Multi-criteria Assessment Tool for Floating Offshore Wind Power Plants

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1. Introduction

Nowadays, more than 91% of all offshore wind capacity is installed in European waters, mainly in the shallow waters of the North, Baltic, and Irish Seas [1]. However, since shallow waters are scarce, it becomes necessary to develop technical solutions to unlock the abundant wind resources of deep water areas. Floating substructures for offshore wind power plants are a promising solution that has been under development in recent years. With lower constraints to water depths and soil conditions floating substructures enable to harness the abundant wind resources of deeper waters [2].

'Lifes50+' is a H2020 funded research project carried out by a consortium of 12 leading European institutions and industry partners that focuses on the development of floating substructures for offshore wind turbines in the scale of 10 MW and for water depths greater than 50 meters. Within this project, a specific tool has been developed with the aim of performing a holistic evaluation of four different floating substructures installed in a hypothetical floating offshore wind power plant (FOWPP) [3].

In this paper a preliminary version of the tool is disclosed and the underlying methodology presented.

2. Approach

The FOWPP assessment tool follows a generic as well as holistic approach. The generic attribute is provided by permitting not only the evaluation of the Lifes50+ specific floating substructures but also the evaluation of a customized FOWPP. The holistic approach is achieved by evaluating the FOWPP on the basis of a multi-criteria analysis. This involves an economic evaluation by calculating the levelized cost of energy (LCOE), a technical assessment in form of key performance indicators (KPIs), an environmental evaluation through a life cycle assessment (LCA) and the determination of risk. The results of each assessment are combined by a multi-criteria evaluation into a final assessment of the FOWPP. This approach allows the comparison of different FOWPP concepts as well as the impact evaluation of different geographical locations.

3. Multi-criteria assessment tool for FOWPP

3.1 Overview

The Floating Offshore Wind power plant Assessment Tool (FOWAT) is divided into three main sections namely in Definition, Modules and Evaluation.

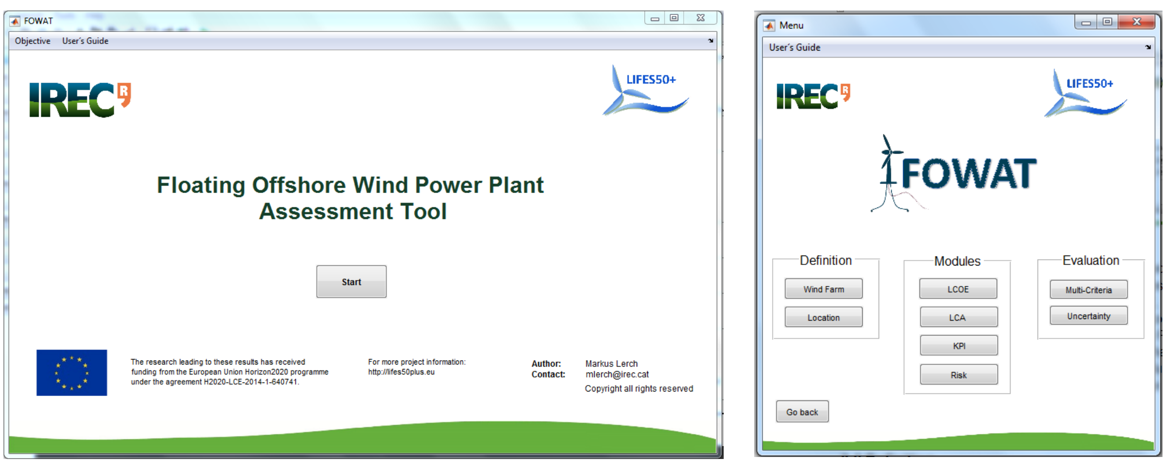

Figure 1: FOWAT main screen

Each section of the tool and the methodology are presented next.

3.2 Definition

The Definition section is used to define the FOWPP and its location. The wind farm layout can be specified as well as the electrical system and the components. Furthermore, in the section 'Location' (see Figure 1) met-ocean conditions are defined and the available wind energy calculated at the specific site.

3.3 Modules

3.3.1 LCOE

The levelized cost of energy (LCOE) is a model used to calculate the cost of energy and is typically applied to compare different power generation technologies. The model relates the discounted cost occurring in the lifetime of the FOWPP to the total energy provided [4].

$$\mathrm{LCOE} = \frac{\text{Life cycle cost}}{\text{Electrical energy provided}} = \frac{\sum_{t=0}^{n} \frac{C_0 + O\&M_t + D_n}{(1+r)^t}}{\sum_{t=0}^{n} \frac{E_t - L_t}{(1+r)^t}}$$

Here, t represents the years and r the discount rate. The life cycle costs (LCC) include the capital costs (C_0), which are the sum of the development, manufacturing, transportation and installation cost, the operation and maintenance cost ($O\&M_t$) as well as the decommissioning cost (D_n) [5]. The LCC calculation is performed for all components of the FOWPP such as the wind turbines, the floating substructures and the complete balance of plant.

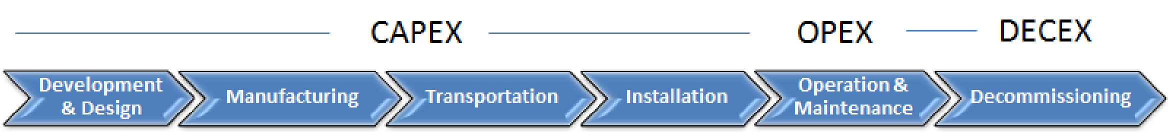

Figure 2: Life cycle cost and phases

Each life cycle stage requires a different approach for the cost calculation. For instance, the transportation and installation cost are based on a range of parameters such as vessel cost, transportation time and harbor activities as well as different installation strategies. A methodology was developed to calculate the cost of each life cycle stage and finally the total cost of the FOWPP.

The calculation of the energy production (E_t) is based on the standard Weibull distribution formula and the power losses (L_t) on the wake effect, dynamic behavior of the platform and electrical losses.

3.3.2 LCA

In order to evaluate each concept's environmental impact life cycle assessment method is applied. Climate change impact, material use and net primary energy use are going to be assessed in terms of LCA. Following the ISO 14040-44 standard [6], a full LCA will be performed considering all project phases from raw materials extraction, to each component manufacturing, transport and installation, operation and maintenance, and decommissioning. The assessment will allow to prioritize the concepts considering their environmental impact as well as to understand the main contributors of the project (life cycle phases, components, processes, etc.) to the environmental impact from a life cycle point of view.

3.3.3 Technical KPIs

Ultimately, the levelized cost of energy, or net present value, is the single most important parameter upon which platform concepts are to be evaluated. However, cost of energy calculations depend, sometimes critically, on a number of assumptions and scenarios. For this reason, evaluation in this project will also use a number of lower-level, technical key performance indicators. These evaluate basic platform performance in static and dynamic stability, survivability, and influence of platform motion on power production. They provide a complementary view, which is less sensitive to scenarios and assumptions, and reveal the stronger or weaker points of the various concepts.

3.3.4 Risk

The risk module developed will form a part of the multi-criteria assessment tool for floating wind turbine substructures, as its exclusion from the FOWAT would omit important considerations when comparing different substructure designs (for example, a substructure for floating wind turbines with the lowest LCOE could, potentially, also be the one with the highest total risk score). The risk assessment module uses a multi-criteria decision-making (MCDM) method to combine different risk areas and their respective consequence scales (e.g. combining health and safety, environment, and cost). Additionally, each risk area has a weighting factor, which can be adjusted depending on the particular situation/analysis being performed, to balance the importance of different risk areas within different contexts and depending on the degree of technology readiness of a design.

3.4 Evaluation

3.4.1 Multi-criteria

The multi-criteria module enables the comparison of the performance of multiple alternatives of floating substructures for different geographic sites by ranking the results obtained in each of the modules using relative scoring values (1 for the worst performance; 4 for the best performance). These scores are calculated considering the statistical distribution of the values obtained in each module. A normal distribution is defined considering the results obtained by each alternative and site. Then the scores are summed up using assigned weighting factors. The output of this module is the ranking of the different FOWPPs that were taken into consideration.

3.4.2 Uncertainty analysis

The uncertainty analysis takes the form of a quantified sensitivity analysis of technological and external uncertainties in the LCOE model, as successfully applied and demonstrated by [7]; where technological uncertainties are those directly associated with the floating wind technology under consideration, for example, fabrication costs, and external uncertainties are those that cannot be influenced by the technology developer, for example, wind speeds at the site (environmental), or exchange rates (financial market conditions).

4. Conclusion

The objective of this paper was to present the FOWPP assessment tool FOWAT developed within the Lifes50+ project and introduce the used methodology. The tool is the first of its kind that is being developed within a large research project that is able to perform a holistic evaluation of a FOWPP and a comparison between different concepts and locations. The outcome of this project may contribute to a favorable promotion of floating wind power by demonstrating the competitiveness of this technology in the market.

5. Learning objectives

In light of the large potential of floating wind power and the increased research and development activities, the presented tool might be of great interest to developers and researchers that want to acquire specific knowledge about multi-criteria assessment of FOWPPs. The following learning objectives are provided:

- Introduction to a multi-criteria assessment tool for a FOWPP;
- Methodology for calculating LCOE of a FOWPP;
- Technical KPIs, LCA and Risk assessment for FOWPPs;
- Multi-criteria and uncertainty evaluation.

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