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Framework for Development of an Economic Analysis Tool for Floating Concrete Offshore Wind Platforms

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Abstract: The objective of this work is to establish a framework for the development of an economic analysis tool for floating offshore wind platforms built in concrete. The operation and usefulness of the beta version of a software, called Arcwind, is explained. It calculates the main economic aspects of offshore wind platforms built in concrete considering different locations in the European Atlantic Arc. This software allows the user to select different input parameters such as: the type of platform, the installation area of the farm, its specific location and in this way create different analysis scenarios. This paper analyzes the case study to install TELWIND® offshore concrete floating platforms in the Canary Islands, in Spain. The software provides data on the main economic parameters of the farm, such as Levelized Cost Of Energy (LCOE), Net Present Value (NPV), Internal Rate of Return (IRR), Pay-Back Period (PBP), as well as the main costs: cost of conception and definition, cost of design and development, cost of manufacturing, cost of installation, cost of operation and cost of dismantling. Using these parameters, a first analysis of the viability of this type of floating technology built on concrete is shown.

Keywords: TELWIND; floating offshore wind; concrete; feasibility; economics

1. Introduction

The global economy is committed to reducing greenhouse gas emissions [1]. With this purpose, policies to reduce them are being promoted. The 2015 Paris agreement [2] highlights the importance of cross-border cooperation in environmental matters between member states, including Spain and Portugal. The priority objective is to reduce greenhouse gases by 20% compared to 1990 and reach 80% by 2050 [3]. In recent years, the European Union has made considerable efforts to increase electricity generation through renewable sources. The percentage of renewable energies in the final electrical consumption has doubled from 8.5% in 2004 to 17% in 2016 [4,5].

According to the WEO 2018 report [6] of the IEA (International Energy Agency), two thirds of the world's electricity generation will come from renewable sources in 2040, and solar and wind energy must produce seven times more than coal in 2040 if the objective of the Paris agreement; to achieve this it is necessary to enhance the use of this type of energy. Within wind energy, offshore wind power has been experiencing a great increase in recent years due to other factors because its visual impact is lower [7–9], there are more possible locations [10–12], and the powers of the turbines are greater.

Numerous changes in technology are being made within offshore wind power in order to make them more economically viable [13]. One of the main changes has been to modify the materials with which the platform is made [14], moving from traditional steel platforms to concrete platforms [15].

The platform to be studied in this article is the TELWIND® platform, developed by the Esteyco company [16]. Esteyco is an independent Spanish civil engineering consultancy and architecture firm founded in 1970 which is dedicated, among other civil sectors, to the development of structures both for onshore and offshore wind power. In this field, this company revolutionized the offshore wind energy sector by building concrete structures replacing steel structures, a predominant material in the construction of subtructures for wind turbines. The steel is light and resistant, but due to restrictions in road transport, it can only be used to manufacture towers up to 80 or 90 m high; this would imply increasing the diameter of the base above 4.5 m which is prohibited in many countries [17]. In addition to this, the problem associated with the corrosion [18] of steel in marine environments that causes maintenance costs to be high is reduced [19], thus reducing the economic viability of the park. Taking these problems into account, Esteyco developed concrete structures as an alternative to steel structures. Although concrete is heavier than steel, it is a cheaper material, less susceptible to temporary price fluctuations and is intensive in terms of both local work-force and raw materials, thus promoting local content.

To this end, Esteyco has participated in several research projects partially funded by the European Commission under the Horizon 2020 program that have facilitated the development of its different concrete wind solutions both for bottom-fixed platforms and floating platforms. Examples of these projects are the ELICAN [20] and TELWIND projects. In the case of ELISA technology for bottom-fixed platforms, it consists of a self-floating gravity foundation (Gravity Base System-GBS) in its maritime transport, together with a self-installing telescopic tower, both made of concrete. The buoyancy of the joint structure, and the telescopic configuration of the tower, allow each unit to be fully mounted on land, including the turbine, and then be conventionally towed to its final position at sea. Once there, it is ballasted to the seabed and is self-hoisted using hydraulic jacks to its final height. The ELICAN project is the construction of a real-scale prototype with ELISA technology. This company subsequently developed the TELWIND® technology which consist of an evolved spar with an integrated telescopic tower [21] both made of concrete, also using the concepts developed in ELISA gravity.

The aim of the present paper is to establish a framework for the development of an economic analysis tool for floating offshore wind platforms built in concrete. The operation and usefulness of the beta version of a software, called Arcwind, is explained. It calculates the main economic aspects of offshore wind platforms built in concrete considering different locations of the European Atlantic Arc. It allows the user to select the type of platform, the area and location of the farm and the alternative to be studied. The tool establishes the beginning to create maps of the locations for concrete platforms in future researches. Floating concrete platforms for offshore wind represent a revolutionary new concept of offshore wind. Therefore, the calculation of their economic aspects is very important in order to carry out the future of offshore wind technology. The research gap of this paper is to calculate them in order to compare them with other substructures. The case study considered takes into account a farm with uses the floating offshore evolved spar platform called TELWIND®, whose technology is designed by the enterprise Esteyco® and located in the waters of Gran Canaria Island (Spain, Europe). The software gives information about the main economic parameters of the farm, such as its costs and economic feasibility indicators (Internal Rate of Return, Net Present Value or Pay-Back Period).

2. Materials and Methods

2.1. Software Description

The objective of the software created is to simplify the way to calculate the main economic aspects of offshore wind platforms built in concrete considering different locations of the European Atlantic

Arc. Castro-Santos et al. previously developed a software to calculate the main economic aspects of floating offshore wind energies, which have been built using steel [22].

This software is a very useful tool for quickly calculating the economic parameters that allow us to know the viability of an offshore wind farm. By changing the location, the program immediately calculates the costs. This program can be useful for companies and entrepreneurs related to renewable energy offshore port which greatly facilitates calculations and saves time.

The program is developed with Matlab to simplify the mathematical formulas that the software contains. In the future it will be shared with the project partners, and although it is developed with Windows, it will be available for Windows and MacOS.

The software can be installed as another application on the computer, without the need to have Matlab installed, using the MATLAB Runtime installer. If the computer has a modern version of Matlab, it would not be necessary to install any additional software.

Figure 1 describes the main operations of the software and Figure A1 (in Appendix A) is an extract of the code that calculates the cost of electrical wiring.

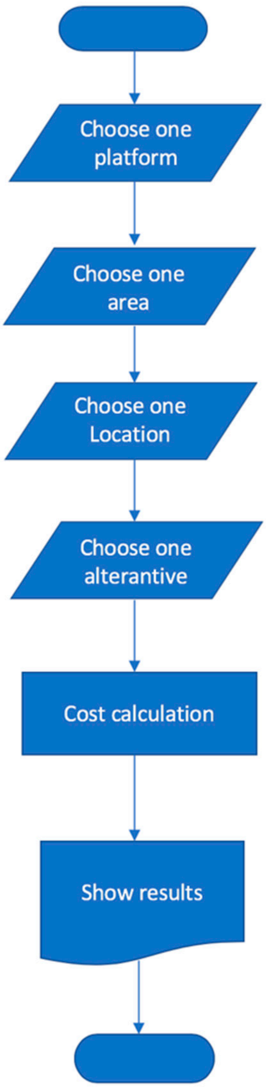

Figure 1. Flowchart.

The welcome window (Figure 2) allows the user to select the different options (steps) that they will see again in the main window. This window gives a quick access to the user.

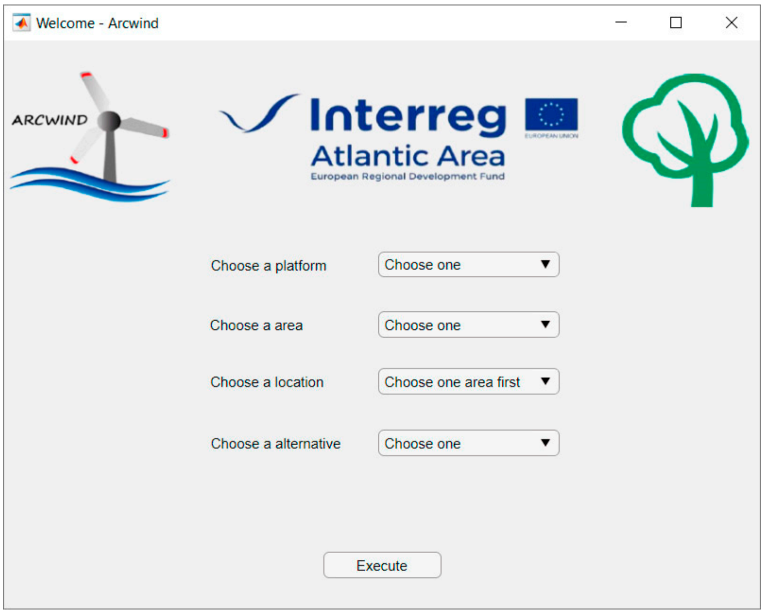

Figure 2. Welcome window.

The software comprises four steps, as Figure 3 is shown on the top:

Step 1: the user should select the platform between the alternatives: TELWIND®. The next versions of the software will allow the selection of more platforms.

Step 2: he user should select the area of the farm. The software was designed for areas included in the Atlantic Arc of the European continent. Therefore, these locations are: Spain (Peninsula), Spain (Canary Islands), Portugal (Peninsula), Portugal (Madeira), Portugal (Azores), France, UK (North Scotland), Ireland (West Ireland) and Ireland (South Ireland). However, it is important to notice that these locations can be increased in the future in order to extend the study to the whole world.

Step 3: the user should select the specific location of the area selected.

Step 4: the user should choose an alternative of study. From the main menu they can create new alternatives to calculate new scenarios. In this beta version of the software, three alternatives have been considered: electricity rate, insurance price and dismantling cost.

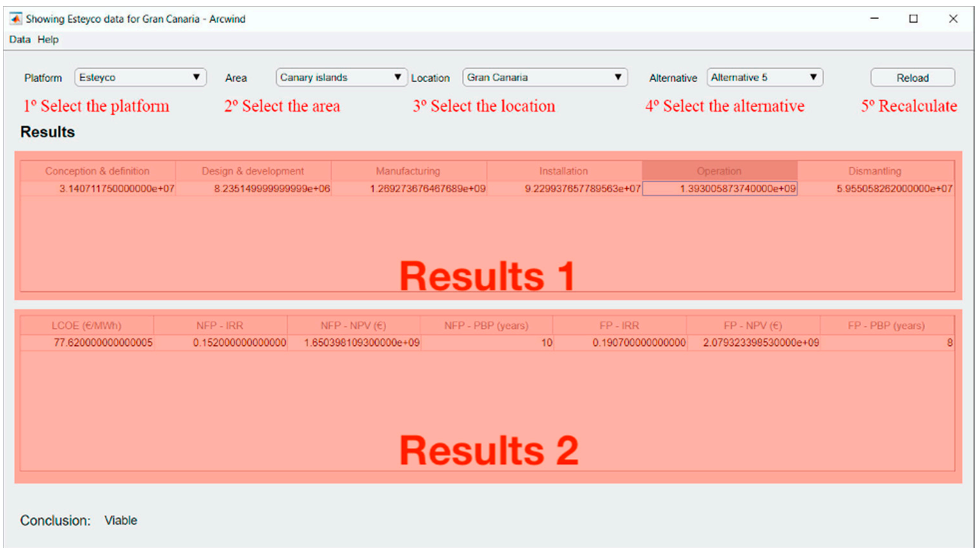

Figure 3. Main window of the software and types of the results depending on the scenario selected.

2.2. Input Values

The input values for each of the steps previously defined are:

Step 1: Platforms

Inputs related to the platform:

- Dimensions of the platform.
- Mass of the main material of the platform without the wind turbine (kg).
- Mass of the auxiliary systems of the platform without the wind turbine (kg).
- Material cost of building the platform (€/platform).
- Labour cost of building the platform (€/platform).
- Indirect cost of building the platform (€/platform).
- Total cost of building the platform (€/platform).
- Inputs related to the mooring lines:
- Material of the mooring lines.
- Type of mooring lines (tensioned, non-tensioned).
- Number of mooring lines.
- Mass of the mooring lines (kg).
- Cost of the mooring lines (€/kg).
- Inputs related to the anchoring:
- Material of the anchoring.
- Type of anchoring.
- Number of anchors.
- Mass of the anchors (kg).
- Cost of the anchors (€/kg).
- Inputs of installing:
- Description of the installation process.
- Description of the decommissioning process.
- Cost of installing one platform (€/platform).
- Inputs related to the maintenance procedure.
- Description of the maintenance process.
- Cost of the maintenance of one platform over one year (€/platform year).
- Cost of the maintenance of one mooring line over one year (€/platform year).
- Cost of the maintenance of one anchoring system over one year (€/platform year).

Step 2: Area & **Step 3:** Location

- Medium wind speed.
- Depth location.
- Height of waves.
- Period of waves.
- Scale parameter.
- Shape parameter.
- Distance from farm to shore.
- Onshore distance of the electric cable.
- Distance from shipyard to port.
- Distance from farm to shipyard.

Step 4: Alternatives

- Assurance cost.
- Dismantling cost.
- Electric tariff.

In the alternatives window (Figure 4) the user can verify the different alternative values and create new ones. By changing the chosen alternative, we can verify whether the wind farm is viable for the scenario selected.

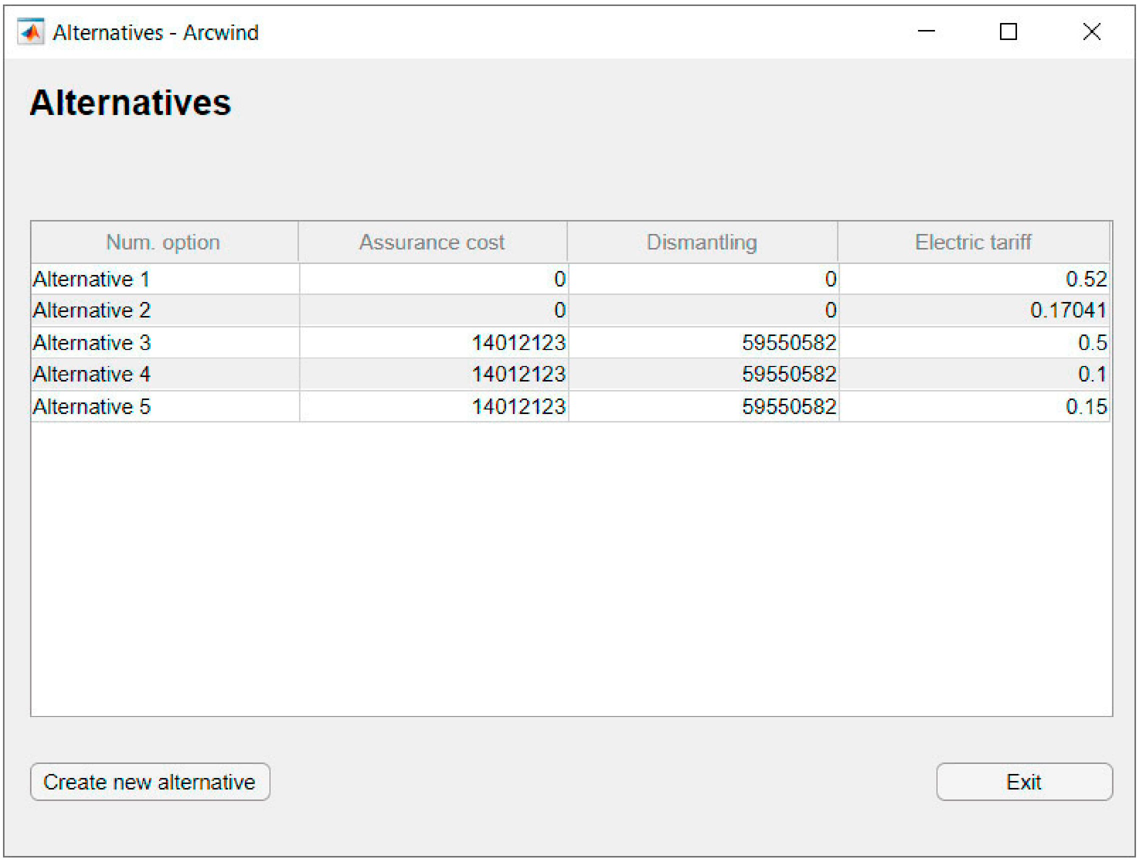

Figure 4. Alternatives window.

2.3. Output Values

The bottom of the Figure 3 shows the two types of results (output values):

(a) Results 1: the costs of the farm are shown [23–25]:

- C1: cost of conception and definition.
- C2: cost of design and development.
- C3: cost of manufacturing.
- C4: cost of installation.
- C5: cost of operation.
- C6: cost of dismantling.

The cost of dismantling is eligible from the alternative menu because as it is developed in the last year of the project it could or could not be considered in the feasibility study.

(b) Results 2: the economic values of the feasibility of the farm are shown:

- LCOE (€/MWh): Levelized Cost Of E Energy.
- NPV (€): Net Present Value of the Non Funded Project (NFP) and the Funded Project (FP).
- IRR (%): Internal Rate of Return of the Non Funded Project (NFP) and the Funded Project (FP).
- PBP (years): Pay-Back Period of the Non Funded Project (NFP) and the Funded Project (FP).

2.4. Functioning

Once the platform and location have been chosen, the software begins to internally calculate the costs of conception and definition, design and development, manufacturing, installation, operation and dismantling. Each process is divided into its own function, where the location and platform values are given and the total cost of each process is returned. Internally, the value of each value can be known, for example: cost of electric cables, cost of anchors, cost of installation of the platform, cost of installation of anchors, etc. For simplicity, the values shown are only the totals. With these total results, the rate of return, the net present value and the payback period are calculated.

To calculate the maintenance, the scheduled checks of the turbine, the cables or the platform are taken into account. The rental price of transport to the park is also calculated based on the distance to the port, the number of people needed and the type of ship.

For example, some of the cost calculations are internally separated into: annual maintenance, crew, maintenance every 5 years, preventive maintenance of the turbine, corrective maintenance of the turbine, cost of spare parts for the turbine, maintenance and inspection of electric cables, maintenance and inspection of the anchors, equipment for inspections, cost of foundation repair, . . .

All these calculations are reflected in the operating cost of the park (C5).

3. Case Study

The costs depend on many variables, such as bathymetry, which determines the length of the submarine cables and the mooring and anchor lines dimensions. However, there are many variables that depend on the characteristics and design of the floating structures selected for each location.

The case study will be focused on the TELWIND® platform (see Figure 5), which is an evolved spar platform designed by the Spanish Enterprise Esteyco®, which is a partner of the ARCWIND Project, that financed the present research. It is an evolved spar floating platform consisting of two bodies connected by steel tendons together with a self-erecting telescopic tower.

Regarding the turbine that this floating structure must support, the project has chosen to use the DTU 10 MW Reference Wind Turbine. The characteristics of the turbine, such as power and height, influence costs and energy production, two very important factors in the economic analysis of the project.

The farm will have a total power of 500 MW. Moreover, the area selected for the case study is the Canary Islands (Spain) and the particular location is the Gran Canaria Island.

The alternative studied has the following values:

- Assurance cost: 14,012,124.74 €
- Dismantling: 59,550,582 €
- Electric tariff: 0.150 €/kWh

Figure 5. TELWIND® platform. Source: Figure courtesy of Esteyco (Reproduced from [16], with permission from Esteyco, 2020).

4. Results

Figure 6 shows the main components of costs of the TELWIND® platform. Manufacturing and Operation costs are the most representative costs in the chart.

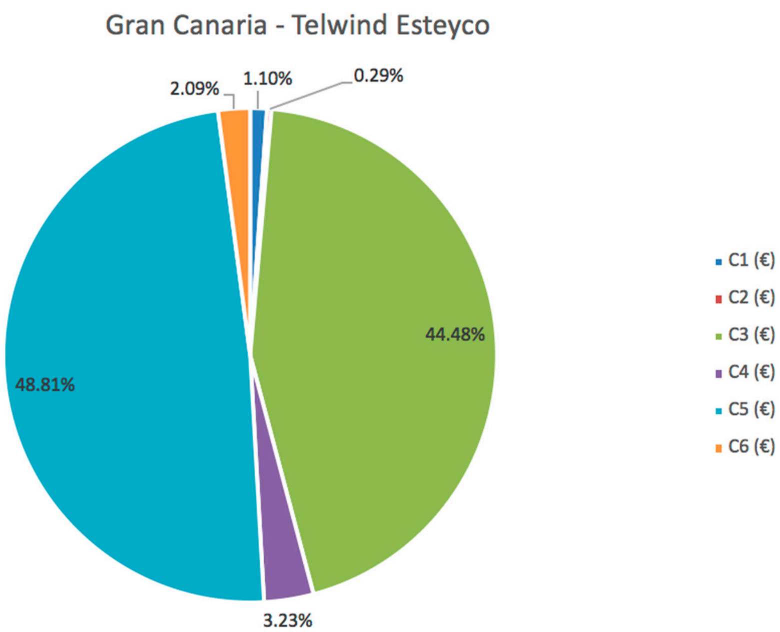

Figure 6. Main components of costs for the TELWIND® platform.

Table 1 shows the results of costs and subcosts for the case study considered: TELWIND® platform in the Gran Canaria location. Offshore logistics is the most important sub-phase for exploitation, reaching 800 M€, due to the high tariff of the means necessary for offshore maintenance tasks, such as special marine cranes. Regarding manufacturing costs, the generators (540 M€) and the floating platforms (473 M€) are the most important sub-phases.

Table 1. Cost estimation for the TELWIND® platform.

Costs	Value
C1 (€)	31,407,117.50 €
C12—Legal aspects	5,000,000.00 €
C13—Wind resource study, sea states study, seabed study	26,407,117.50 €
C2 (€)	8,235,150.00 €
C3 (€)	1,263,873,385.65 €
C31—Generator manufacturing cost	540,771,740.60 €
C32—Floating platform manufacturing cost	473,837,908.79 €
C33—Mooring manufacturing cost	183,531,825.6
C34—Anchoring manufacturing cost	9,983,040.00 €
C35—Electric systems manufacturing cost	55,748,870.66 €
C4 (€)	92,299,376.58 €
C41—Generator installation cost	6,875,000.00 €
C42—Floating platform installation cost	33,560,240.84 €
C43—Mooring and anchoring installation cost	31,334,135.73 €
C44—Electric systems installation cost	20,530,000.00 €
C5 (€)	1,392,951,900.30 €
C51—Assurance cost	13,958,150.30 €
C52—Administration and Operations cost	50,468,750.00 €
C53—Maintenance cost	444,150,000.00 €
C54—Onshore logistics	17,187,500.00 €
C55—Offshore logistics	867,187,500.00 €
C6 (€)	59,550,582.62 €
C61—Generator dismantling cost	28,304,668.59 €
C62—Mooring and anchoring dismantling cost	28,200,722.16 €
C63—Electric system dismantling cost	3,045,191.86 €

Regarding the installation costs, the turbine does not involve so many costs as compared to the floating platform and its anchorage to the seabed due to its ability to be commissioned onshore and under controlled weather conditions.

Regarding the economic feasibility results, considering the alternative selected, the Internal Rate of Return (IRR) is 19.07%, the Net Present Value (NPV) is 2,079,323,398 € and the Discounted Pay-Back Period (DPBP) is 8 years. These results indicate the economic feasibility of the project because the IRR is higher than the capital cost considered (6%), the NPV is higher than zero and the DPBP is less than the life-cycle of the project (20 years). Obviously, these results are very good because the alternative selected is considered to be a good electric tariff (0.150 €/kWh) considering the Spanish tariff. However, this tariff is closed to other European countries where the offshore wind is greatly developed.

5. Discussion

The goal of the present work has been to explain the beta version of a software that calculates the main economic aspects of offshore wind platforms built in concrete considering different locations of the European Atlantic Arc.

The software allows the user to select the type of structure, the location where the farm will be installed and the alternative of study (predefined or created by the user).

The case study analyzed studied a farm which uses the floating offshore spar platform called TELWIND®, whose technology is designed by the enterprise Esteyco®. The location selected has been the Gran Canaria Island (Spain, Europe), a region close to the location of the 5 MW prototype that was installed in 2017 by the same enterprise. In addition, it is important to notice that this type of technology can be very useful for islands, whose isolation and low onshore surface causes other types of renewable technologies to become less effective in the future.

The software gives information about the main economic parameters of the farm, such as its costs and economic feasibility indicators (Internal Rate of Return, Net Present Value or Pay-Back Period).

The most important costs are the manufacturing costs of the platforms and the wind turbine, and Operation and Maintenance costs. The costs of offshore operations represent an important cost to the life cycle of an offshore wind farm, due to the need to use marine cranes that work at high altitude to repair the rotor and the blades of the wind turbine (the turbine hub is located at more than 100 m high). O and M costs can be reduced by optimizing the maintenance strategy.

Another influential factor in costs is the manufacturing of the floating structure, which should develop the concept innovation and subsequently use the economy of scale to reduce costs and reach commercial level.

Generally, the lower the costs in the cycle life of an offshore wind farm, the greater the probability that this project will reach an acceptable economic viability. However, it is important to keep in mind that there are many other factors, such as the energy produced.

The energy generated by the wind turbines at each location must be taken into account. Energy production depends on the characteristics of the location, the distance to the coast, the meteorological conditions and the metaoceanic data. Therefore, the costs of the life cycle of a project are not definitively indicative of feasibility.

It is also important to mention that this software allows us to identify the phases of the life cycle that have the greatest impact, and therefore where measures should be taken to reduce costs and improve the competitiveness of floating technology in the future.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

```
% section
section_11 = 1;
auxCable(2) = num2cell(section_11);
% power
power_11 = P * section_11;
auxCable(3) = num2cell(power_11);
% Intensity
I_11 = (power_11 * 10^6) / (cos_phi * (3^0.5) * V_inter * 10^3);
auxCable(4) = num2cell(I_11);
% Max intensity

interCable = sortrows(Cable, 8, 'ascend');
validCable = cell(1, 4);
valid = false;
i = 1;
while valid == false
    if str2double(interCable(i,8)) > I_11
        validCable(1) = interCable(i, 8);
        validCable(2) = interCable(i, 9);
        validCable(3) = interCable(i, 10);
        validCable(4) = interCable(i, 11);
        valid = true;
    end
    i = i + 1;
end
I_max_11 = str2double(validCable(1));
auxCable(5) = num2cell(I_max_11);
% Section (mm^2)
section_11 = str2double(validCable(2));
auxCable(6) = num2cell(section_11);
% line cost
valid = false;
i = 1;
aux_line_cost_11 = 0;
while valid == false
    if cell2mat(triCost(i,1)) == section_11
        aux_line_cost_11 = cell2mat(triCost(i, 2));
        valid = true;
    end
    i = i + 1;
end
line_cost_11 = aux_line_cost_11;
auxCable(7) = num2cell(line_cost_11);
% length (m)
length_11 = L_turbine;
auxCable(8) = num2cell(length_11);
% Total cost (€)
total_cost_11 = line_cost_11 * (length_11 / 1000);
auxCable(9) = num2cell(total_cost_11);
% resistence
resistence_11 = Cu_resistivity * length_11 / (section_11 / 10^6);
auxCable(10) = num2cell(resistence_11);
% Resistence 90°
resistence_90_11 = (resistence_11 * (1 + (coefficient_var_tmp * temp_diff))) / (length_11 / 1000);
auxCable(11) = num2cell(resistence_90_11);
```

Figure A1. Example of the software code.

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