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Planning the Installation of Marine Renewable Energies in Portugal - a tool for decision making

Teresa Simões, António Couto, Ana Estanqueiro

teresa.simoes@lneg.pt , antonio.couto@lneg.pt , ana.estanqueiro@lneg.pt

Corresponding author: teresa.simoes@lneg.pt

Abstract. In the latest years, the European governments have developed and published the goals for their countries in terms of energy and climate as requested by the European Commission - The National Energy and Climate Plans (NECPs). In this sense, an intense activity on the planning of the installation of renewable energy systems took place in each Member State in order to meet the goals established on the NECPs. Following the recent energy crisis and the urgency to transform Europe's energy system in Europe, the NECPs are also being adapted to this situation and the installation of renewable energy systems assumed an even higher relevance. In this sense, offshore wind, due to its characteristics – high wind resource, less occupation issues and others – will play a key role in the future energy mix. This work proposed the development and application of a holistic planning methodology considering the available offshore renewable resource, restrictions to the installation of marine energy systems and economic indicators, which resulted in a techno-economic platform – MarinePlan, developed in the scope of a National funded project – OffshorePlan

1. Introduction

Offshore energy is one of the key areas of focus for RepowerEU, as it has the potential to provide large amounts of renewable energy while reducing dependence on fossil fuels and reducing greenhouse gas emissions. Offshore energy refers to the generation of electricity from renewable energy sources located in offshore environments, such as wind, wave, and tidal power. After the Energy crisis that is happening all over the world, the offshore wind energy will have a relevant role in the energy mix being the most expressive contribution for the increase of renewable energy production in the coming years. Also it represents the most representative offshore energy in terms of installed capacity when compared with other offshore renewable sources, such as waves and tidal, and it is rapidly expanding in Europe [1]. The EU has set a target of producing at least 60 GW of offshore wind energy by 2030, which is expected to provide around 15% of the EU's electricity demand [2]. As in many countries in the world, renewable energies from marine exploration have great potential in Portugal, on the one hand, due to the country's geographical situation, with its extensive coastline and one of the largest exclusive economic zones (EEZ). On the other hand, previous studies carried out in recent years [3] show that Portugal has good indicators of existence of a high energy resource. Despite these studies, there are still several barriers to overcome for the dissemination of renewable energy technologies with greater applicability in Portugal – offshore wind and waves – which are essentially related to: i) accurate mapping of the energy resource and its experimental validation; ii) shortage of services and means for installing and maintaining these systems; iii) power grid reception capacity; and iv) socioeconomic impact, among other.



The OffshorePlan project - Planning the installation of offshore renewable energies in Portugal - funded by the POSEUR program (Operational Program for Sustainability and Efficiency in the Use of Resources) of Portugal 2020 - emerged following the identification of a set of constraints associated with the implementation and dissemination of technologies of harnessing energy for the production of electricity in a marine environment. This project, ended in 2020, produced a valuable set of results which include, marine renewable potential atlases – wind and wave – for different technological types (for wind, different floating and bottom fixed technologies, and for waves, different types of converters) [4], identification of suitable areas for marine renewables' development and socio-economic constraints identification. The outcomes of this project are the basis for the work presented in this paper. During the development of this project, Portugal started to develop its first offshore wind farm, and at this time, issues related with the costs of marine renewables, whether concerning the equipment, installation logistics, or even the physical constraints impact is some of the problems that the developer had to face, since this sector is in its infancy phase.

Portugal has a great offshore potential to be explored [5], [6] and an efficient planning was needed, not only for a suitable site identification, but also to guarantee that the planning would be efficient in energetic and economic terms. To overcome this problem, a tool was developed in the scope of OffshorePlan project that enabled the developers to map the economic parameters based on wind and wave potential information and for different technologies, considering the physical and environmental restrictions on the Portuguese coast. Despite the existence of some web platforms that allow to compute some economic parameters as the levelized cost of energy (LCOE), to the best knowledge of the authors, no techno-economic platform tool such as the one presented in this work is publicly available. This paper describes the methodology behind this tool and an application example.

In a general way, a spatial planning methodology for offshore projects can be defined by a set of information and georeferenced information that defines the set of operating restrictions managed by a geographic information platform capable of connecting and relating the spatial information normally designated as “layers”. The results are areas / regions suitable for the implementation of offshore wind parks (or waves' energy converters, for example) and information on sustainable offshore wind and waves energy potential available for a region of interest - a country or a specific area.

For this end, a large set of information is needed, and in the case of offshore wind energy systems, it can be divided into two main categories; 1. Wind resource mapping and 2. Conditions/Restrictions to the installation of wind turbines. Most researchers dedicated to the planning of the identification of suitable sites for the installation of offshore renewable energy systems use Geographical Information Systems (GIS) for this purpose. GIS are very powerful tools, since they enable the use of large amounts of georeferenced information, especially relevant to this type of work. Also, the type of needed information can be obtained in different formats and topologies – vector maps, raster, shape files, and tables with varied information. In addition, there is the need to consult and obtain information from very different sources and process it inside the same project. This is usually a very complex task and GIS makes this job much easier and less time-consuming.

It is also common to use multi-criteria techniques for decision-making in the GIS. This enables to define several conditions for each project according to the specificities of the area/region under study. Besides information on environment, renewable resource and other conditions, most of the published research also includes economic parameters for the planning of the offshore renewable energy systems development. In fact, these are of utmost importance, especially for areas where the offshore renewable sector is in its earlier stage, since it enables to hierarchize the most suitable areas for investments and build a robust development plan. L. Castro-Santos *et al.* [7] have in fact performed one of the first planning studies for offshore renewables in Portugal. They have developed the marine spatial planning for the installation of offshore wind and wave systems, estimating the renewable capacity to install these systems and developed an automated GIS tool to analyze the techno-economic feasibility of these projects. This tool was the basis for the development of a Technical-economic planning platform for marine energy harnessing systems - MarinePlan, that is presented in this paper. A. Vinhoza and R. Schaeffer [8] made the assessment and determination of the energy potential of offshore systems by

mapping the resources and establishing a set of conditions. These authors used multi-criteria spatial analysis and hierarchically ranked the results, ordering the identified locations according to their viability for the installation of this type of project, using techno-economic criteria, namely the LCOE as one of the main ranking criteria. The major difference from what is presented in this paper is that the methodology proposed by Vinhoza & Schaeffer does not deliver an interactive tool reducing the replicability potential of the method. Nevertheless, the methodology developed by these authors also includes socio-economic aspects, and economic parameters are included as additional information so that the reader can have indicative values on the economic analysis on the suitable areas. M. Mahdy and A. S. Bahaj [9] propose a new methodology for determining suitable locations for the installation and operation of offshore wind parks using hierarchical analysis, spatial evaluation by multicriteria GIS and LCOE, preparing a cost map per MWh of energy generated with these systems. L. Castro-Santos *et al.* [10] developed a methodology to estimate the economic viability of floating offshore wind parks by calculating the most relevant economic parameters – LCOE, net present value (NPV) and internal rate of return (IRR). The methodology developed by these authors was of particular importance since it considered three main phases – geographic, phase where the wind resource, energy production and bathymetry maps were developed; economic phase, where the economic parameters were mapped and restrictions application phase, where the areas along the coast where it was impossible to install renewable energy systems (e.g. environmental protected) were removed from the overall maps. Also, the authors tested three types of wind offshore technologies: semi-submersible platforms, tensioned leg platforms or spar platforms.

1.1 Considerations regarding conflicts and impacts of the marine renewable energies

It is assumed that any activity that foresees the installation of infrastructures in the sea can affect the biodiversity and fishery activity, since it will occupy a certain space that will no longer be available for navigation or to the use of certain types of fisheries. The European Parliament has manifested concern specifically with the impacts of the offshore wind parks, and on the 7th of July 2021, approved a resolution about the impact on fisheries from offshore wind parks and other renewable energy systems (2019/2158(INI)) [11].

Fishing, recreation and leisure, maritime transport, safeguarding the Cultural Heritage, are examples of uses that cannot be drastically affected and, for this reason, the planning exercise is critical. The spatialization of activities has to be done by taking advantage of the three-dimensionality of the ocean, considering the best scientific and technological knowledge, in order to develop a model of occupation of maritime space that is the best compromise between common and private uses. Offshore renewable energies, represent one of the greatest challenges to the compatibility of uses, either because of the enormous size of the space they compromise, or because of the very nature of the infrastructures involved that presuppose the conditioning of the maritime space in its three dimensions (seabed, water column and water plane). Among the common uses, fishing is undoubtedly the most affected activity, forcing fishermen to use the space allocated to offshore energy devices in a different way than they had done until now when possible.

Protected areas are one of the main, if not the main, mechanism that ensures the protection, conservation and recovery of marine ecosystems. In the case of Portugal, the maritime areas adjacent to the Continent are essentially classified as Rede Natura. All preferential areas for offshore wind exploration should be located outside maritime spaces classified with protection status, and the installation of wind parks in these areas assumes that the need for allocation will respect the conservation objectives that led to the integration of those spaces into the Natura 2000 Network.

The resolution of July 7, 2021, on the impacts of offshore wind parks on fisheries proposes that the combination and integration of offshore wind parks in marine protected areas be assessed in light of habitat and biodiversity conservation objectives, namely those relating to fishery resources. With this proposal, the EP intends to minimize impacts on fishing, reinforcing non-extraction conditions in protected marine areas.

Floating offshore wind energy production systems are identified as having the least impact on marine biodiversity, compared to those that resort to fixing turbines through pillars embedded in the seabed, especially with regard to impulsive noise. In fact, fixed wind parks, during the installation phase, produce significant impulsive noise, through hammering, vibrations and drilling in the seabed, with proven negative effects on marine mammals.

In this paper, a GIS approach will be followed using a set of restrictions in order to produce offshore wind potential maps to be used as input for the techno-economic planning tool – MarinePlan, where the economic parameters will be calculated and/or mapped. In this case, social aspects and fisheries were not considered due to the lack of precise information. However, the input maps can be adapted to include these aspects before including them in MarinePlan (see section 2.).

This article is organized as follows: section 2 provides an overview of the methodology. In section 3 the results from the MarinePlan tool are presented to highlight the potential of the tool to support investment decisions. Finally, in section 4 some final remarks and future development of the tool are presented.

2. Methodology

The holistic planning methodology is split into two main steps. The first where the information related to the offshore renewable potential (wind and wave) and the restrictions to the installation of each technology was processed using a GIS tool. In the second, the MarinePlan techno-economic tool was developed (see section 2.2) and applied to Portugal. Figure 1 depicts the main steps of this methodology and a detailed description of each step of this interactive tool is provided in the next subsections.

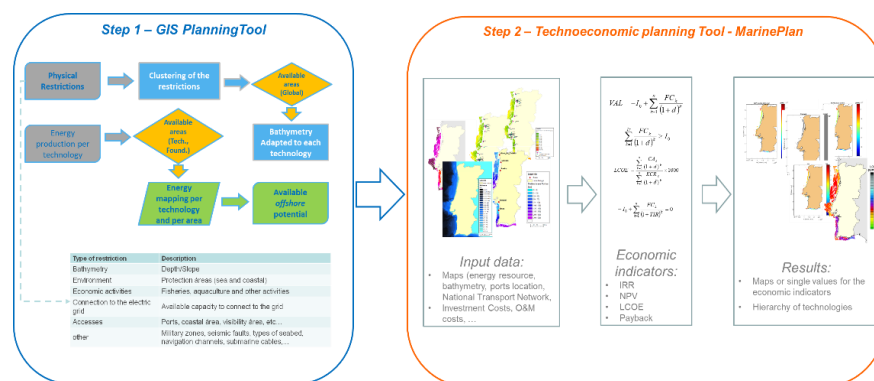


Figure 1. Overall planning methodology

2.1 GIS methodology

The first stage of the methodology intends to identify the most suitable areas for the installation of offshore renewable energy systems, in energetic terms. This stage produces the inputs for MarinePlan tool, by identifying all the restrictions to the installation of these systems and exclude the correspondent areas from the energy maps.

As referred in section 1, a planning methodology includes two main categories of information; 1. Renewable resource mapping and 2. Conditions/Restrictions to the installation of offshore renewable energy systems.

2.1.1 Offshore Renewable Resource Mapping

- Wind resource mapping

The wind resource map is obtained with numerical modelling, in this case using Mesoscale Fifth Model (MM5) [12] which is suitable for extensive regions (above 100 km²) and validated with experimental data [3]. As detailed presented in Couto *et al.* [3], the spatial resolution of the wind resource data is 3 km. Also, since the goal is to consider different offshore wind technologies – fixed and floating – a wind

energy annual production map was calculated for two different wind turbine models; one referred to bottom fixed technologies, in this case, monopile and jacket – 6MW wind turbine, and another for floating technologies, in this case, WindFloat and Hywind – 8MW wind turbine. In addition to the annual production, maps of number of hours at full capacity (NEPs) were also computed. All the resource maps were developed for an area from the coastline until the 300m bathymetric since it corresponds to the depths where the actual equipment available in the market can be installed, according to the manufacturers and developers. These maps are then inserted into the GIS and submitted to a criterion threshold condition that establishes, for example, the minimum value for economic sustainability that guarantees the profitability of the project. In this case, the criterion was applied to the NEPs parameter and according to work published in [4], [6], [7].

- *Wave energy potential*

The wave energy potential is calculated by using sea wave data, obtained by either using numerical models, wave buoys (directional or non-directional), pressure transducers, satellites (radars), or resistive or capacitive transducers. Sea agitation data may correspond to a significant height, peak period, average zero and/or energy, power (or energy flow), average wave direction, etc. Based on these parameters, obtained for several time intervals, that can make up to several years of data, it is possible to determine long term maritime agitation statistics. These statistics define the climate and wave energy resource for a given location. In this project, the mapping of the wave energy resource is obtained from the coupling of the information of a numerical model (MAR3G from IPMA – ONDATLAS) with the observed data. As input data, the model uses buoys data from the Portuguese Hydrographic Institute – 10 years of data from two buoys and other available buoys with, approximately 5 years, located near the coast. The results are an estimate for the wave energy atlas based on numerical and experimental data, resulting in a statistical base mapping of the wave energy spatial distribution along the Portuguese coast.

2.1.2 *Conditions/Restrictions to the installation of offshore renewable energy systems*

In order to prepare the final maps to feed the MarinePlan Tool, it is necessary to identify and remove from the results the physical restrictions to the installation of the equipment. These restrictions are directly dependent on the type of technology one wishes to study being the most relevant difference among the technologies, the characteristics of the seabed. This information can be found, in most cases, in public databases of georeferenced layers related to environment, territory management or similar. The most common types of restrictions can be consulted in table 1. Please note that information related with social aspects and fisheries (as discussed in section 1) was not included in this phase, but can be included in the input maps as long as the information is available in georeferenced format.

All the identified restrictions are inserted into the GIS together with the offshore renewable resource maps. The first step is to merge all the restrictions in one single layer to exclude them from the resource maps in a simpler and straightforward way. This will result in a set of areas where the different equipment can be installed. The next step is to apply conditions and threshold values for the selection of the final suitable areas. The planning processes and the MarinePlan application will only be worked in the non-restricted areas.

Table 1. Restrictions applied in planning methodologies for renewable offshore systems [13].

Type of restriction	Description
Bathymetry	Depth/Slope
Environment	Protection areas (sea and coastal)
Economic activities	Fisheries, aquaculture and other activities
Electric grid	Available capacity to connect to the grid
Infrastructures and accessibility restrictions	Ports, coastal areas, visibility areas, etc....

Other relevant in offshore environments	Military zones, seismic faults, types of seabed, navigation channels, submarine cables,...
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In the work here presented, the resolution of the raster maps – wind resource, bathymetry and slope, have been developed with 1 km x 1 km resolution and the extent corresponds to the 300 m bathymetric. In the case of the environmental, economic, and other relevant issues, the information's topology corresponds to polygon features, therefore the resolution is not a relevant factor, and the extent of the maps is variable according to the theme.

In what concerns the different technologies, the main differences are, related with the seabed – existence of rocks, for example, the installation costs and the depths. The installation (and equipment costs) in the case of fixed technologies is usually lower than the floating technologies. Since near the coast the energy production is normally lower, the distance also influences the grid connection costs, and the logistics related with the vessels' costs are also less costly, it is also usual to consider different threshold values regarding the NEPs parameter. In this sense, lower values for the NEPs parameter are defined for fixed wind technologies than for floating wind systems. Tables 2 and 3 present the technologies selected in this work and their main characteristics.

Table 2. Wind energy systems characteristics.

Name	Bottom-fixed		Floating	
	Monopile	Jacket	Windfloat	Hywind
Type of foundation	-	-	Semi-Submersible	Spar-Buoy
Mooring	-	-	Catenary system (3 cables)	Catenary system (3 cables)
Depth (m)	10 - 30	25 - 50	> 50	> 100

Table 3. Wave energy systems characteristics.

Types	Type 1	Type 2	Type 3
Description	Floating two-body heaving converter	Bottom-fixed oscillating flap	Floating oscillation water column
Acronym	F-2HB	B-OF	F-OWC
Capture length ratio (%)	27	58	41
Characteristic dimension (m)	20	26	24
Operation depth (m)	65 – 200	13 – 25	25 - 200
Type of mooring	Floating - Moorings	Bottom-fixed	Floating - Moorings

2.1.3 Criterion applied to the selection of the most suitable areas for renewable offshore systems

After gathering all the restrictions (seabed rocky areas, submarine cables, seismic faults, navigation routes, environmental protected areas – natural parks, Natura 2000 areas, aquaculture areas, protected habitats – in this case, the public information, bathymetry and slope maps) and introducing them into the GIS with the resource maps, the project is ready to apply the selections and conditions for the most suitable areas, and therefore, produce the final maps to use as input in the MarinePlan tool. The exclusion parameters are all the ones presented in table 1, and some variations are considered for the resource and bathymetry values (table 4). In the case of wave energy technology, the identification of the suitable areas, was performed with the application of the depth

parameter presented in table 2, since in this case the technical characteristics are very specific and no threshold values for the remaining parameters were considered.

Table 4. Criterion applied to identify the most suitable areas.

Technology	Type of foundation	Type of restriction	Condition applied/considered
Wind	Bottom-Fixed	NEPs	>3000 h/year
		Depth	According to Table 2
		Seabed	Avoid rocky areas
	Floating	NEPs	>3500 h/year
		Depth	According to Table 2
		Seabed	none
Waves	Bottom-Fixed and Floating	Depth	According to Table 2

In addition, all the areas with any kind of environmental protection, or in the presence of submarine cables, seismic faults, navigation channels and aquaculture were excluded from the resource map.

2.2 MarinePlan Tool – description of modules implemented

The MarinePlan tool was designed to enable the planning and economic analysis of renewable energy projects in the offshore domain of wind and wave resource exploitation. The analysis focuses on economic and energy indicators typically used in the renewable energy sector. These indicators can be obtained for a particular offshore renewable plant, according to two distinct application modes: i) offshore mapping considering that the renewable plant can be located in any location of the exclusive economic zone respecting the constraints and constraints applicable to the technology of the plant to be installed; and ii) single point where the renewable plant is treated as an isolated point without a specific spatial location with the user providing the relevant input parameter values. Another application of the tool is to analyze and rank the spatial projects created by the user based on each economic indicator and taking into account the spatial results. Figure 2 provides an overview of the modules implemented in the tool: *Economic Analysis – Spatial*, *Economic Analysis – Point*, and *Spatial projects – Indicators hierarchization*. The modules can be used independently and simultaneously, i.e., keeping all three modules active during the use of any one of them is allowed, except during computational calculation periods. In figure 2 the input and output parameters are also indicated.

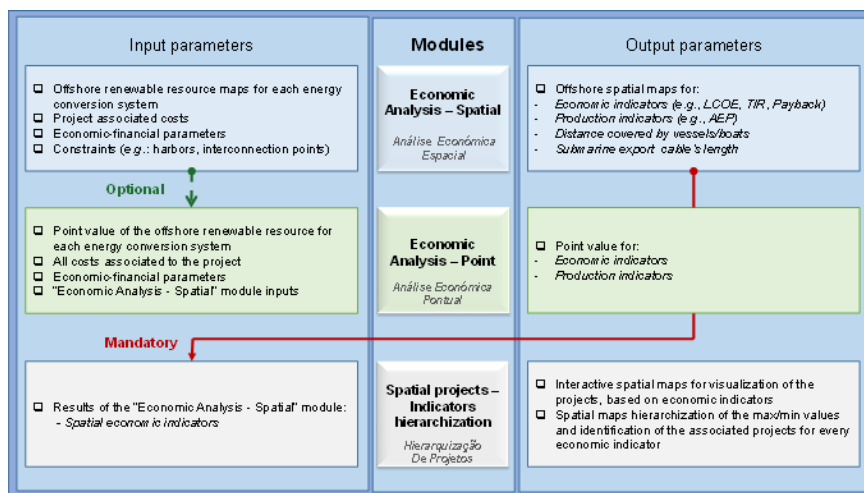


Figure 2. Input and output parameters and main modules of the MarinePlan tool.

2.2.1 Module Economic Analysis – Spatial

This module allows obtaining spatial maps of the economic and energy indicators calculated for a selected offshore renewable plant dimensioned according to the user's interest as well as the spatial resolution of the input data. Currently, the spatial resolution of the public version of the tool is five kilometres. Nevertheless, within the scope of the OffshorePlan project, the results were processed with one-kilometre spatial resolution. In both cases, a linear interpolation of the original data was performed.

The spatial calculation of these indicators projected for the Portuguese continental offshore coast uses the information presented in section 2.1 and the additional input information:

- i) costs associated with offshore renewable plant projects (investment costs, operation and maintenance costs, and decommissioning costs);
- ii) economic and financial variables associated with renewable energy projects (remuneration for energy produced, investment financing, main taxes and fees). The detail related with the calculation of these parameters can be found in [10];
- iii) information regarding the location of interconnection points to the power grid and the embarkation ports. This information is already provided and integrated into the tool for the specific case of Portugal.

In Figure 3 the menu of the module *economic analysis – spatial* is presented. In this menu, it is possible to observe all the parameters that users need to insert as well as the information regarding the calculations and outputs available in this module. The menu is presented in a column-based organization: 1) *Offshore renewable plant - Configuration*, 2) *Project costs*, 3) *Economic indicators*, and 4) *Calculate and output results*. Within each column, the specifications of the simulation are grouped by topics for example: “*Type of technology and system*”, “*Project sizing*”, “*Energy Losses*”, “*Capital Expenditure (CAPEX)*”, “*Investment funding*”, “*Fees and taxes*”, among others.

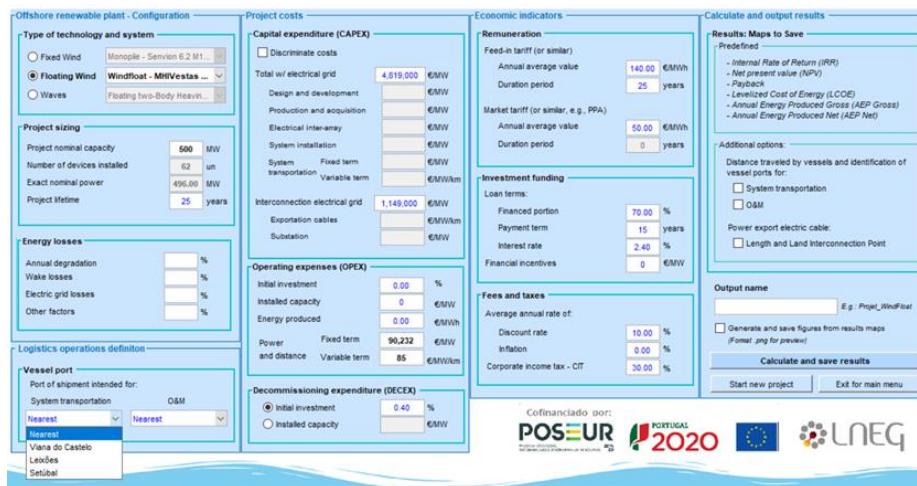


Figure 3. Module *economic analysis – spatial*.

By default, the outputs from this module are spatial maps for economic and energy indicators, table 5. Optionally, maps related to parameters that aim to reflect the distance-to-coast dependence in cost determination can also be obtained, namely: 1) the distance travelled by vessels and the identification of the ports shipment for i) system transport and ii) maintenance operations – in both cases the user can select the closest or one specific port available in the tool, 2) the length of export cables and the identification of optimized interconnection points for the shortest cable length.

Table 5. Outputs from the “*Economic analysis – spatial*” module.

Output	Designation of parameters associated with result maps
Pre-defined	Internal Rate of Return (IRR)
	Net Present Value (NPV)
	Investment Payback Period
	Levelized Cost of Energy (LCOE)
	Gross Annual Energy Produced (Gross AEP)
	Net Annual Energy Produced (Net AEP)
Optional	Distance travelled by vessels and identification of respective ports for system transport and also for operating and maintenance (O&M)
	Length of the electrical power export cable and identification of the interconnection points.

- *Further details of inputs in the “Define Project Costs” section*

One of the options available in the “*Economic analysis – spatial*” module, in the “*Project Costs*” section where the impact of distance travelled by vessels for the installation and operation and maintenance (O&M) costs can be assessed in the “*Capital expenditure (CAPEX)*” and “*Operating expenses (OPEX)*”, respectively. The determination of the distances in CAPEX and OPEX is directly related to the options selected by the user in the “*Logistics operations definition*” section, namely, the desired vessel port for each of these cases. A methodology was implemented in the tool to obtain the path between the two points (origin/destination). By origin/destination, it is meant the location point of the vessel port and each spatial point on the map associated with the possible location of an offshore renewable power plant. Due to the physical constraints associated with the minimum depth required for transporting the structures of different energy conversion systems and location of the identified vessel ports along the Portuguese continental coast, the methodology established uses predefined navigation corridors. Considering the different minimum depths required for transporting the structures and for vessels used in the maintenance operations, three navigation corridors were created using three minimum depth values (5, 50, and 100 meters) imposing a route that also allowed the shortest distance to be travelled. The paths defined for the three navigation corridors are shown in figure 4. These navigation corridors aim to serve mainly the following applications: depth of 5 meters - displacements associated with maintenance operations of renewable power plants, and transportation and installation of bottom-fixed technologies (e.g., monopile and jacket structures); depth of 50 meters - transportation and installation of some floating technology structures (e.g., WindFloat and Floating Oscillation Water Column); and depth of 100 meters - transportation and installation of some floating technology structures (e.g., Hywind and Floating two-Body Heaving Converter).

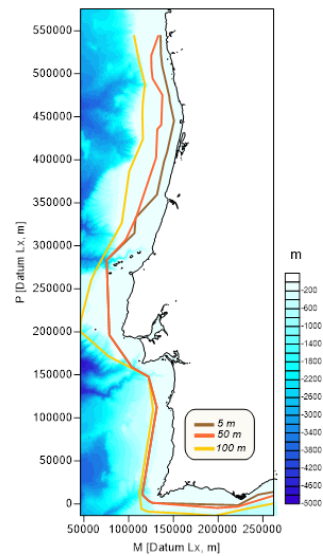


Figure 4. Route of the three navigation corridors and identification of available embarkation ports.

The total length of each route between the power plant location and a particular vessel port passing through a specific navigation corridor is obtained by the sum of three determined parts in the following way and sequence:

1. Determination of the location of the point on the corridor that allows obtaining the shortest route to the renewable power plant location (point on the map);
2. Determination of the location of the point on the corridor that allows obtaining the shortest route to the port location;
3. Calculation of the length of the route of the corridor itself between the location of the two points obtained in 1) and 2).

Once the distances travelled for all existing possibilities are obtained, the solution with the lowest value is automatically selected. Thus, this approach only considers existing physical constraints and depth. The cost of interconnecting an offshore power plant with the main grid is essentially determined by the length of the necessary cable and its capacity. MarinePlan covers this aspect by allowing users to insert the costs associated with the exportation cables in the CAPEX.

2.2.2 Module Economic Analysis – Point

This module aims to provide a quick visualization of the economic and energy indicators obtained for a specific arbitrarily defined offshore renewable power plant, dissociated from any spatial location. In contrast, equivalent information is requested from the user to translate an arbitrary spatial location, namely: i) the value of NEPs and the nominal power of the system in the case of a wind power plant or the characteristics of the power converter and the resource in the case of a wave power plant, ii) the distance travelled by vessels for system transportation and O&M operations, iii) the estimated length of the energy export cable.

In this module, the results are instantly obtained and presented. In addition to the economic and energy indicators presented, graphical information is also provided on the distribution of costs introduced. These results can be exported at any time to an Excel file.

2.2.3 Module Spatial projects – Indicators hierarchization

This module presented in figure 5 allows the comparison of results obtained in “Economic Analysis – Spatial” module by performing the hierarchization of the available results for each calculated economic indicator: LCOE, IRR, NPV, and Payback. Thus, for each set of available projects that an user wants to compare, the tool provides a hierarchy of the projects feasible for each spatial point according to the maximization or minimization of an indicator (also selected by the user). If it is found that no technology can be installed in a particular point due to restrictions, the result for that point is presented as N.A. (Not

Applicable), and the maps appear as blank. Figure 5 provides an example for two projects where it is possible to observe in the first graphic the minimum LCOE value while in the second it is possible to see the corresponding project. The figures are interactive by clicking on each spatial point users can see the results.

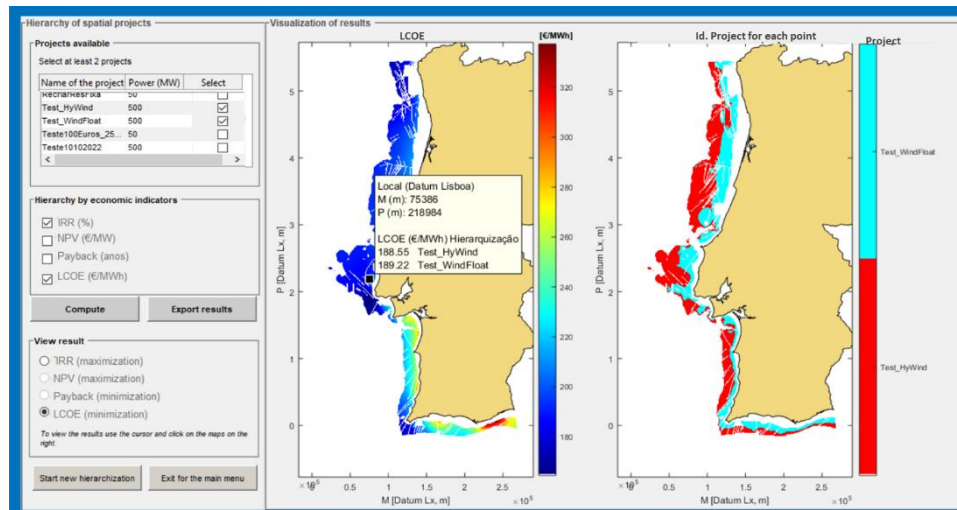


Figure 5. Menu Module Spatial projects – Indicators hierarchization.

2.2.4 Limitations of the tool

Currently, the module *economic analysis – spatial* is restricted to a predefined set of technological options. This limitation becomes especially relevant in the context of wind offshore technology, where there have been in recent years rapid advancements in blade diameters and the nominal power capacity of wind turbines. Moreover, as the national strategies for exploring offshore renewable energy sources evolve and the need to increase the protected areas by 2030, new conditions and restrictions for installing these systems can emerge. These developments can be easily introduced in the tool but require updating the input data maps using the GIS tool by contacting the developers and cannot be updated by users. Currently, the tool allows for fixed remuneration values to be included for "feed-in-tariff" and "market tariff" throughout the entire support period. However, given the dynamic nature of markets and the importance of identifying suitable support mechanisms, there are plans to introduce a new feature in future versions of the tool enabling it to consider more dynamic yearly prices. This feature will enable the representation of various support schemes, helping policymakers decide how to appropriately remunerate and ensure a return on investment for these technologies for investors without increasing the costs for the end-users consumers.

It is essential to emphasize that the tool only addresses technical and economic aspects, and it does not cover aspects of the value chain or social impact associated with the installation of offshore renewable technologies. If available in a georeferenced format, this type of information can be easily included in the input file. Also, any values suggested by the tool should be considered indicative and not used as definitive references.

3. Results from the application of the tool MarinePlan

The MarinePlan tool's main objective is to help developers to obtain a techno-economic analysis of their projects and to hierarchise different runs in order to select the best option for the project the user wishes to develop. In this sense, this tool is publicly available at the project's web site

(<https://offshoreplan.lneg.pt>), and includes the resource maps for the technologies here presented and standard investment values so that the user can operate the tool when these are not available. An example considering the WindFloat technology for wind energy is presented using the input values presented in table 6. As in the default values provided in the tool, the values used in this section are only indicators and results cannot be used without specifying the conditions from table 6.

Figure 6 presents the results obtained in the tool with the values presented in table 6.

As an option, the user can also map the (a) area of operation for each port, and the distances that the vessels will have to do for (b) O&M operations and (c) equipment transportation, as represented in figure 7.

Table 6. Standard input values included in the MarinePlan Tool.

Project Dimensioning:		Decommissioning cost	
Project's installed capacity:	50MW	Initial Investment	0.80%
Nr. of devices installed	6	Remuneration	
Installed capacity (exact value)	48MW	Feed-In tariff-value	140 €/MWh
Lifetime of the project	30 years	Feed-In tariff-duration	30 years
Energy losses		Market tariff - value	50 €/MWh
Annual degradation of the equipment	1%	Market tariff - duration	0 years
Wake effects	3%	Investment funding	
Electric grid	1%	Funded parcel	70%
other	1%	Payment duration	15 years
Shipment Port		Interest tax	2.40%
System transportation	The closest	Funding incentive	0 €/MW
O&M	The closest	Fees and taxes	
Investment costs		Discount rate	10%
Total (Except Export. grid)	4819000 €/MW	Inflation	0%
Total Export. Grid	1149000 €/MW	Fee - IRC	30%
Annual O&M cost			
Installed capacity – Fixed term	109232 €/MW		
Installed capacity – Variable term	28 €/MW/km		

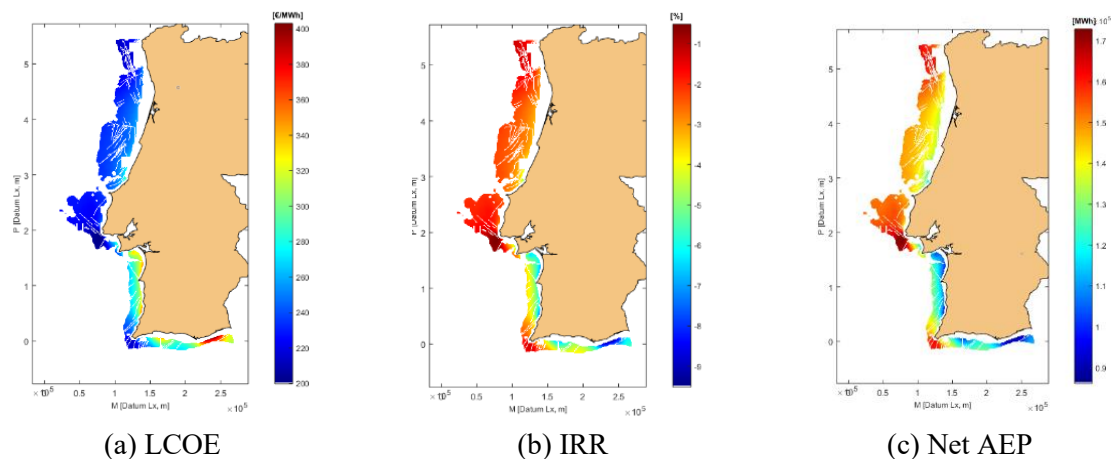
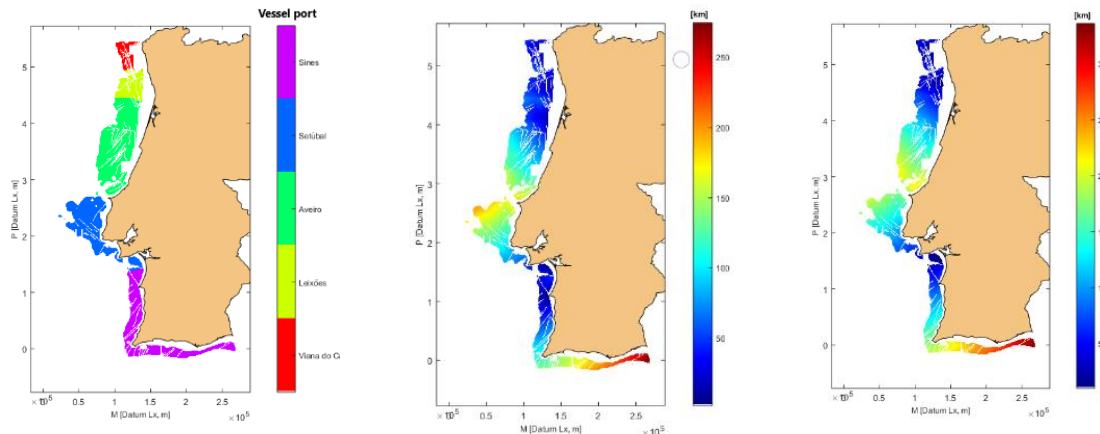


Figure 6. Results from the operation of the MarinePlan tool.

Besides the spatial results the values presented in table 6 can also be used to obtain the economic parameters in a specific location, and in this case, the user needs to add the information related with the renewable resource of the technology of interest. Although the spatial mode includes a larger set of results that can support the user in its projects, the point mode can be very useful when a specific location has already been selected.



(a) Available vessel ports for O&M operations. (b) Distance travelled for O&M operations. (c) Distance travelled for installation of the systems.

Figure 7. Optional results available in MarinePlan tool.

4. Final Remarks and Future Developments

This document presents the methodology and application of a techno-economic tool developed with the objective of supporting the policymakers and investors in offshore renewable energy systems. The methodology includes the use of results from the resource assessment and the application of restrictions and conditions to the installation of marine renewable systems using GIS techniques. This information is then used in MarinePlan tool, which enables to obtain economic relevant parameters such as levelized cost of energy and payback of the project by select several options according to the technology of interest.

This tool will continue to be developed in the near future, by integrating more detailed restrictions and updating of the resource maps to new equipment, for example, considering new offshore wind turbine models with higher capacities that are now available for this purpose; social aspects; and exclusion of fishing zones in the input maps. The interactivity possibilities will also be improved by introducing the option to change resource maps developed by the user in a more straightforward way.

This tool is publicly available for download at <https://offshoreplan.lneg.pt>, and can be easily adapted to any other geographies. As an independent and interactive techno-economic planning platform, the tool can empower stakeholders to make well-informed decisions concerning project location and technology selection for offshore renewable energy development.

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