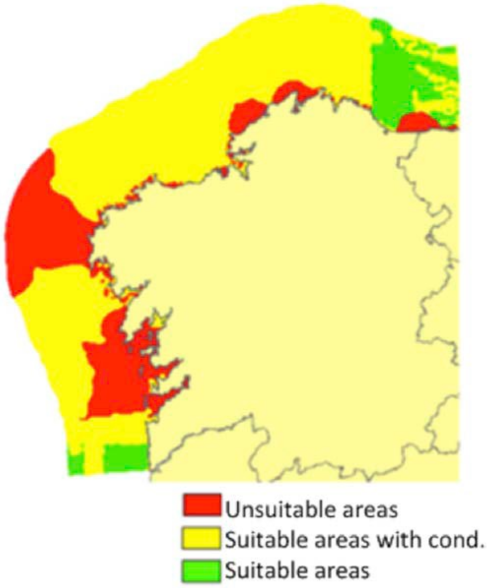

Fig. 3. Types of areas [32].

Considering the previous study, the restriction selected is based on the unsuitable areas (red), as shown Fig. 4.

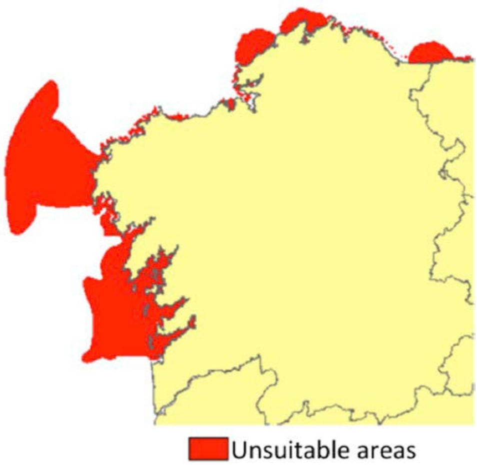

Fig. 4. Unsuitable areas.

However, the previous strategic study establishes for the yellow areas that it is very important to study each particular project. This is the reason why other types of restrictions have been considered. Therefore, there are two main types of restrictions: those independent of the type of platform and those dependent on the type of substructure.

The general restrictions, which are independent of the kind of offshore platform, have been georeferenced using a GIS (Geographic Information System) software. They are shown in Fig. 5:

- Navigation areas [33].

- Seismic fault lines [34].

- Fishing grounds [35].

- Fishing banks [35].

- Environmental protected areas [36].

- Rocky areas [37]. Seabed conditions can be considered as part of the floating wind project. However, in this case it has been considered that if the area is a rocky region then the farm cannot be installed, because its costs will be high.

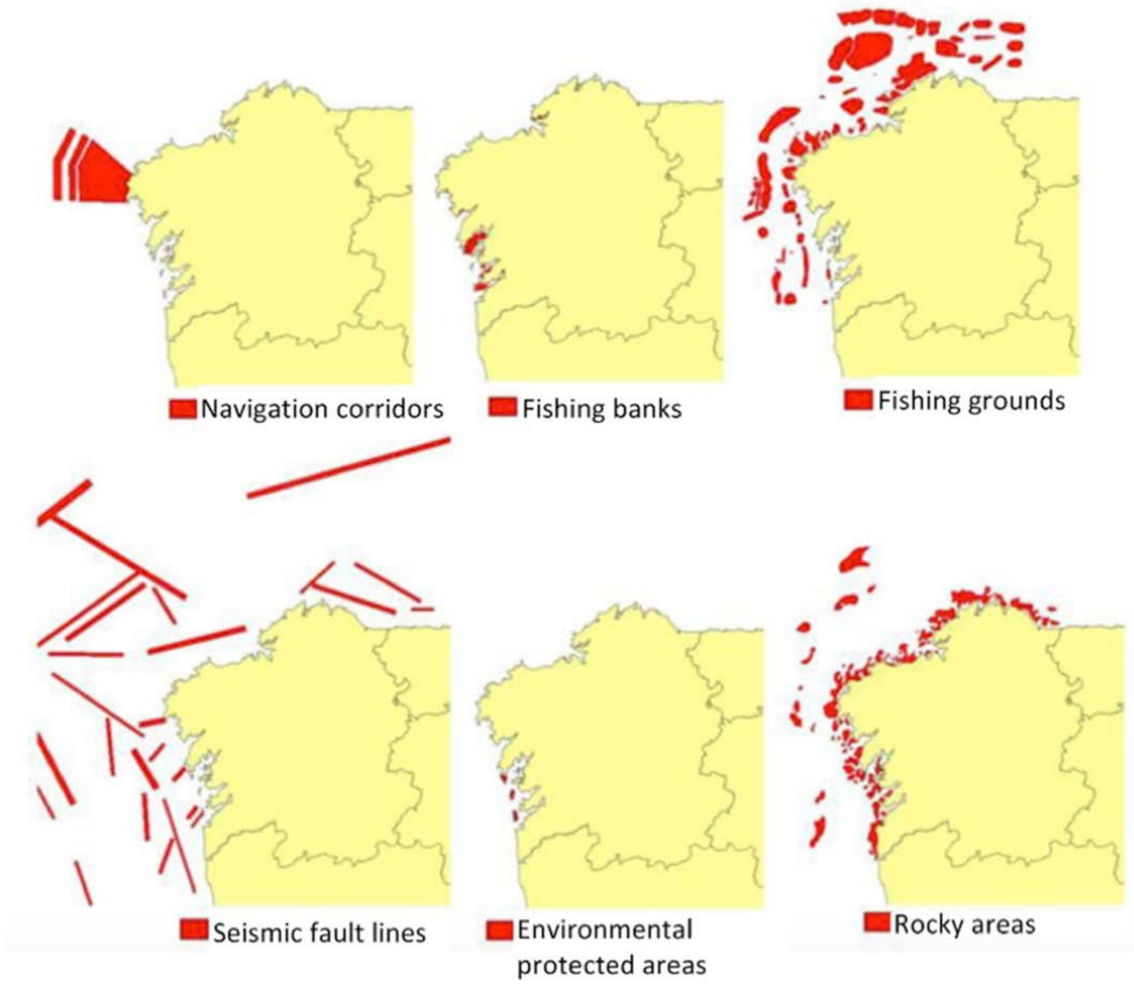

Fig. 5. General restrictions.

On the other hand, there are restrictions whose value differs depending on the type of offshore wind substructure in terms of the bathymetry [38]. The case of study considers only one type of floating platform: the semisubmersible structure. Therefore, it has been established a minimum value of 62 m of bathymetry and a maximum value of 1000 m of depth.

Moreover, the draft has been taken into consideration as a restriction for ports and shipyards because they should support the draft of the installation vessel, which can be between 3 and 8.9 m [39–41], depending on the type of vessel selected for the manoeuvres.

Nevertheless, this value can be higher, up to 12.5 m [42] for the case of using a tug to move the structure from port or shipyard to the farm.

On the other hand, the storage area will be calculated considering the number of offshore wind turbines and their main characteristics (length, height of the tower, etc.).

The restrictions of shipyards and ports considers a buffer of 100,000 m and they have the values shown in Table 1.

Table 1. Restrictions for shipyards and ports.

Restriction	Concept	Value
Port	Draft	12.5 m
	Storage area	13,500 m^2
Shipyard	Draft	12.5 m

4. RESULTS

The map of the restriction of the bathymetry considering a semisubmersible platform is shown in Fig. 6. It shows the areas (white regions) where the floating offshore wind farm can be installed in term of a minimum bathymetry of 62 m and a maximum bathymetry of 1000 m of depth.

Fig. 6. Restriction of bathymetry.

Otherwise, results for restrictions of shipyards and ports considering the inputs of minimum and maximum draft, storage area and distance from port/shipyard to the farm are shown in Fig. 7.

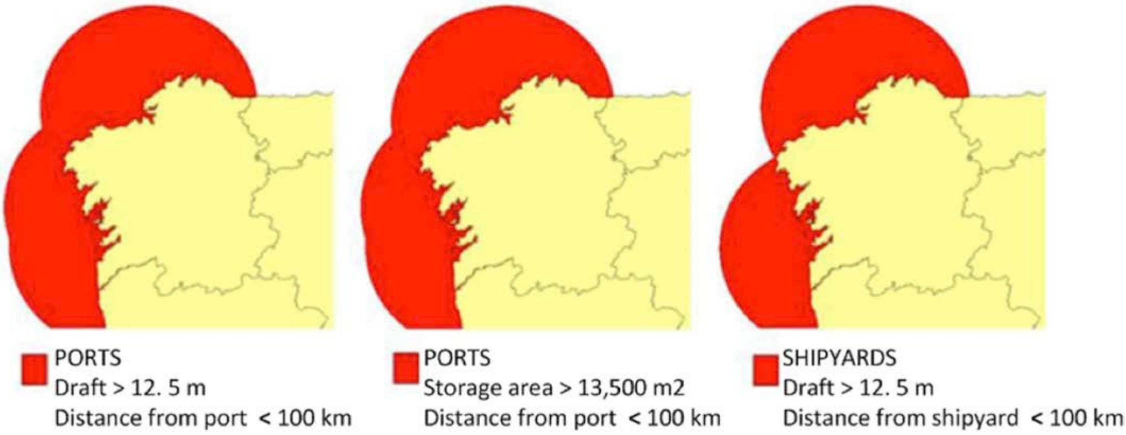

Fig. 7. Restrictions of shipyards and ports.

The map that results of the tool for general restrictions (TGR) and that considers all the restrictions is shown in Fig. 8. The red areas are the unsuitable areas considering all the restrictions (environmental, seismic fault lines, etc.).

Fig. 8. Map with all the restrictions.

However, if the restriction of bathymetry, which depends on the type of floating offshore wind substructure, and restrictions of ports and shipyards are introduced, the area of the suitable areas (blue region) is reduced, as Fig. 9 shows.

Fig. 9. Map with all the restrictions.

The final economic map will be calculated once all the restrictions have been carried out using the tool for restrictions of ports and shipyards (TRPS). Therefore, the economic map shows the specific economic parameter but with all the restrictions previously introduced in the tool, which helps to analyse better the feasibility of a floating offshore wind farm. The map is made by adding all the restrictions with the GIS software. The restricted areas will have a value of 0, which when multiplied by the economic map will result in the economic map with restrictions, where restrictions have zero value. Therefore, the final map will one have economic values for the allowed areas (non-zero values).

Fig. 10 shows an example of the economic parameter of the internal rate of return (IRR) in % (a), the net present value (NPV) in millions of euros (b) and the discounted pay-back period (DPBP) in years (c), for a case of a floating offshore wind farm with a particular electric tariff.

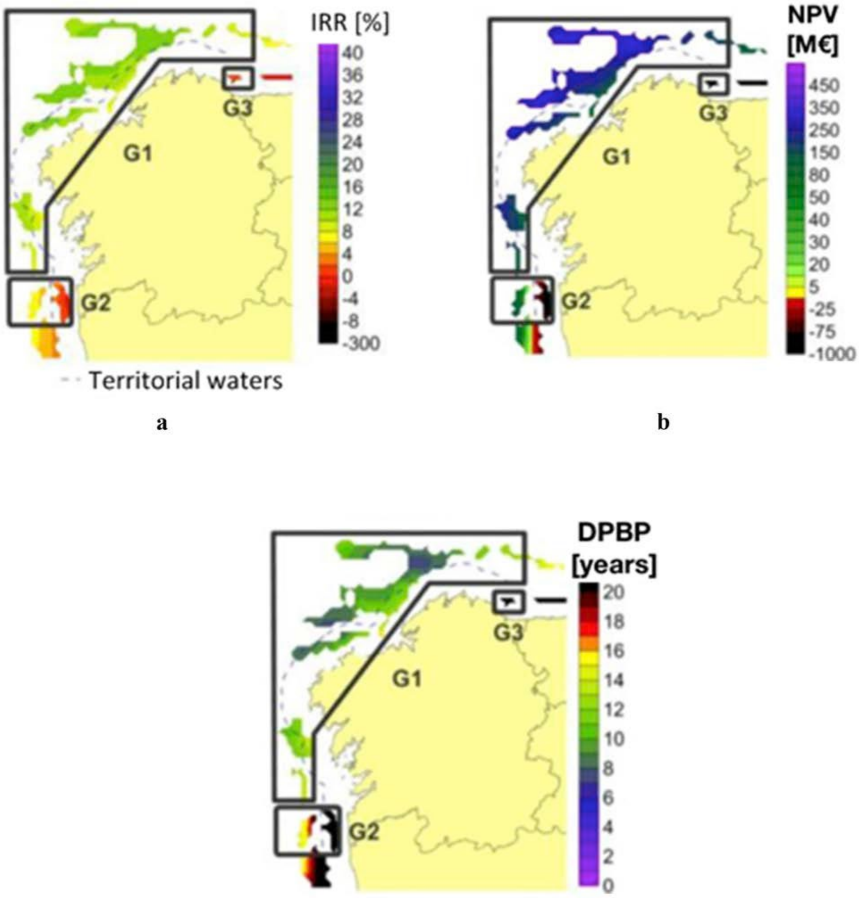

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Fig. 10. Economic map with restrictions for IIR (a), NPV (b) and DPBP (c).

5. CONCLUSIONS

The objective of this work has been to develop a methodology for planning a floating offshore wind farm using Geographic Information Systems (GIS). It analyses the significant restrictions, which are involved in the development of a floating offshore wind farm. In this context, the methodology is based on two tools: the tool for general restrictions (TGR) and the tool for restrictions of ports and shipyards (TRPS). TGR calculates the suitable areas considering general restrictions such as environmental protected areas, navigation corridors, fishing grounds, bathymetry, seismic fault lines, ports, shipyards or seabed conditions. Otherwise, TRPS considers the restrictions of ports and shipyards (draft, distance from port/shipyard to the farm, storage area) and takes into account the output of the previous tool given as result the economic map with all the restrictions (general, ports and shipyards).

The method has been applied to the Galician area, a region of the North-West of Spain, where the offshore wind resource is appropriate to develop this type of emerging technologies.

The results obtained are maps of the particular location previously considered with all the restrictions that the user had introduced as inputs.

This tool is useful to select locations where a floating offshore wind farm can be developed. Therefore, enterprises or Governments can use the tool to recognize the limitations of a particular area. In this sense, there are locations where the quantity of wind is very good, but where there are some restrictions (legal, strategic or environmental aspects) that limit the installation of a floating offshore wind farm.

APPENDIX A. SUPPLEMENTARY DATA

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpol.2019.103803.

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