# A DECISION SUPPORTING TOOL FOR THE LIFECYCLE LOGISTICS OF OCEAN ENERGY ARRAYS

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## ABSTRACT

This paper describes a methodology for the development of a numerical tool for the lifecycle logistics optimization of ocean energy arrays. Within the frame of the DTOcean European project, an innovative approach to select the best combination of ports, vessels and associated equipment, for supporting all phases of a wave and tidal energy farm, is discussed. The methodology consists of a suite of appropriate algorithms that ranks the ports and vessels with the objective of having a logistic solution minimizing the Levelized Cost of Energy (LCoE). A set of preliminary results illustrating the use of thr lifecycle logistics tool is also provided

## 1 INTRODUCTION

Lifecycle logistics represent a significant proportion of the overall capital costs (CapEx) and operational cost (OpEx) of an offshore project. The Institute of Shipping economics and Logistics (ISL) (ISL, 2012) estimates that the share of logistics expenses can reach up to 20% of the total cost of an offshore wind farm with an average value around 15%. While in the long term, one can expect similar share for the lifecycle logistics of the wave and tidal sector, in the first small pre-commercial arrays this share may be even higher (Carbon Trust, 2011).

Figure 1: Top-left: Jack up platform "Neptune" ("DEME Group," 2014) installing a wind turbine at Thorntonbank OWF in 2012. Top-right: "Jules Verne" Cable Laying Vessel ("Prysmian," 2014) Bottom-left: "Aquata" Crew Transfer Vessel ("DEME Group," 2014) at Thorntonbank OWF in 2012. Bottom-right: "Hydro Plow" submarine trencher ("Prysmian," 2014)

The coordination of complex operations such as lifting, towing, positioning and manipulating heavy structures in the open sea environment is challenging. That is why it is crucial to find the most appropriate logistic solutions for an array of MRE devices. Figure 1 illustrates a sample of the diversity of the maritime infrastructures used for the offshore wind industry.

The DTOcean project (DTOcean, 2014) is a key EU project aiming to develop open-source tools to help developers planning the first MRE arrays. DTOcean is structured around four content-orientated Work Packages (WP3-6) guided by two defining work packages (WP1-2) which set the underpinning scope in relation to a range of array sizes and hydrodynamic layouts as shown in Figure 2.

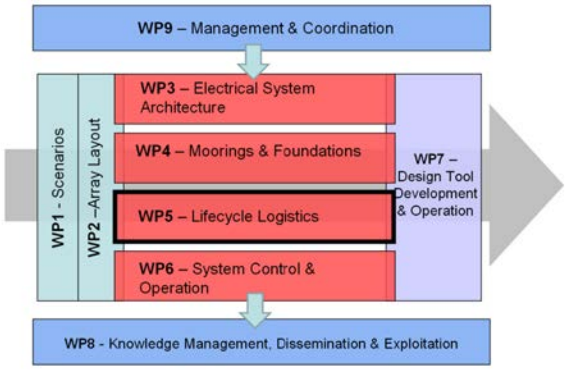



Figure 2: Operational structure and interrelation of the Work Packages in DTOcean

In this context, WavEC Offshore Renewables ("WavEC Offshore Renewables," 2014) is responsible for the development of a lifecycle logistics module (WP5) as well as the creation of the cost functions associated with WP2-6. The main objective of the DTOcean design tool is to reduce the Levelised Cost of Energy (LCoE). For a given project lifetime, Y, the LCoE may be defined as follows:

$$LCoE = \frac{\sum_{y=y_0}^{Y}\left(CapEx(y) + OpEx(y)\right) \times (1 + D_r)^y}{\sum_{y=y_0}^{Y} EP(y) \times (1 + D_r)^y}$$

where $y_0$ is the first year of the project, EP is the energy production in kWh and $D_r$ is the discount rate.

To date, research in the area of logistics of MRE is concentrated on the most mature technology, i.e the offshore wind (Dinwoodie et al., 2013; Douard et al. , 2012; Hofmann & Sperstad, 2013; Lange et al., 2012; Maples et al., 2013; Obdam et al., 2007; Quante, 2012; Rademakers et al., 2009) Nevertheless, recent work on techno-economic analysis of wave energy farms initiated the development of numerical tools featuring simplified considerations for the lifecycle logistic implications, with special focus on the weather windows (O'Connor, Lewis, & Dalton, 2013; Raventos et al., 2010; Teillant et al., 2012). Most recently, MojoMaritime Ltd has released the first commercial version of the Mermaid software (Morandeau et al., 2013) which is tailored for the analysis and optimisation of marine energy installations.

In this paper, we make use of a methodology expressly designed for the lifecycle logistics optimisation of MRE parks which has been reported in the Deliverable 5.1 of DTOcean (Teillant et al., 2014). The lack of operational experience in the sector is overcome throughout simulations of marine operations using original techniques which draw on the expertise available from related industries, such as offshore wind.

The structure of the paper proceeds as follow. Initially, section 1 articulates the methodology implemented to apply the lifecycle logistics model. Secondly, section 2 illustrates the use of this methodology for one test scenario.

# 2 METHODOLOGY

## 2.1 Architecture of the model for lifecycle logistics optimisation of ocean energy arrays

The lifecycle logistics, as schematically represented in figure 3 model articulates three modules, namely:

- Characterization of the logistic requirements; the design specifications of the array of ocean energy devices are translated into logistic requirements for the ports and vessels that will be operating over the course of the project lifetime.
- Selection of the maritime infrastructure; this steps is a feasibility assessment of the suitable maritime infrastructure capable of meeting the logistic requirements previously identified.
- Performance assessment of the maritime

infrastructure; the final stage of the model discriminates between the feasible logistic solutions in terms of time efficiency, cost estimations, level of risk, and qualitative environmental impact assessment.

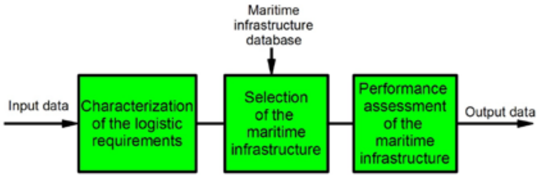



Figure 3: Overview block diagram of the lifecycle logistics model in DTOcean

The methodology incrementally and progressively select and assess the performance of suitable ports, vessels and associated equipment capable of carrying out some aspects of the lifecycle of a MRE project. Figure 4 gives a flow chart showing the flow of data circulating between the 3 modules of the lifecycle logistic tool. The information flowing between the components is represented by:

- Horizontal black lines reflecting the progress of the selection process from left to right and,
- Vertical black lines showing the interactions between key logistic phases.

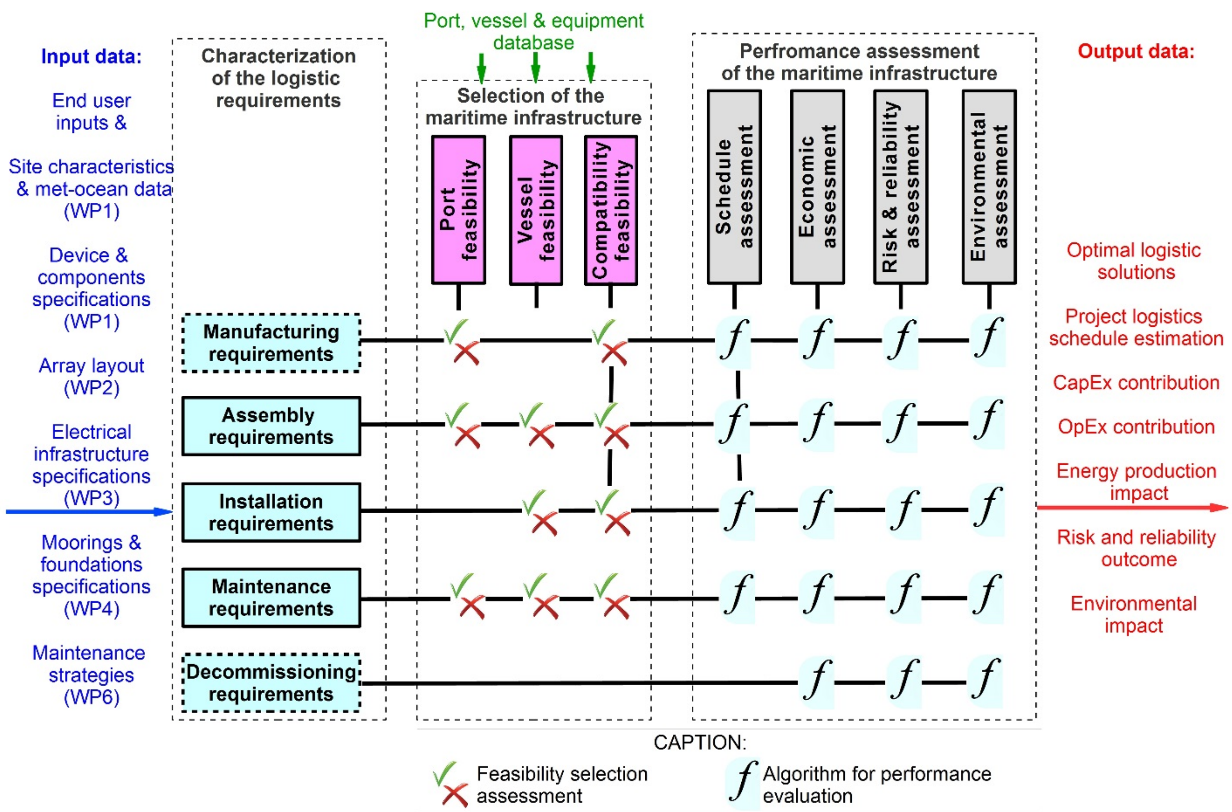



Figure 4: Flow-chart of the lifecycle logistics model in DTOcean

### 2.2. Inputs to the lifecycle logistics model

The inputs to the lifecycle logistics model derive either directly from the users, either from the outputs of the other modules of the DTOcean tool, or from the global database build-in within the DTOcean tool. Six categories of inputs have been identified as listed below:

- Site characteristics and met-ocean data: inputs describing the onsite location, bathymetry, the seabed and the met-ocean resource data (wave height, wave period, wind speed, current speed…).

- Devices & components specifications: inputs listing the specifications of the main components of the devices such as their dimensions and weight as well as the description of the assembly and installation strategy preferred for the device.
- Array layout: inputs defining the array layout configuration such as the number and spatial coordinates of the devices and the interspacing configuration.
- Electrical infrastructure specifications: inputs covering the relevant characteristics of the grid connection (e.g. the cable types and lengths, substation requirements…)
- Moorings & foundations specifications: inputs covering the relevant specifications of the moorings and foundations (e.g. the dimensions and weights of its components, the spatial configuration…)
- Maintenance & decommissioning requirements: all relevant information relative to the maintenance activities concerning the monitoring, the preventive and corrective actions (e.g. type of operation, date, dimensions and weight of components to be replaced…)
- Maritime infrastructure database: a database collecting the key characteristics of ports, vessels and associated equipment (e.g. storage area at port, lifting capacity of the cranes, vessel maximum deck load and area, operating and renting cost of a trenching machine…)

### 2.3. Scope of the lifecycle logistics model

The boundaries of the model have been defined with the view to find a balanced compromise between three objectives:

- Cover the lifecycle of a commercial MRE project as exhaustively as possible with a strong focus on the logistic activities most influencing the LCoE
- Reach a satisfying level of detail in the description of the logistic activities, but maintaining the tool as simple and user-friendly as possible
- Ensure the manageability of the tool with respect to its flexibility, its interactions with other modules of the tool and the budget allocated to develop it

In order to develop a useful tool for the industry, several potential end-users of the tool have been consulted. Among the persons interviewed, there was device developers, maritime contractors and utilities. The general feedback was positive and some valuable detailed technical recommendations were formulated. From a global perspective, it was advised to focus more on the marine operations rather than on the land operations. The importance of incorporating a reliable weather windows estimator was also repeatedly expressed.

As a result of this consultation round, it has been decided to build a simplified model for the procurement, manufacturing and decommissioning phases and, reversely, to reach an in-depth description of the assembly, installation and O&M phases. There are other phases that involve logistics in MRE projects, but that have been considered as not relevant (because of their relatively low anticipated contribution to the LCoE) or out of the scope of an array design tool. For example, in the context of a commercial MRE project development, the surveying phase (surveys related to characterization resource, geophysics, and environment) is done prior to the final design of the array, which is the focus of DTOcean.

### 2.4. Outputs of the lifecycle logistics model

The overall main objective of the DTOcean global design tool is to minimize the LCoE. As one propagates through the lifecycle logistic model, intermediate outputs aggregate to form a pile of information. With the objective to generate a consistent set of outputs for the end-user, the results of the model may be divided in six categories:

- Logistical solutions: a description of the set of ports, vessels and equipment that have been selected.
- Schedule: an expected schedule of the logistical activities with their estimated durations.
- CapEx and OpEx contributions: classify all the costs estimations associated with the logistic activities.
- Energy production impact: outputs affecting the energy production are essentially the downtime due to the maintenance activities and the schedule of the installation procedure. In turn, this will give the availability of the farm for power production throughout the lifetime of the project.
- Risk & reliability outcome: a summary of the information corresponding to the issues related to the reliability/risk during the installation and O&M procedures should be reflected in the form of ranges of uncertainty for the key outputs. The reliability outcome would contain the summary of the consequences of the maintenance activities on the logistic performance.
- Environmental impact: outputs relative to the environmental impact should be included in a qualitative format.

# 3 RESULTS

## 3.1 Definition of the case study scenario

Though being currently under development, a simplified version of the lifecycle logistics model was tested independently of the rest of the others DTOcean modules. This paper reports the preliminary results obtained from the test run of a case stuy. We consider an array of 10 generic floating MRE devices. To overcome the lack of publicly available operational data, the values to populate the failure modes and effects and other indicative operational costs were retrieved from the NREL offshore 5MW wind turbine documented in (Maples et al., 2013). 21 years of time series resource data (wind speeds, Hs and Tp) off the North-West coast of Portugal ("Agaçadoura": 41.467N, -8.850E) have been used for this study.

In this example, the paper assumes a set of operational working conditions with a maximum $H_s$ of 2 meters and a maximum wind speeds of 12 m/s. Such values typically correspond to the use of a Rigid Inflatable Boat (RIB) while navigating in order to, for example, transfer personnel to a floating offshore structure.

## 3.2 Accessibility and weather windows

In this section, we present the results for the percentage of time that the above mentioned operational conditions occur. These statistics provide valuable insight on how frequently favourable conditions occur to maneuver with a RIB. Figure 5 attests of an accessibility around 80% during the summer months, which would allow teams to be assigned almost permanently to the farm without significant costs. In Autumn and Winter, however, the drops to 40% of the time on average.

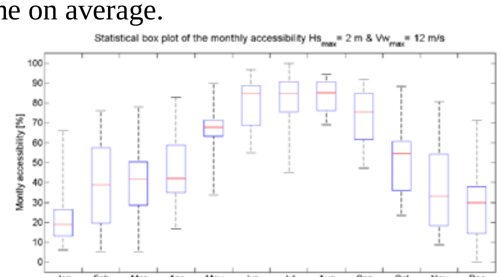



Figure 5: Monthly accessibility box plot at "Agaçadoura"

The plot below shows the total number of weather windows over the 21 years of data sorted by their size ranging from 3 to 24 hours.

Such values give valuable input when considering the maintenance of a multi-units offshore renewable energy park.

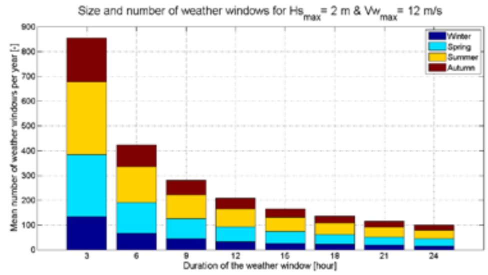



Figure 6: Number of weather windows and their size at “Agaçadoura” between 1990 and 2010

Figure 7 presents the average waiting times against the duration of the mission (i.e the expected duration of a marine operation). The information in this figure is mostly relevant for corrective maintenance, because such operations cannot be planned in advance but require immediate action. To generate average waiting time, it was assumed that a failure could occur at any point in time during the 21 years, and computed the time needed to obtain a given weather window as a function of the duration of the mission. Figure 7 is annotated to highlight that an intervention requiring 8 hours of marine operation would imply a waiting time of one week on average for suitable weather window.

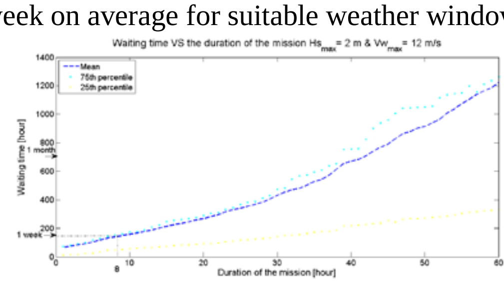



Figure 7: Average waiting time observed for different duration of mission at “Agaçadoura”.

### 3.3 Productivity and costs

In this section, it was assumed that the closest shipyard, in Viana do Castelo (10km distance) would meet the maintenance requirements and that the farm would be operational for 20 years. Random failure events have been simulated based on the baseline study of NREL (Maples et al., 2013). On-site visits every 5-years and a mid-life refit was also computed. All together, the model has assessed:

- The waiting time until a suitable weather window is found for every marine operation
- The transit time to access the target location
- The downtime associated with the failures and other maintenance activities

In figure 8, the breakdown of the downtime indicates a very large share (83%) of the downtime related to corrective maintenance is caused by waiting for proper access conditions. Furthermore, the farm availability for energy production, as shown in figure 9, allows a straightforward visualization of three phases: e.g the deployment, the service life with the impact of the O&M and the recovery phases.

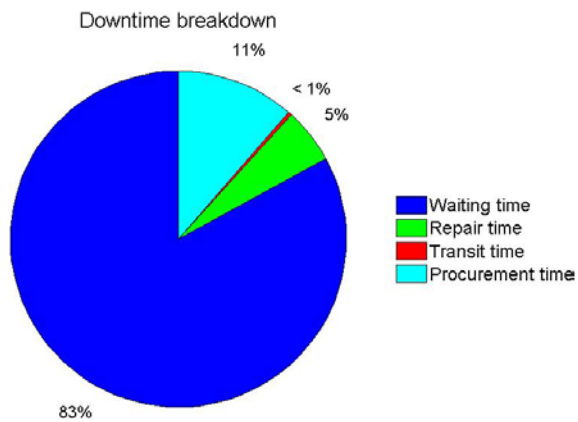
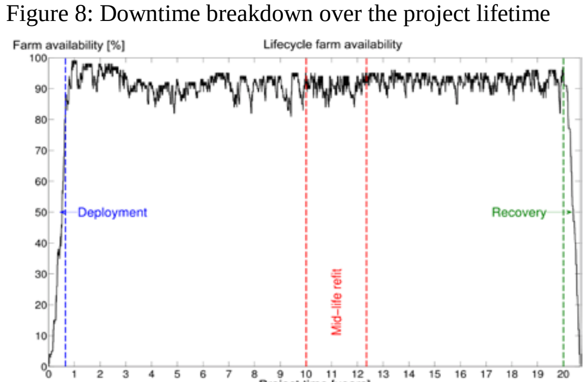
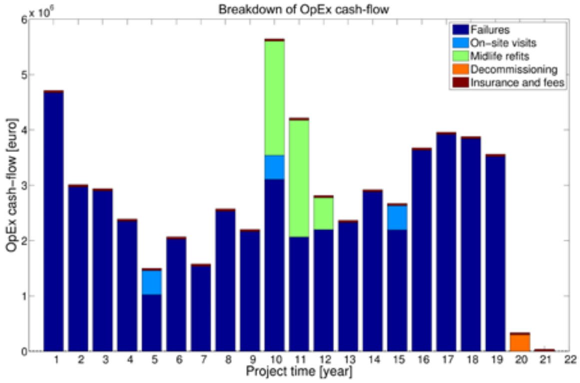



Figure 8: Downtime breakdown over the project lifetime




Firgure 9: Farm availability for energy production over the project lifetime

Lastly, figure 10 is the yearly OpEx breakdown calculated from the operational costs estimates provided in the DOWEC report XX.




Firgure 10: OpEx cash-flow breakdown over the project lifetime

## 4 CONCLUSION

In this paper, a methodology for the development of a lifecycle logistic model is presented. As part of the DTOcean suite of design tools for optimizing the arrays of wave and tidal energy devices, a module to identify the set of ports, vessels and equipment minimizing the LCoE is depicted.

A simplified version of the module is tested for a generic case study scenario. The preliminary results suggest that logistic issues strongly affect both the downtime and the expenses of an ocean renewable energy project. As the wave and tidal energy industry matures, such lifecycle logistics tool should be upgraded to refine its input estimates. At a design stage, the model may assist the project/device developer in assessing the potential impact of factors such as, for example:

- Improvement of the access: how a MRE farm can benefit from operating safely with harsher conditions. This could lead to significant reduction of the time and, hence, drives the innovations for personnel transfer techniques and specialized vessels.
- Economies of scale: the tool can help deciding how larger MRE farms could be managed effectively in terms of logistics, notably through the investigation of different strategies for vessel mobilization and procurement.
- Balance between predictive and corrective maintenance: the tool should allow the assessment of a large variety of maintenance strategies.

In the future, further testing of the lifecycle logistics tool shall improve its functionalities and increase its capabilities. The implementation of an uncertainty analysis shall also bring added value.

## ACKNOWLEDGEMENTS

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