Deliverable 5.1: Methodology report and logistic model flow charts

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Abstract

This deliverable includes the proposed logistic model architecture in terms of flow charts, including data flows within the model and with other WPs and external databases and tools.

For this purpose, a detailed analysis of existing external databases and tools was performed. Also interviews with project developers of wave and tidal arrays (the end-users of the tool) as well as marine contractors and wave and tidal technology developers were carried out to define the scope of the tool and validate the proposed approach.

Firstly, the suitability to integrate existing tools and databases into the ocean energy logistic model is assessed. Given a review of the most relevant offshore logistics tools and maritime infrastructure databases available, a conclusion is made on how the lifecycle logistics model under DTOcean can benefit from previous work.

Secondly, the type of inputs and outputs that will be flowing through the logistic model and the interactions with other modules is detailed. In the end, the flows of information circulate into logistic functions allowing the user to assess logistic operations time, costs, reliability and environmental impacts.

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1. INTRODUCTION

Logistics may be defined as "the detailed coordination of a complex operation involving many people, facilities, or supplies"[1]. This definition of logistics is general and may refer to a very large variety of activities. Since the focus of the DTOcean project is on the wave and tidal energy sector, this report will consider only logistics within the frame of an offshore project.

It is believed that the different logistics phases of a wave or tidal project will be very similar to those of an offshore wind project. As shown in ***Figure 1***, the purpose of offshore lifecycle logistics is primarily to manage the flow of resources required to perform the various activities during the procurement, manufacturing, installation and servicing stages of a project. In particular, ports, vessels and installation equipment represent three essential resources indispensable in the logistic process of a Marine Renewable Energy (MRE) project. Ports, vessels and associated equipment and personnel must be suitable for supporting all the phases of an industrial MRE project.

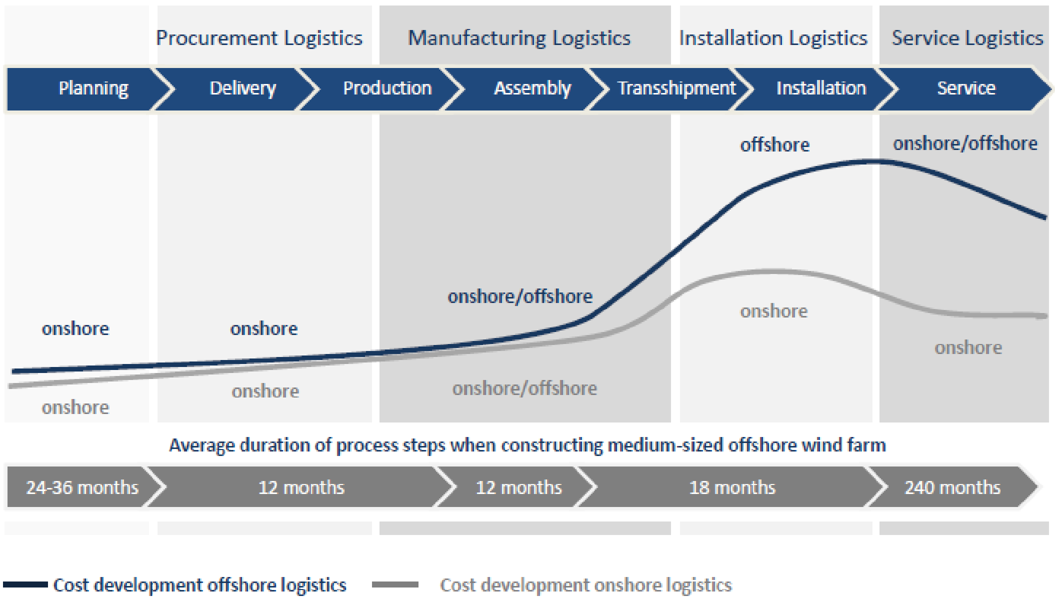

Figure 1. Development of costs over the course of the individual logistics phases in the onshore and the offshore sector for the offshore wind industry (source: [1])

Lifecycle logistics costs 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) [1], [2] estimates that the share of logistics expenses can reach up to 20% of the

[1] Definition according to the New American Oxford Dictionnary
http://www.oxforddictionaries.com/definition/american_english/logistics

total cost of an offshore wind farm with an average value around 15%. While in the long term, one can reasonably expect similar share for the lifecycle logistics of the wave and tidal sector, in the first small pre-commercial arrays the share of logistic costs may be even higher [3].

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 2*** illustrates the diversity of the offshore production infrastructures used for the oil industry. The offshore wind industry also utilizes a broad variety of vessels such as: jack-up barges (***Figure 3***), cable laying vessels (***Figure 4***), crew transfer vessels (***Figure 5***) and anchor handling tug supply vessel (***Figure 6***).

Figure 2. Alternative hydrocarbon production systems (source: Oilfield Publications Ltd., Houston, US)

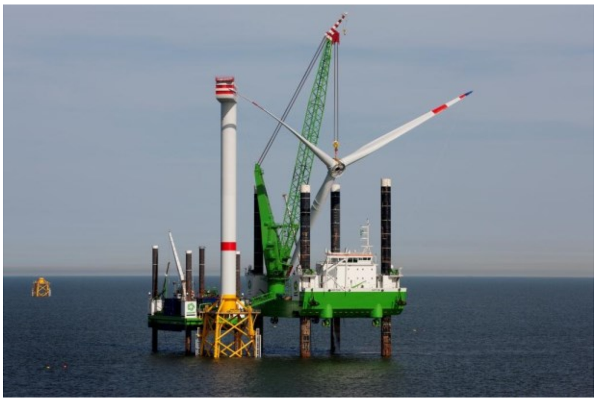

Figure 3. Jack up platform Neptune installing a wind turbine at Thorntonbank OWF in 2012 (source: GeoSea)

Figure 4. Jules Verne of Cable laying vessel (source: Prysmian)

Figure 5. Crew transfer vessel “Aquata” at Thorntonbank OWF in 2012 (source: GeoSea)

Figure 6. Anchor handling tugs “Afon Cadnant” (source: Holyhead Towing Company Ltd.)

Given the financial importance and high level of complexity of the logistics for the offshore environment as discussed in both paragraphs above, it is arguably crucial to anticipate and plan the lifecycle logistics of a MRE farm carefully, especially from a project developer perspective. This report seeks to pave the way for designing a tool/model to support the decision making process for the logistics phases encountered during the development of a

MRE project. It is important to define what will be the capabilities and limitations of the tool in terms of logistics. Ultimately, the model aims to design optimal logistic solutions for ocean energy arrays. In other words, the tool should select the best combination of ports, vessels and installation equipment to operate all the phases of an ocean energy project, and eventually other specific services that may be pointed out by the end users. It will assess feasible combinations of ports, vessels and installation equipment and prioritize them according to their contribution to minimize the Levelised Cost of Energy (LCoE) but also the risks and/or environmental impacts.

The final end-users of the tool are MRE project developers, in supporting investment and management decisions and discriminating between alternative logistical offers. However, other users may also benefit from the tool, such as:

- Prospective investors in assessing the relevance of any MRE project development in terms of logistic issues and in mitigating the financial risks,
- Technology developers in guiding their R&D program and prioritizing their financial efforts with the view to facilitate the logistic requirements of their technology,
- Maritime contractors in anticipating the need for specialized equipment and evaluating the level of competitiveness.
- Specialized consulting companies provided services to the before mentioned players.
- R&D institutions and universities in designing new solutions that streamline marine operations and reduce its associated costs and risks.

This report is articulated in two main sections. The first section deals with the analysis of the existing offshore logistic tools and maritime infrastructure databases. These have been primarily developed for the offshore wind sector. A conclusion is also made on how the lifecycle logistics model that will be developed under DTOcean can benefit from those tools and databases. The second section of this report covers the methodology for the lifecycle logistic model as proposed under DTOcean. The architecture of the model as well as the interactions with the other work packages is discussed. The last section of this deliverable contains a summary of the overall document together with an outlook of the forthcoming work.

2. EXTERNAL TOOLS AND DATABASES

Offshore logistics have been studied in other offshore industries, more mature than the wave and tidal sector, such as the oil and gas and the offshore wind. Despite differences between these industries, it may be time saving to rely upon existing external tools and databases instead of building an offshore lifecycle logistics model from scratch. In this section, a review of the existing tools and databases is conducted to reflect the state-of-the-art of the simulation and data collections of offshore logistics, relevant to the wave and tidal energy sector. The suitability of integrating the existing tools and databases into the offshore logistics model that will be developed under WP5 is eventually examined.

2.1. REVIEW OF OFFSHORE LOGISTIC TOOLS

Acknowledging the full complexity of logistics issues for offshore energy production projects, one can expect to find available tools for supporting the logistics planning in related industries such as oil & gas and offshore wind. During the research of existing offshore logistics tools, a wide range of software with significantly different purposes have been discovered. For instance, there are tools for real time logistics management systems designed for the oil and gas production [4], tools for tracking vessel management systems [5], and many others [6]–[8].

Many of these purposes are not in line with the overall goal of what the tool developed under DTOcean should deliver in terms of logistics explained in section 1. With the purpose of narrowing the scope of the research only to the most relevant existing tools, the remainder of this section will be restricted to offshore wind tools as it is considered as the unique industry sharing enough common characteristics with the wave and tidal sector in terms of logistics issues. Moreover, logistic tools designed to be employed in real time during the operational stage (or in planning an operation very shortly before the operational stage) will not be further reported in this section. Nonetheless, the leading tools of this category have also been investigated to inspire the methodology of the lifecycle logistics tool for DTOcean. Within DTOcean, the lifecycle logistics tool will not be directly applicable for real time applications. It should be noted that there exist tool developers with the capabilities to provide services for both the planning and the operating phases.

Table 1 (see APPENDIX A**. REVIEW OF LOGISTIC TOOLS** for a more detailed description of the tools) introduces a list of existing numerical tools for the offshore wind logistics in line with the objectives of DTOcean. Nine tools were identified as relevant to the requirements of the wave and tidal energy sector. Interviews with these tool developers were undertaken wherever possible. The discussions resulting from these interviews have highlighted that the immaturity of the offshore wind sector implies some a wide variety of expectations from the industry and a need for specialized case studies that prevent the use of a single interface capable of covering all the special needs. However, tool developers are confident in the commercial prospects of their products as the offshore industry progresses. They also encourage the idea to develop logistics tools at an early stage of the ocean energy sector in order to:

- Facilitate the definition of best practices for logistic procedures by contributing to its standardization.
- Decrease the costs associated with the logistics.
- Identify the gaps and barriers in the currently available maritime infrastructures

Table 1. Summary list of relevant existing tools for supporting offshore logistics management.

Tools developer	**Overview of the tool**
Institute of Shipping economics and Logistics (ISL)	Offshore wind installation vessels based on SIEMENS PLM software (Plant Simulation from Tecnatromix) + in-house tools
Frauhnofer IFF	Several tools to support logistic planning for the wind farm industry (onshore and offshore) in collaboration with ISL
Mojo Maritime Ltd.	MerMaid-Marine Economic Risk Management aid is a software to consider the impact of scheduling and metocean conditions on complex marine operations
Energy research Centre of the Netherlands (ECN)	Offshore wind O&M optimization software. The tool can compare a large variety of maintenance scenarios and provides the impact on the techno-economic performance.
National Renewable Energy Laboratory (NREL)	Combination of a customized NREL offshore cost model BOS and the ECN O&M tool to optimize installation and O&M strategies for offshore wind
WavEC Offshore Renewables	Research project providing an Excel sheet for the optimization of specific installation task of floating offshore wind turbine.
EDF Group	ECUME- Mean cost of operation of an offshore wind farm project and risk measurement of O&M operations (based on ECN's tool)
SINTEF-NOWITECH	NOWIcob- Life-cycle cost and O&M optimisation tool for offshore wind farms
Overspeed GmbH Co. KG	OutSmart – Offshore wind O&M strategy simulator. Based on the logistic scenario and historical weather data, the tool delivers the downtime and OPEX.
University of Strathclyde	Research code dealing with offshore wind O&M optimisation
University of Stuttgart	Research code dealing with offshore wind O&M optimisation

Among the list of tools dedicated to the modelling of offshore logistics operations in ***Table 1***, Quante's Diploma thesis [9] is technology specific. This works focuses on the installation of a floating offshore wind turbine. Quante's model implements an Analytic Hierarchy Process

(AHP) which demonstrates the suitability of AHPs to be used as decision making tools for the selection of a goal according to a broad variety of criteria, such as the selection of the maritime infrastructure in the context of a complex offshore operation. Most recently, one should mention the MerMaid software of Mojo Maritime Ltd. [10] which potentially simulates all marine operations that may occur over the course of a MRE project.

The first two rows in ***Table 1*** refer to two German organizations which have been collaborating to develop a set of numerical tools designed for the key logistic operations during the deployment of an offshore wind farm. The ISL [2] has provided is expertise in the shipping industry while Fraunhofer [11] has shared its extensive experience in dealing with wind energy systems. In the end, they possess common simulation tools that they use for consultancy purposes in conjunction with their other in-house tools and expertise. In particular, they render services for managing the installation phase of offshore wind park. Their tools continue to be refined as the industry matures. However, the commercial availability of these tools is restricted to project developers.

The second main type of tools for offshore wind logistics encountered addresses essentially the O&M stage. ECN [12], [13] O&M optimisation software claims the leadership in the current offshore O&M wind market. ECN software makes use of information such as the durations and rates of preventive maintenance activities, the failure rates and the degradation of components to estimate the annual O&M costs of the plant. ECUME [14] is a tool based on ECN software, which is developed by the EDF group. It introduces a risk measurement of the O&M strategies in addition to the mean cost of the operation. Similarly, NOWiTech [15], with their tool called “NOWicob”, as well as the University of Strathclyde [16] and the University of Stuttgart [17] are currently developing their own numerical model for the optimisation of offshore wind O&M.

For further information about these nine tools, including a comparison through a scoring system, please refer to APPENDIX A**. REVIEW OF LOGISTIC TOOLS**.

Despite the fact that the wave and tidal energy industry is at an relatively early stage when compared to the offshore wind sector, early work on thorough techno-economic analysis of MRE converters was already accounting for some logistic issues in terms of impact on the energy production and costs. Two different approaches are generally implemented to cope with the simulation of logistic operations. On the one hand, the *statistical approach*, as employed by Raventos et al. [18] and Dalton et al.[19], [20], relies on scatter diagrams and probability of exceedance for describing the resource. As such, the probability of occurrence for a given weather window (duration and accessibility criteria) can be determined. On the other hand, the *time series approach*, as implemented by Teillant et al.[21] and O’Connor et al.[22], makes use of measurements of the resource for a period of time as long as possible at the site of interest. While this second approach allows more sophisticated and realistic analysis of the accessibility to the site, it requires in-situ measurements which are not always available.

2.2. REVIEW OF THE MARITIME INFRASTRUCTURE DATABASES

To support the decision making process in the selection of the optimal maritime infrastructures, it is necessary to have a data collection of vessels and ports. The end-users of DTOcean design tools should obtain the most suitable combination of vessels and ports according to the inputs specified. A review of the existing databases of maritime infrastructures was conducted to determine the most appropriate strategy to build the WP5 database for DTOcean.

Table 2. Summary list of existing databases of ports and vessels potentially suitable for the MRE sector

Database developer	**Description of the database**
4Coffshore	2 commercial databases of offshore wind vessels (installation and services) 1 online database of offshore wind ports Customized databases and reports available on request
ORECCA	1 database of offshore wind vessels and 1 of ports (based on 4Coffshore)
FleetMom	2 Databases with international coverage (vessels and ports)
WorldPortIndex	Free access international database of ports
WorldPortSource	Free access international database of ports
InField	Oil&gas specialist vessels database
Eagle	Database of vessels with ABS classifications
VTExplorer	Database tracking system of vessels using AIS
Clarkson Research	Database of vessels and associated market study reports. Strict commercial use
SI Ocean	Online GIS map for the wave and tidal sector including information of ports in Europe (based on ORECCA and WorldPortIndex)
IEA-OES	Online GIS map for the wave and tidal sector including information of ports worldwide (based on ORECCA and WorldPortIndex)

Table 2 (see **APPENDIX B. REVIEW OF LOGISTIC PORT AND VESSEL DATABASES** for a more detailed description of the databases) summarizes the findings of this review, which is by no means complete since only the databases containing suitable data for the wave and tidal energy sector have been selected. Unlike the offshore logistics tools, there exist databases applicable to several notable industries including fisheries, shipbuilding companies, oil and gas production and the offshore wind sector. Databases may be free to access or a fee may be required. As it was expected, the more detailed databases are usually accessible only when a fee is paid.

The first databases on maritime infrastructure for the wave and tidal sector have been published (two EU projects: ORECCA, SI Ocean; IEA-OES). The data provides a good starting point for DTOcean, which will gather further information to increase the level of detail. 4COffshore delivers valuable information concerning the offshore wind industry including a database of vessels involved in the lifecycle logistics of existing offshore wind parks. Two separate data collections are accessible for a fee, namely the installation vessels database and the servicing vessels database. While a high level of technical characteristics describing the vessels is available, these databases have only limited information with regards to the economics and the operational working conditions of the vessels and it is not clear whether this information is accurate/complete or not.

2.3. SUITABILITY TO INTEGRATE EXISTING TOOLS AND DATABASES INTO DTOCEAN MODEL

In the end, WP5 would benefit from identifying the best approaches to develop a lifecycle logistics model from the review presented in sections 2.1 and 2.2 and eventually build the logistic model upon existing models applied to other sectors. Facing the lack of operational experience of full scale ocean energy arrays, it seems logical to look at the offshore wind sector since it is simply the industry that has most in common with the wave and tidal sector. However, based on the communication established with the key tool developers listed in ***Table 1***, none existing offshore logistics tool can be directly integrated into the suite of tools of DTOcean, mainly because of the open-source nature of the DTOcean project. Furthermore, the wave and tidal sector shows some specific logistics requirements which are different to those of the offshore wind sector. Nonetheless, existing offshore wind logistics software will be used as a source of inspiration to determine the methodology for developing a tool dedicated to arrays of MRE devices.

For the reasons mentioned above, a new lifecycle logistic tool will be developed within the frame of the DTOcean project. An effort will be made to facilitate the possibility, for the end-user of DTOcean's software, of using other existing (or in-house code) logistic tools in replacement of WP5 module on lifecycle logistics if preferred.

One objective of WP5 is to provide an updated database of suitable maritime infrastructure for the ocean energy arrays defined in the scenarios in Deliverable 1.1, including detailed specifications to match array logistic requirements. To fulfill this objective, it is advised to rely upon external data collections and upgrade them to cover the geographical regions of interest and include the latest information available with a satisfying level of details.

Several key institutions which have compiled a first set of databases, involved in the ORECCA and SI Ocean projects [23, 42] and IEA implementing agreement on Ocean Energy [43], are partners of the DTOcean project so they can share their spreadsheets of vessels and ports with DTOcean collaborators. Therefore, the databases for ports and vessels will be built upon previous work, ensuring no duplication of efforts. Furthermore, 4Coffshore [24] is a reference for the offshore wind industry. Ongoing discussions with 4COffshore may conclude on the purchase of a customized vessels database to serve as a solid basis for the lifecycle logistics tool. The most appropriate vessel classes (or categories) will be determined as the work in WP5 progresses so that the lifecycle tool will select a type of vessel rather than an individual vessel. The use of average values (with an associated standard deviation) for some very volatile parameters such as the vessel availability will also be preferred.

As for the ports database, the World Port Index was identified as one of the largest resources for port and harbors specification worldwide (which has served as input to ORECCA, SI Ocean and IEA-OES). Searching the internet for port information has also proven to be quite a simple and efficient way to populate a database.

Additionally, information sheets consisting of forms to be completed by external entities (shipbuilding companies, vessels' operators, administrative representative of ports, etc…) should be distributed among partners of the different regions to upgrade the database. In turn, the information sheets would be post processed by WP5 leader to update the information of the DTOcean database. In particular, early participation and strong commitment of partners is critical. This is especially true for those based in the regions that are excluded from existing databases, or only partially considered such as Western Europe (France, Ireland, Portugal and Spain). The lack of available data sets in these regions can be explained by the inexperience in the offshore wind industry compared to other European countries (Belgium, Denmark, Germany, the Netherlands and UK).

The DTOcean website [25] could also serve as a platform for online questionnaires. Following the format of the information sheet, multi-step online surveys would be constructed in the manner of a series of questions. In turn, the actors of the DTOcean project would be able to share the link with targeted contacts to widen and strengthen the data collection process. Finally, as soon as a well-proven database of ports and vessels will be available for DTOcean, a set of plugins may be developed to automatically update it with the relevant external source (e.g WorldPortIndex, 4COffshore, customized fact sheets, online questionnaires, etc…) on a regular basis. This can only be decided on a later stage of the project.

3. METHODOLOGY FOR THE LIFECYCLE LOGISTICS MODEL

This section explains the architecture of the lifecycle logistics model as initially proposed in this first deliverable. The scope of the model was determined so that the essential logistic phases of a commercial ocean energy project are included. A description of the range of application envisaged for the tool was provided in section 1 of this document. In summary, the tool should enable to identify the most suitable scenario for ports, vessels and installation equipment and potentially of other specific services to operate all the phases of an ocean energy project. This section presents how the model is structured including its interactions with other WPs.

The structure presented below results from a consultation round with key industrials at the forefront of the offshore renewable energy sector including: technology developers (both wave and tidal), project developers, utilities and marine contractors. All the persons interviewed during this consultation are potential end-users of the DTOcean tool. In general, the discussions were very constructive so that WP5 can build a logistic tool as useful as possible for the sector. The invaluable offshore experience gained by these industrials greatly helped in refining the scope of the lifecycle logistic tools and determine the critical lifecycle logistic issues encountered during an offshore renewable energy project. WavEC Offshore Renewables would like to gratefully acknowledge all the persons consulted.

A summary of the main conclusions of the consultation is the following:

- Positive feedback on the general approach of the methodology.
- Interest in the output and asked to be informed in the next steps
- Keep the first version of the module as simple as possible to test it and improve it as the tool matures
- Focus on the marine operations (vessels) rather than on the onshore operations.
- An accurate weather window calculator is critical.
- The availability of the vessels should be taken into account.
- Integration of a risk and uncertainty analysis is strongly advised.
- The flexibility to replace some of the module of the DTOcean global tool by in-house code is a very attractive feature.

3.1. GENERAL DESCRIPTION OF THE MODEL

The flow chart represented in ***Figure 7*** gives the schematic overview of the lifecycle logistics model. Each block corresponds to a module of the lifecycle logistics model that will be developed within the frame of WP5 of the DTOcean project.

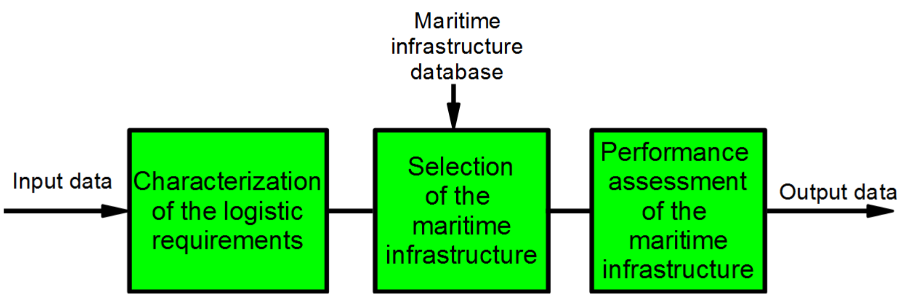

Figure 7. Overview top level flow chart of the lifecycle logistics model

The lifecycle logistics model is articulated in three modules incrementally assessing the feasibility and the performance of the logistical resources necessary to support the development of an array of MRE devices. The first step consists of defining the logistic requirements for all phases forming the industrial MRE project development. Then, the model will eliminate the combination of ports, vessels and installation equipment that do not match with the logistic requirements previously determined. Finally, the performance of the feasible logistical solutions is examined in terms of schedule, economics, risk & reliability and environment. The outputs will then a description of the chosen solution(s) with the associated schedule, costs risk and environmental data.

Assuming the maritime infrastructure database contains a wide variety of offshore logistical equipment, the selection of feasible combination of ports, vessels and installation equipment and personnel is justified to avoid assessing the performance of irrelevant logistic resources. The approach depicted in ***Figure 7*** allows a straightforward and efficient procedure to deal with some aspects of management of the offshore logistic issues in the context of an energy production project.

A more detailed flow chart showing the flow of data circulating between the three modules of the lifecycle logistic tool is given in ***Figure 8***. It specifies the type of inputs and outputs of the model and also introduces labeled boxes to split the modules into individual components.

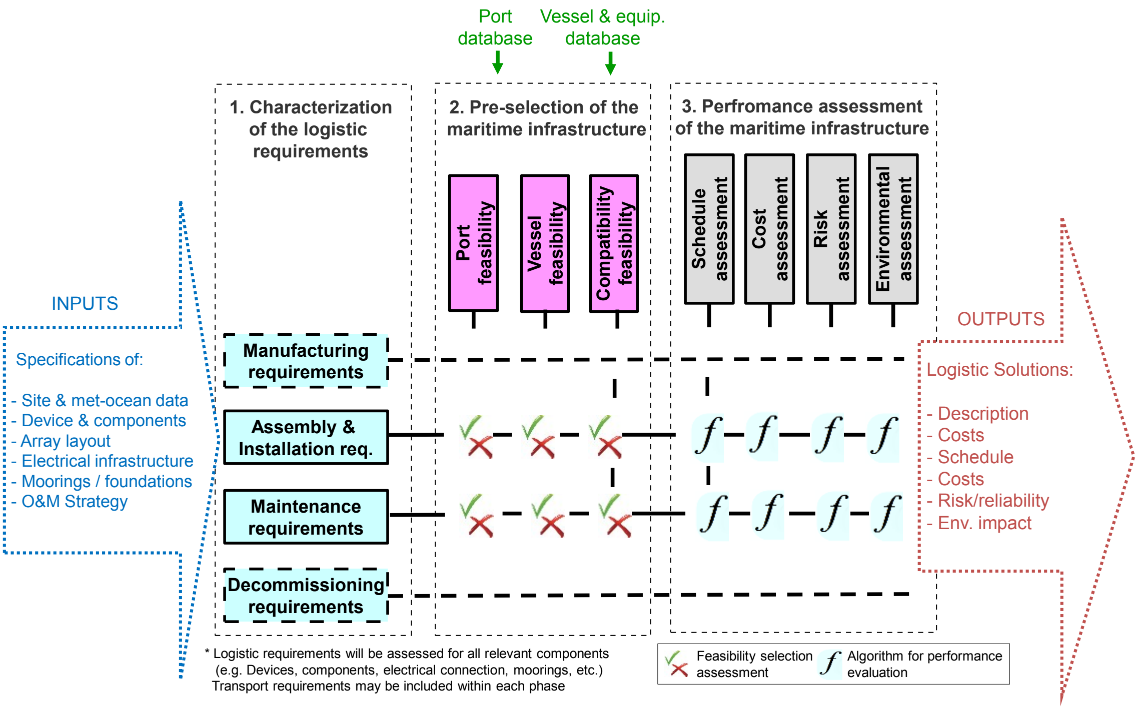

Figure 8. Detailed flow chart of the lifecycle logistics model

The flow of information circulating 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 certain logistic phases.

The module for the selection of maritime infrastructure contains images representing "a green check and red mark cross" that illustrate a feasibility selection assessment. Similarly, the module for the performance assessment of maritime infrastructure uses an "f symbol" where an algorithm for performance appraisal will be developed. It is important to mention that in the "vessel & equip. database and feasibility assessment" other non-vessel resources required in marine operations will be included, but have not been named for simplification (such as divers, ROV, specific equipment, helicopter, technicians, etc.).

The diagram presented in ***Figure 8*** was discussed with the potential end-users. One of the main conclusions from the interviews is to focus on vessel selection and schedule assessment for installation and O&M operations, and with particular interest the calculation of weather windows. Due to the strong interaction between installation and assembly (some devices are assembled on-site during the installation phase), both phases have been merged. Also, the initial diagram had a separate transport phase but, as transport may be required in between each phase[2], transport will be integrated in each phase. Finally, the logistics involved in the manufacturing facilities (and transport to the installation port) as well as the decommissioning stage were considered secondary, and will be considered using simplified models (this is why a dotted line is included in the figure).

3.2. INPUTS TO THE LOGISTIC MODEL

Initially, the logistic model requires a set of inputs to define the characteristics of the project that will affect the choice of the optimal logistic solutions. There exist two types of inputs:

- User scenario description,
- Global DTOcean database and relevant outputs from other WPs, and
- Database of maritime infrastructure and their performance capabilities as indicated in green in ***Figure 8***.

The input will derive either directly from the users, or from the outputs of the other modules of the DTOcean tool e.g. the electrical infrastructure or the moorings and foundations. Six categories of inputs have been identified as mentioned below along with their main WP provider:

- Site characteristics and metocean data (WP1): inputs describing the onsite location, bathymetry, the seabed and the metocean resource data (wave height, wave period, wind speed, current speed, etc…).
- Devices & components specifications (WP1): 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 (WP2): inputs defining the array layout configuration such as the number and location of the devices and the interspacing configuration.
- Electrical infrastructure specifications (WP3): inputs covering the relevant characteristics of the grid connection (e.g. the cable types and lengths, substation requirements, etc…)
- Moorings & foundations specifications (WP4): inputs covering the relevant specifications of the moorings and foundations (e.g. the dimensions and weights of its components, the spatial configuration, etc…)
- Maintenance & decommissioning requirements (WP6): 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, etc.).

[2] e.g. from the manufacturing facility to the assembly port, from the assembly port to the site for installation, and from the site to the O&M port for maintenance.

An Excel file containing the expected list of inputs for each category will be prepared to disseminate between the WP coordinators. For each input, the WP provider will be specified according to the DTOcean proposal.

The second type of input concerns the use of a database for maritime infrastructure required to meet the logistic requirements. As discussed in section 2, the logistics model will require a collection of information concerning the ports, vessels in Europe, but will also include generic information of other relevant resources (specialized workforce and equipment). For this reason, WP5 is responsible for assembling existing data sets and additional external contributions in order to compile a list of vessels/equipment and ports with their associated characteristics (task 5.3). The database of maritime infrastructure should be sufficiently large to cover the geographical regions of interest for DTOcean. It should also include the appropriate levels of detail to extract all useful information for the selection of the best maritime infrastructure within manageable levels for the implementation of a user-friendly tool.

3.3. MODULES OF THE LOGISTICS MODEL

In this section, the working principle of the three main modules introduced in section 3.1 is presented.

3.3.1. CHARACTERIZATION OF THE LOGISTIC REQUIREMENTS

In ***Figure 8***, one can identify 4 boxes corresponding to various phases of an MRE project which involve logistic support. Each box refers to the logistic requirements associated with the phase. A key objective of defining the logistic requirements consists of complying with the guidelines [26]–[31] and standards [32], [33] available for the offshore industry.

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
- 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.

ASSEMBLY, INSTALLATION AND O&M PHASES

As previously mentioned the results from the interviews from industry indicated that the key phases where such a tool should be most valuable are installation and O&M, so these phases will be the core of the tool and characterized in detail, while other phases will be included when necessary.

The installation requirements concern primarily the selection of the most appropriate set of vessels to perform the following operations:

- Trenching, laying and protecting the electrical cables,
- Installing the other electrical infrastructure equipment and, in particular, the substation where necessary,
- Positioning and pre-installing the moorings and foundations,
- Transferring and assembling all components of the devices from the port to the site,
- Installing, positioning and connecting the devices to the electrical infrastructure and the moorings and foundations hardware equipment.

The design specifications and constraints associated with the electrical infrastructure, the moorings and foundations and the devices with all its components, will guide the choice of the vessels capable of accomplishing these operations. Note that the original purpose of the final DTOcean tool is to support the design of an array of ocean energy devices. The use of such a tool is not to provide real time management software. For this reason, the lifecycle logistics model will opt for average values for the locations, the costs and the availability of the vessels instead of vessel live tracking system and quotes for individual vessels. The variation of vessel daily rates due to different seasons and other factors will be incorporated in the model in the best possible way within reasonable limits.

Whilst a suitable port for the O&M activities will have similar requirements as a port for the assembly and transportation of MRE devices, certain factors such as the distance to site, the availability of specialized personnel will become more influent. In the maintenance requirements, the description of the type of maintenance operations to be carried out will set the choice of the port(s) and vessel(s) eligible to execute the O&M activities [34].

MANUFACTURING

After the interviews with the industry, and due to the variety of projects and contracts, the tool will assume that the manufacture and provision of the goods will be assumed by the supplier. The scope of the tool will start at the installation/O&M port, and costs and delivery time of the components/devices will be direct inputs from the user or simplified compared to the installation and O&M phases.

However, since the manufacturing and assembly requirements are generally strongly linked, the lifecycle logistics model will attempt to consider some of the manufacturing requirements if necessary. For instance, depending on the location of the manufacturing of the main components and the assembly strategy, the selection of the best port(s)/shipyard(s) at the deployment phase (i. e. transportation and installation of the farm) may differ. Consequently, the port manufacturing capabilities, the storage capacity, lifting and maneuvering equipment will be included to cover both the manufacturing and the assembly requirements.

DECOMISSIONING

At the current stage of development of the wave and tidal energy sector, forecasting the requirements for the decommissioning stage of a MRE farms is a difficult task because:

- No fully commercial arrays of MRE devices have been decommissioned yet.
- In 20 years' time (or more), when the first commercial arrays of wave and tidal farms are expected to be decommissioned, the state-of-the-art of the infrastructure and policies could be significantly different.

In the offshore wind industry, the typical method to account for the decommissioning in a project feasibility assessment is simply to consider the costs of this phase as a percentage of the installation & assembly costs based on available numbers for related industries (oil & gas) and the type of moorings/foundations of the array (see [35], [36]). More sophisticated costing functions (see[37], [38]) may be implemented following the work that has been done in the offshore wind industry but it is suggested not to apply these functions at such an early stage of the MRE industry.

OTHER PROJECT PHASES

There are other phases that involve logistics in MRE projects, but that have been considered as not relevant 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. Thus, the surveying phase will not be implemented in the logistic model.

3.3.2. SELECTION OF THE MARITIME INFRASTRUCTURE

As soon as the requirements for the logistics are defined, one can identify the resources that meet these requirements among a list of available ports and vessels. This is the purpose of the second module entitled "Selection of the maritime infrastructure".

The logic behind the selection of maritime infrastructure consists of discarding the ports, vessels and equipment that do not satisfy the logistic requirements determined upstream, i.e. during the previous module entitled "Characterization of the logistic requirements". The selection of the maritime infrastructure straightforwardly looks for the ports and vessels available in the database that matches the logistic requirements. As a result, only the suitable ports and vessels are considered for further analysis. It is assumed that the "selection of the maritime infrastructure" will result in different possible sets of ports and vessels.

In addition to individual feasibility assessment for ports and vessels, a compatibility check to ensure the feasibility of the combination of port and vessels selected should be performed. This step would prevent situations where, for example, vessels do not fit in the selected port or the distance between the average location of the vessels and the place of the port are not acceptable.

From a project manager perspective, there might be additional requirements to ensure that only effective and competent ports and vessels are considered during the deployment phase from manufacturing until complete installation. For instance, it could be an end-user defined constraint that only one single port must be used for manufacturing, assembly, installation and O&M (or a combination of them).

3.3.3. PERFORMANCE ASSESSMENT OF THE MARITIME INFRASTRUCTURE

The decision making process of what set of maritime infrastructure is the most efficient for an array of wave and tidal energy devices are based upon four criteria:

- Schedule: the total duration of each operation will be calculated from the net duration of the operation and, if applicable, the downtime due to external factors such as the availability of weather windows, delivery times for supplying a replacement, skilled personnel, etc.
- CapEx and OpEx: the costs associated with the lifecycle logistics,
- Risk level: risk assessment of the different operations,
- Environmental impact: impact on the environment of the different operations.

For each type operation different one or more logistic solutions will be obtained (depending on the overall DTOcean optimization process to be discussed within the project partners). Results for schedule, costs, risk and environmental impact will be attached to each logistic solution. The tool may allow the user to constrain different logistic solutions (e.g. use the same port/vessel for several operations, start one operation only after another has ended, etc.).

First, a schedule assessment is performed to calculate the estimated time required for the completion of all the logistic operations. Providing the selected feasible combination of vessels and ports, the site characteristics and the metocean data, the schedule assessment determines the weather windows, the transit times and the duration of the operation. In the end, one can extract estimates of the overall durations for the various phases of the lifecycle logistics. The commissioning schedule and the availability of the farm over the entire lifetime of the project are therefore constructed.

Secondly, a cost assessment algorithm sums up all the cost estimates associated with the logistic operations. For instance, the daily rates of the vessels will multiply the total duration, calculated from the net duration plus the downtime due to weather conditions.

Thirdly, the risk assessment attempts to value the risk of encountering an issue during the preparation or the completion of a logistic operation. Depending on factors, such as the availability of the vessel and supply or the difficulty to have long-term weather forecast, the implications of having to delay, abort or modify a marine operation should be reflected through a risk analysis. Monte Carlo simulation has been identified over the course of the preparation of this report as a powerful method to deal with risk assessment, and will be considered for this purpose.

Lastly, an environmental impact assessment provides a qualitative measure of the influence of the choice of the logistic resources on the environment. It is planned to implement a scaling system to facilitate the identification of the most favorable options.

3.4. OUTPUTS OF THE LOGISTICS MODEL

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 and for WP7, the results of the model may be divided in six categories:

1. Logistical solutions: a description of the set of ports, vessels and equipment that have been selected.
2. Schedule: an expected schedule of the logistical activities with their estimated durations. The impact on energy production due to the downtime in the maintenance activities or delays on the installation procedure will be probably assessed in WP6, as it is required to have information on the operation of the array during that period (info which is not required for the rest of WP5 tasks).
3. CapEx and OpEx contributions: all the costs estimations are gathered and tagged with "capital expenditures" or "operational expenditures"[3].
4. Energy production impact: the 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.
5. Risk & reliability outcome: a summary of the information corresponding to the issues related to the reliability/risk during the installation and O&M procedures could be valuable. Risk could be reflected in the form of ranges of uncertainty for the key outputs but is yet to be decided. The reliability outcome would contain the summary of the consequences of the maintenance activities on the logistic performance.
6. Environmental impact: outputs relative to the environmental impact should be included as in other WPs.

The LCoE was chosen as the objective value to optimize for the DTOcean tool. As a result, the selected feasible combinations of ports, vessels and installation equipment should be compared in order to find the set of logistical solutions minimizing the LCoE. However, it is not possible to decide which the optimal solution for the array is if other modules interact with the decisions taken. The final optimization process will be defined in agreement with the rest of the consortium and should be guided by WP7.

[3] The economic assessments that are performed under other WPs are excluded here. Only the costs associated with the logistics activities are compiled (the other costs will be assessed within each module in order for each WP to be able to work stand-alone during the development of their tool).

4. SUMMARY

This report presents the methodology for the lifecycle logistics assessment of ocean energy arrays and its range of application as proposed for the DTOcean project. A summary of the state-of-the art of the offshore logistic tools relevant to the wave and tidal energy sector is initially depicted. In addition, the availability of information with regards to the maritime infrastructure is examined.

The proposed model relies on inputs that can be either defined by the user or provided by upstream WPs outputs. Furthermore, inputs relative to the maritime infrastructure and the components to the model can be obtained in a database that will be constructed from data for similar industries. Ultimately, the model is to feed WP7 with the lifecycle logistical algorithms evaluated through a suite of appropriate functions reflecting all the important phases of an ocean energy array project. More detail on the different components of the model will be determined during the coming months of the project and provided in the future deliverables to be produced.

As the work under WP5 progresses, the development of the lifecycle logistic model and the construction of the database of maritime infrastructure will rely upon the work reported in this document.

A wide variety of project partners and external companies (end-users) have been consulted to define the methodology for a lifecycle logistics model. These interactions have allowed the identification of the areas of interest for the targeted end-users of the DTOcean tool.

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APPENDIXES

APPENDIX A. REVIEW OF LOGISTIC TOOLS

This appendix reviews the list of the selected offshore logistic numerical tools relevant to MRE sector. First, a brief description of every logistic tool encountered is provided. Any useful image illustrating the methodology or the capabilities of the tools found in the literature is pasted in this appendix.

The first two rows in table 1 refer to a common logistic tool developed in cooperation with the Institute of Shipping Economics and Logistics (ISL) and Fraunhofer Institute for Factory Operation and Automation (IFF) that have customized in-house solutions to use in conjunction with their main common tool. Their model is designed for the offshore wind sector. It encompasses both the onshore and the offshore logistics issues. In particular, the transport network includes not only the sea transportation but also the road, rail, inland waterway. ***Figure 9*** shows a schematic overview of the model.

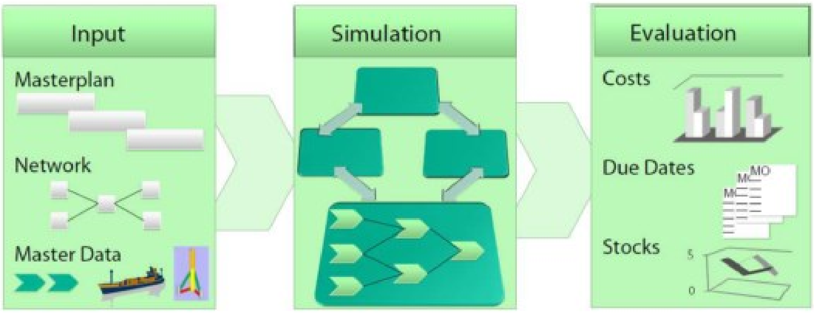

Figure 9. Overview of the offshore logistic tool common to the ISL and Fraunhofer (source: [2])

The second tool of the list is called MERMAid and is being developed by MojoMaritime Ltd. It is the only tool identified that is not specific to the offshore wind sector but rather designed for a wide range of complex marine operations with a strong will to suit the marine renewable energy sector. The tool operates on a task progress basis considering not only the available weather window, but also the severity of the met-ocean conditions and their impact on the working efficiency of a vessel and its crew. In parallel to scheduling the marine operations, MERMAid estimates the costs of the marine operation through the vessel day rate (operating and stand-by) as well as the accommodation and port fees As shown in ***Figure 10*** and ***Figure 11***, the preliminary results obtain from the software are related to the installation of an array tidal energy devices. A module to deal with the maintenance activities is planned for the near future.

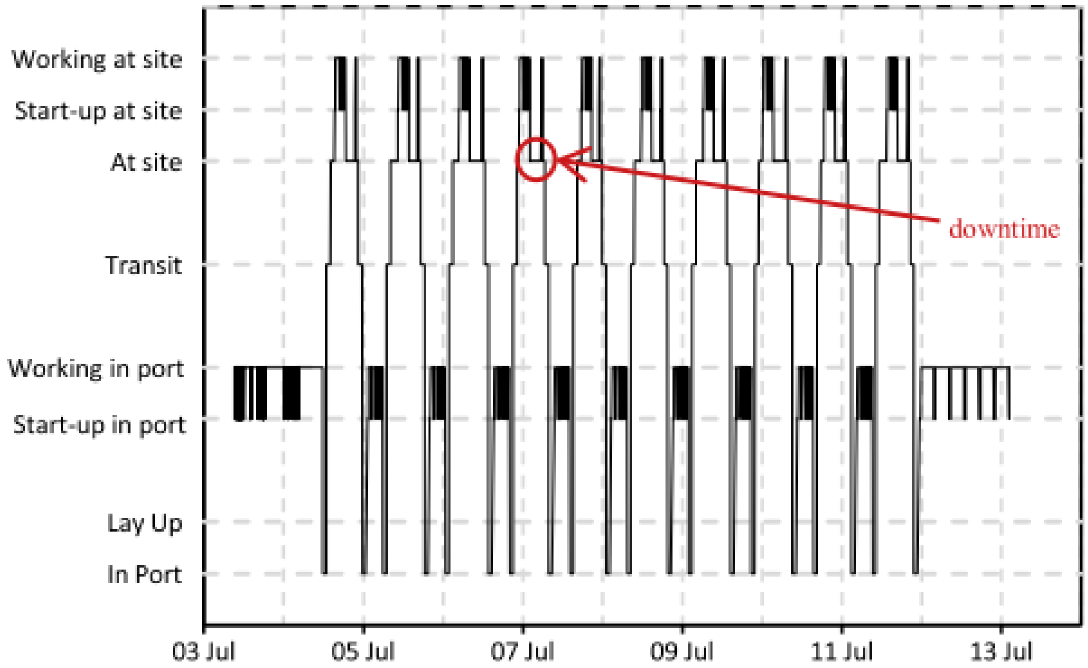

Figure 10. Example of a vessel turbine installation states with MERMAId (source: [10]*)*

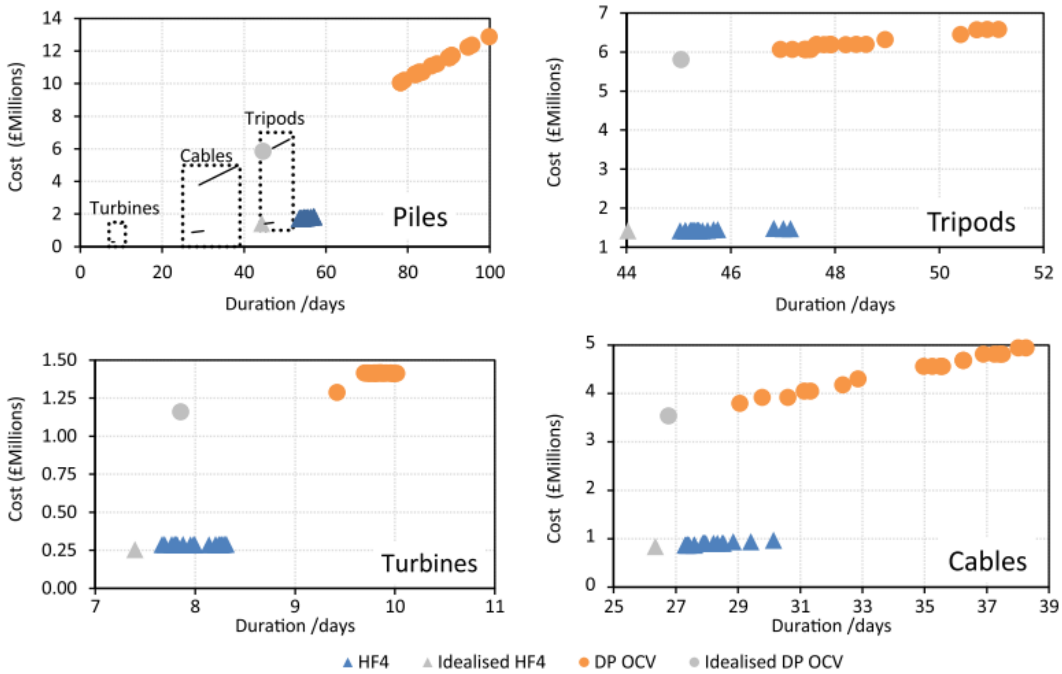

Figure 11. Example of cost variation against the phase length for different type of vessels with MERMAId (source: [10]*)*

Energy research Centre of the Netherlands (ECN) is one of the leading consultancy service providers for the O&M optimization of offshore wind farms. Their software, with over 15 years of development, can not only be used at a planning stage using long term yearly average but also to make estimates for relative short period of time (1, 2 to 5 years) based on a time domain approach. In the end, the tool allows the simulation of a wide range of maintenance activities (calendar based / predetermined, condition based and unplanned corrective) with a high level of details. ***Figure 12*** gives the schematic overview of the OMCE concept developed by ECN and ***Figure 13*** exemplifies the results delivered by the statistical analysis on logistic data.

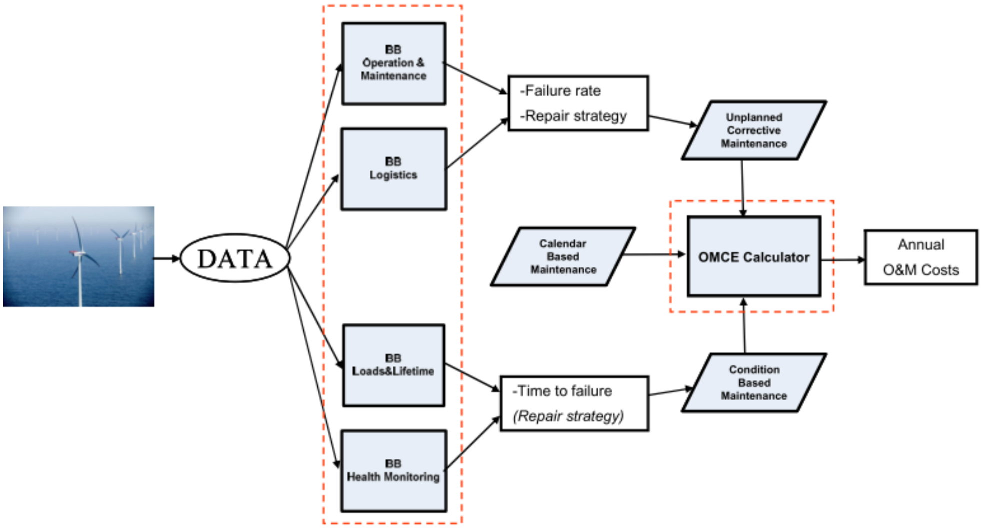

Figure 12. Schematic overview of the OMCE concept developed by the ECN (source: [13]*)*

Reporting period from .... to ....

Turbine ID	#		Total downtime							
Total number of alarms reported	1000	[-]	10000	[hr]						
Number of relevant events	**650**	**[-]**	**11000**	**[hr]**						
							Dowtime per event			
1. Resets (auto or remote)	**500**	**[-]**	**1500**	**[hr]**			**Min**	**Average**	**Max**	
1.1 Errors	280	[-]	1000	[hr]			0,1	3,6	25,7	[hr]
1.2 Control, ambient	220	[-]	500	[hr]			0,1	2,3	5,3	[hr]
	#		**Total downtime**		**# of visits**		**Dowtime per event**			
2. Visit required	**150**	**[-]**	**9500**	**[hr]**	**264**	**[-]**	**Min**	**Average**	**Max**	
2.1 Preventive	40	[-]	250	[hr]	40	[-]	5	6	8	[hr]
2.2 Planned corrective cond. based)	40	[-]	250	[hr]	40	[-]	5	6	8	[hr]
2.3 Paint	4	[-]	140	[hr]	8	[-]	20	35	60	[hr]
2.4 Corrective small	50	[-]	2000	[hr]	100	[-]	20	40	80	[hr]
2.5 Corrective crane ship	16	[-]	6860	[hr]	76	[-]	200	429	1000	[hr]

Figure 13. Example of format to report results of statistical analysis of logistic data with the ECN's O&M tool (source: [13]*)*

NREL has been investigated the path towards reduction of the cost of installation and O&M for offshore wind farms in the USA. For this purpose, the O&M tool developed by ECN was used along with a customized version of the Balance Of Station (BOS) tool to deal with the installation phase. The NREL BOS models the CAPEX during the installation phase providing typical values, expected ranges, and assumptions made based on today's technology and best practices. ***Figure 14*** describes some of the assembly and installation strategies that can be compared with the NREL tool. Moreover, ***Figure 15*** depicts a tornado diagram informing on the main results of the case study on the different installation strategies.

<table>
<tr><th>WT Install Method</th><th>Total Lifts</th><th>Lower Tower</th><th>Upper Tower</th><th>Nacelle</th><th>Hub</th><th>Blade 1</th><th>Blade 2</th><th>Blade 3</th></tr>
<tr><td>Individual components</td><td>7</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td>Bunny ears with 2-part tower</td><td>4</td><td>1</td><td>2</td><td colspan="4">3</td><td>4</td></tr>
<tr><td>Bunny ears with 1-part tower</td><td>3</td><td colspan="2">1</td><td colspan="4">2</td><td>3</td></tr>
<tr><td>Pre-assembled rotor with 2-part tower</td><td>4</td><td>1</td><td>2</td><td>3</td><td colspan="4">4</td></tr>
<tr><td>Pre-assembled rotor with 1-part tower</td><td>3</td><td colspan="2">1</td><td>2</td><td colspan="4">3</td></tr>
<tr><td>Fully pre- assembled</td><td>1</td><td colspan="7">1</td></tr>
</table>

Figure 14. Example of offshore wind installation strategies investigated with the NREL tool (source: [39]*)*

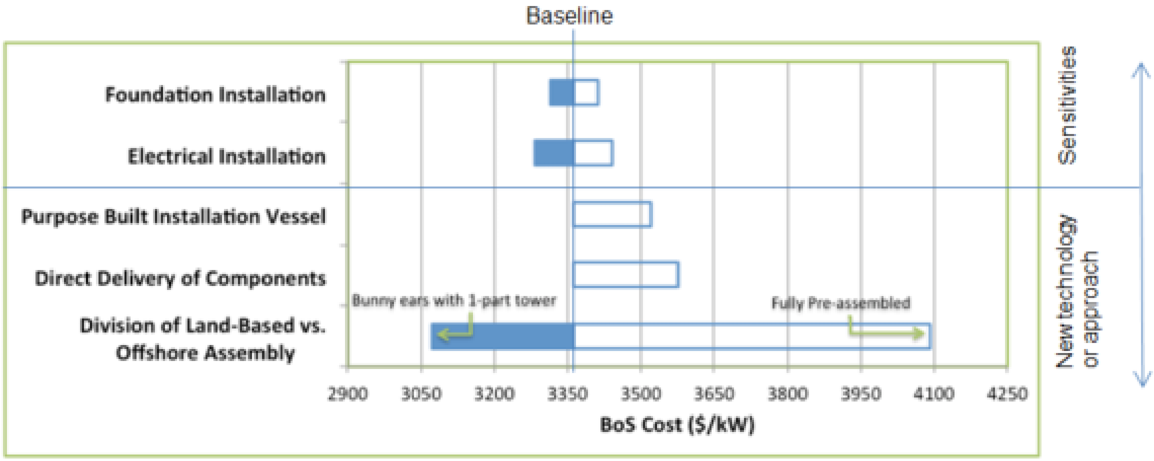

Figure 15. Tornado graph results of the offshore wind installation strategies investigated with the NREL tool (source: [39]*)*

In the early days of the wind industry, the EDF Group started to develop the ECUME tool drawing on the ECN O&M cost model. ECUME evaluates the operation total mean cost of an offshore wind farm project. This total cost is made of deterministic and probabilistic cash flows. 2 key improvements have been brought to the ECUME tool to better suit the offshore wind industry: a hidden Markov Chain model was designed to model the meteorological parameters and an event based Monte-Carlo simulation was implemented to model the failures and maintenance actions. ***Figure 16*** shows a simple flow chart of the improved ECUME tool.

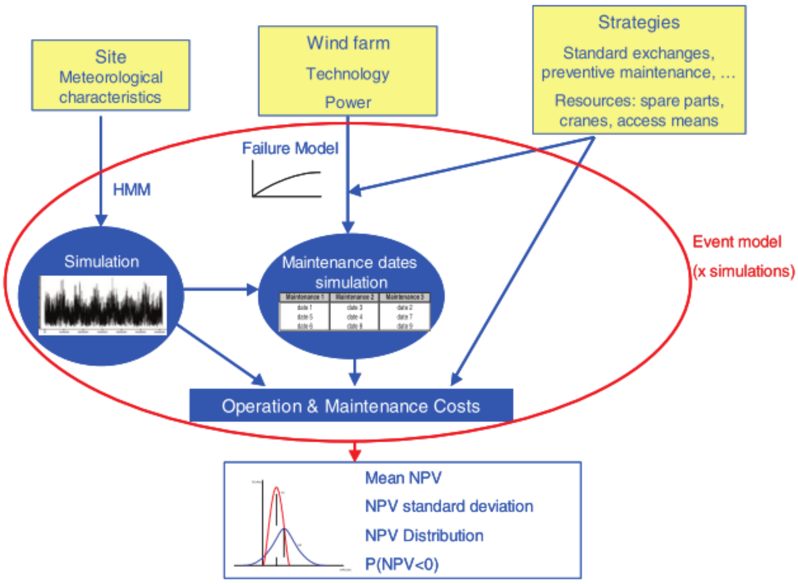

Figure 16. Schematic overview of the improved ECUME tool developed by the EDF Group (source: [14]*)*

The OutSmart tool consists of two parts: the EBITDA calculator and the strategy simulator. The EBITDA calculator has a large variety of costs structures build in that can be adjusted for some location. EBITDA estimates the cost of a given logistic scenario. Then the strategy simulator processes the data belonging to the logistic scenario, delivering production loss and wind turbine stop hours. The strategy simulator makes uses of the historical weather data of the specific site. OutSmart suite of tools are primarily designed for the operational phase but can also be used at a preliminary design stage.

The next tool, named NOWIcob, is being developed by SINTEF NOWiTech. The model is based on a time-sequential event-based Monte Carlo technique. NOWIcob can simulate time-based / predetermined, condition-based and corrective maintenance tasks with different vessel concepts. It delivers results in form of availability, life cycle profit, operation and maintenance cost, produced electricity and other performance criteria [15]. ***Figure 17*** shows a simplified diagram of the NOWIcob and ***Figure 18*** shows 2 results for a case study of an offshore wind farm including an O&M mothership strategy.

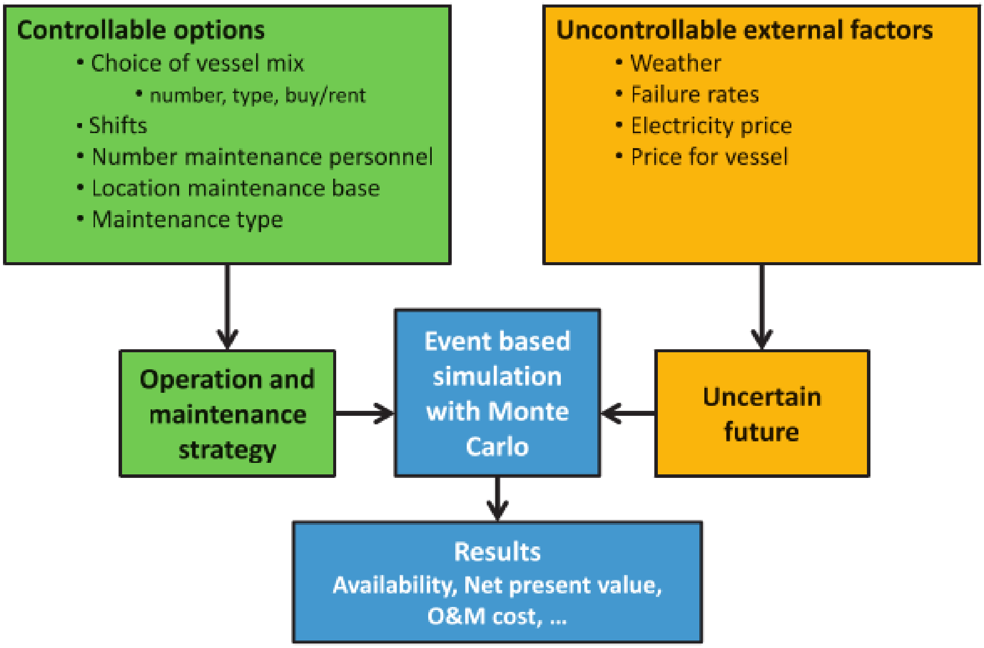

Figure 17. Schematic overview of the NOWIcob tool developed by SINTEF (source: [15]*)*

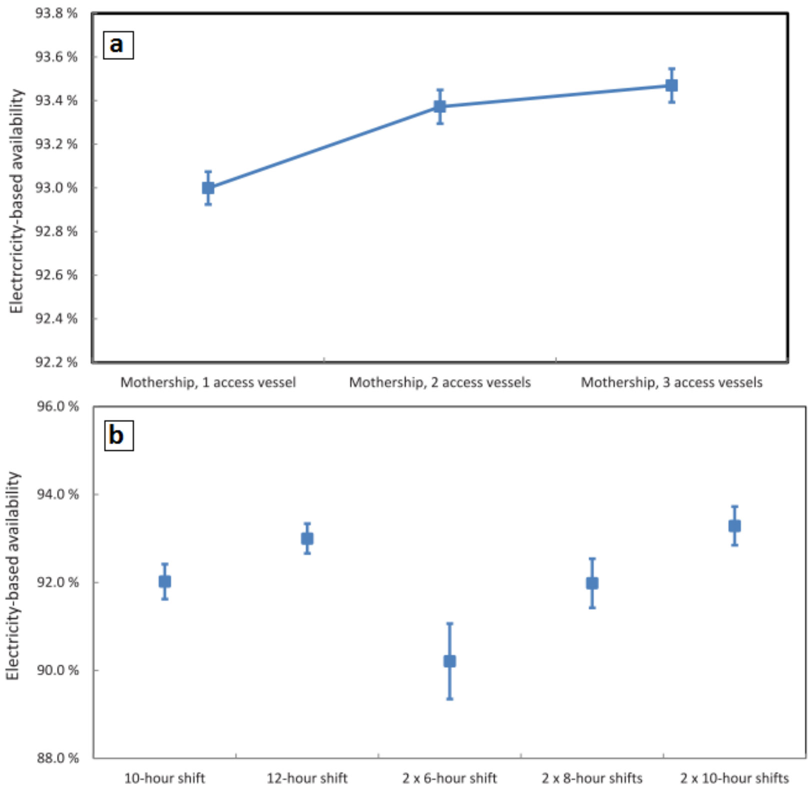

Figure 18. Example of results on availability for an O&M mothership wind farm scenario with the NOWIcob tool developed by SINTEF (source: [15]*)*

Another O&M tool for the offshore wind sector is under development at the University of Strathclyde. It implements Bayesian Belief Networks (BBN) and decision trees at various stages throughout the project life time in order to model high-dimensional probability distributions reflecting the significant uncertainty of some parameters. ***Figure 19*** presents a diagram of the BBN approach and ***Figure 20*** shows the probability of reaching a certain lost in revenues under different O&M strategies.

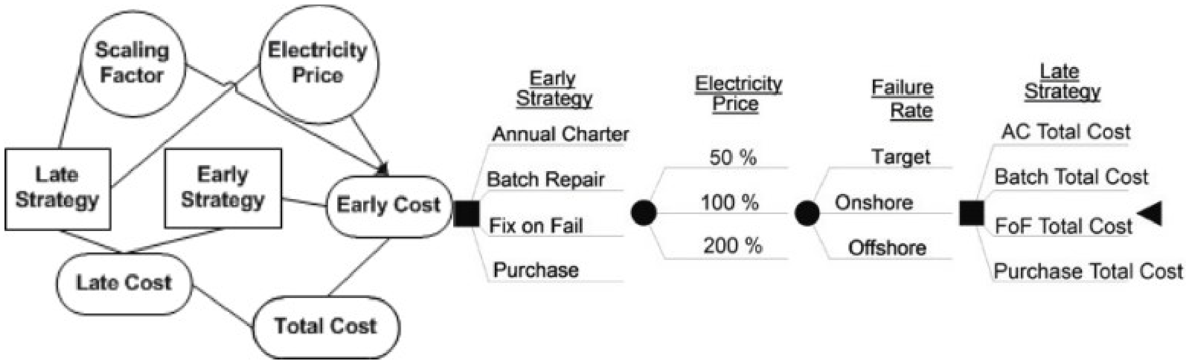

Figure 19. Diagram of the BBN approach O&M tool developed by the University of Strathclyde (source: [21])

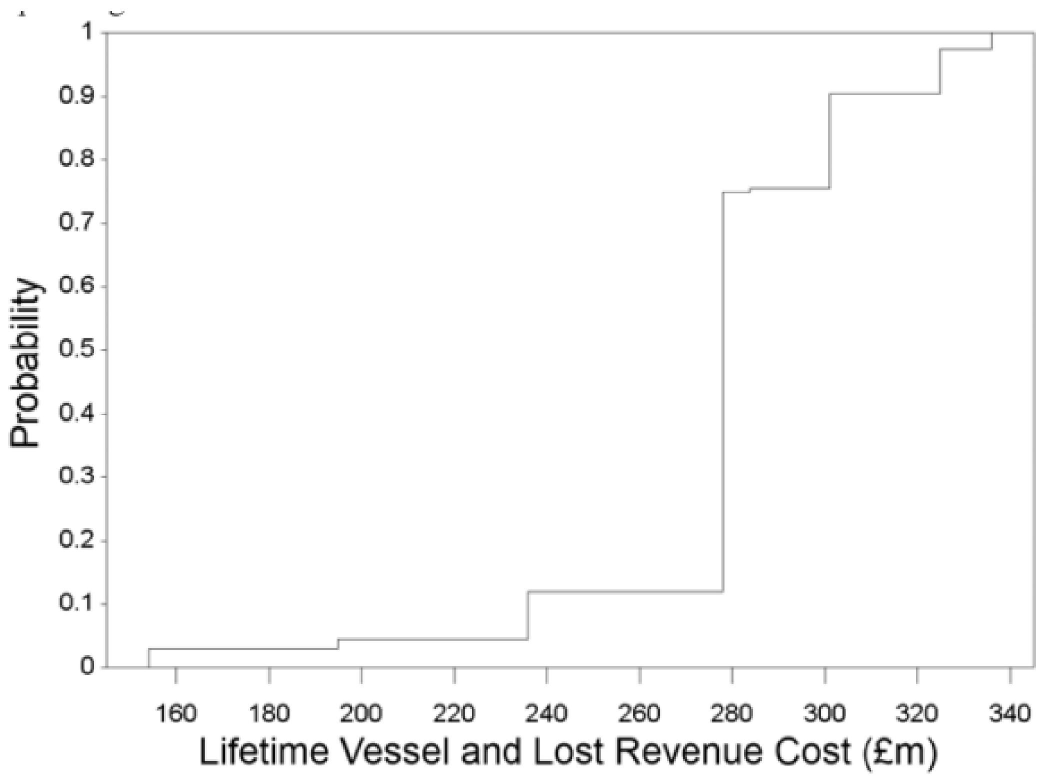

Figure 20. Probability of reaching a certain lost in revenues (source: [21])

Similarly, the University of Stuggart is working on an O&M tool describing the significant wave height by means of discrete Markov chains. The tool has the capability to evaluate the influence of the maintenance fleet on the O&M strategy performance. In ***Figure 21***, the flow chart of the model is depicted. Some results generated by the tool are given in ***Figure 21*** summarizing its capabilities.

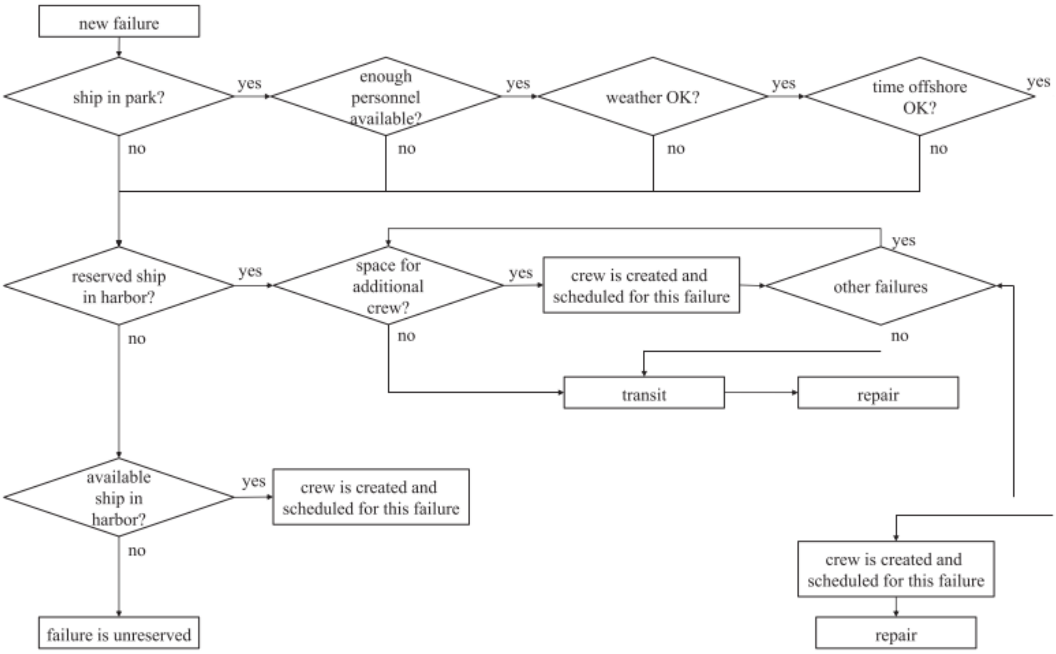

Figure 21. Flow chart with the O&M tool developed by the University of Strathclyde (source: [22])

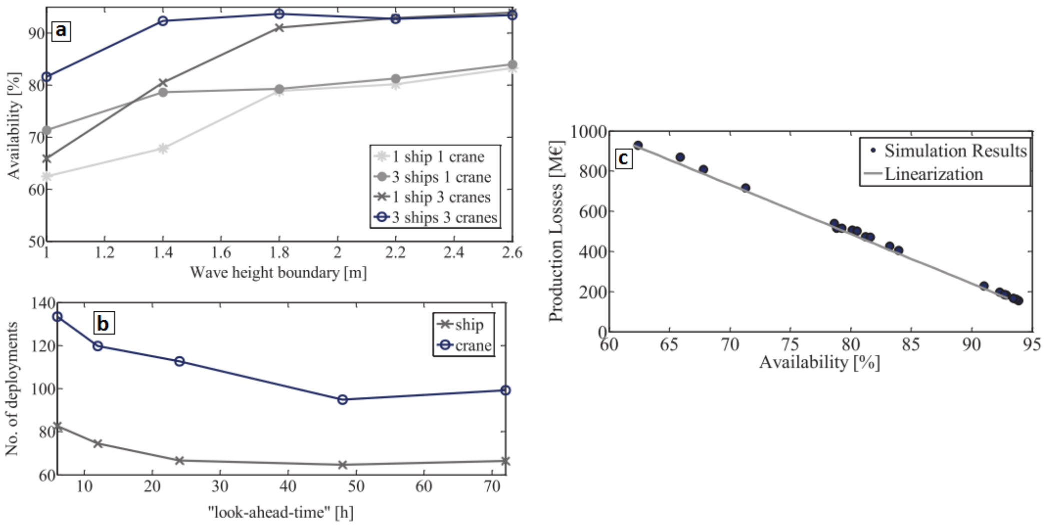

Figure 22. Summary of the capabilities of the O&M tool (source: [22])

Finally, the last tool included in table 1 consists of an Analytical Hierarchy Process implemented in Excel with the use of VBA macros. The tool is able to provide a list of feasible ports and vessels based on criteria such as technical abilities and experience with offshore wind installations. This tool was successfully applied in the context of a case study for a floating offshore wind scenario. However, the results are confidential and hence, cannot be shown in this report.

For comparison purposes, a scoring system was implemented to discriminate between the tools in terms of:

a. Characterization of the resource (climate and maritime infrastructure)
b. Characterization of the logistic operations
c. Scheduling assessment
d. Costing assessment
e. Risk & uncertainty assessment
f. Environmental impact assessment

The scoring system based comparison reported herein derives from the work of Bonini [40]. The scoring system relies on a scale including 5 different levels. Although the attribution of one level remains a subjective process, the following degree of evaluation have been considered for the 6 categories previously enunciated:

1. Nonexistent or very poor description of the overall characteristics
2. Limited description of the main characteristics
3. Simplified description reflecting the main characteristics
4. Elaborated description reflecting the main characteristics as well as some of the secondary ones
5. Comprehensive description reflecting the current state-of-the-art

In addition, when there is a lack of detailed information for describing the modelling of some aspects of a tool, the corresponding area of evaluation of the tool is penalized. Individual fact sheets were completed for every tool so that they can be identified and compared with more convenience. Table 3 compiles fact sheets and the results of the analysis of the tools. A link to the main source of information can be found in the last column.

Arguably the most striking finding of the analysis in Table 3 is the complete absence of consideration towards the environmental impact assessment among the selected offshore logistic tools. This omission may be explained by the difficulty to access data on the environmental footprint of the maritime infrastructure. Figure 23 shows the cumulative results of the tools to the scoring system.
In general, tools making use of historical time series or sophisticated probabilistic approach for the description of the climate resource were favored over more simplified statistical description. Higher scores for the resource characterization were attributed to the tools including other considerations such as the port and vessel characteristics, the personnel and equipment. Similarly, the best scores for the logistic operation characterization were given to the tools detailing the requirements associated with complex marine operations, mixing different type of work.

The score associated with the scheduling assessment was mainly based on the method chosen for the weather windows calculation with particular emphasis on the choices made for the operational working conditions and limiting factors. Despite very little information with regard to the methodology for the costing assessment, the nature of the economic indicators generated has guided the scoring discrimination. Different techniques are implemented in the tools to account for risk and uncertainty. The Monte Carlo method and other well-known probabilistic approaches have been awarded the best scores.

Table 3. Analysis of relevant existing tools for supporting offshore logistics management.

Number	Tool developer	Name of the tool	Short description of the tool	Software	Price	Characterization of the resource	Characterization of the logistic operations	Schedule assessment	Costing assessment	Risk & reliability assessment	Environmental impact assessment	Source of information
1	Institute of Shipping economics and Logistics	N/A	Offshore wind installation vessels based on SIEMENS PLM software (Plant Simulation from Tecnatromix)+in-house logistic tools for the shipping industry	MS Project, Excel + @RISK + VBA, MatLab	Quote on request	4	4	4	4	3	0	[2], [41]
2	Fraunhofer IFF	N/A	Several tools to support logistic for the wind farm industry (onshore and offshore) collaborate with ISL	MS Project, Excel + @RISK + VBA, MatLab	Quote on request	4	4	4	2	3	0	[2], [11]
3	Mojo Maritime Ltd.	Marine Economic Risk Management aid (MERMaid)	MERMaid is a software to consider the impact of scheduling and met-ocean conditions on complex marine operations	N/A	Quote on request	4	5	3	3	3	0	[10], [42]
4	Energy Centre of the Netherlands	Operation and Maintenance Cost Estimator (OMCE)	Offshore wind O&M optimisation software. It determines the cost effectiveness of maintenance and the availability and energy production of an offshore wind farm in every possible scenario	N/A	Quote on request	5	4	4	3	3	0	[12], [13], [43], [44]
5	National Renewable Energy Laboratory	Balance Of Station (BOS)	Combination of a customized NREL offshore cost model BOS and the ECN O&M tool to optimize installation and O&M strategies for offshore wind	NREL BOS + OMCE (ECN) + others	Currently not available	4	5	3	4	4	0	[39]
6	EDF Group	ECUME	ECUME evaluates the total mean cost of operation of an offshore wind farm project. It models the failure risk, the evolution of meteorological and marine parameters. It also evaluates inaccessibility risk.	N/A	Quote on request	4	3	2	4	5	0	[14]
7	OutSmart & TUV NORD	N/A	OutSmart is an offshore wind O&M strategy simulator. Based on the logistic scenario and historical weather data, the tool delivers the downtime.	Summary output in Excel	Quote on request	4	3	4	4	1	0	[45]

8	SINTEF NOWiTech	Norwegian Offshore Wind benefit and cost model (NOWIcob)	Life-cycle cost and O&M optimisation tool for offshore wind farms. The model takes into consideration weather uncertainty and other relevant aspects for the operational phase of an offshore wind farm.	MatLab	Quote on request	4	3	2	3	4	0	[15]
9	University of Strathclyde	N/A	Offshore wind O&M optimisation tool that simulates operating costs and lost revenue, based on wind farm specification, climate and operating strategy.	MatLab	Research code	2	3	2	4	4	0	[16], [46]
10	University of Stuttgart	N/A	It simulates the operating phase of a wind farm with special emphasis toward the modeling of failures and repair.	MatLab	Research code	4	3	2	3	3	0	[17]
11	WavEC Offshore Renewables	N/A	Optimization of floating offshore wind turbine installation. The tool implements an Analytical Hierarchy Process method	Excel+VBA	Internal use only	2	4	2	2	2	0	[9]

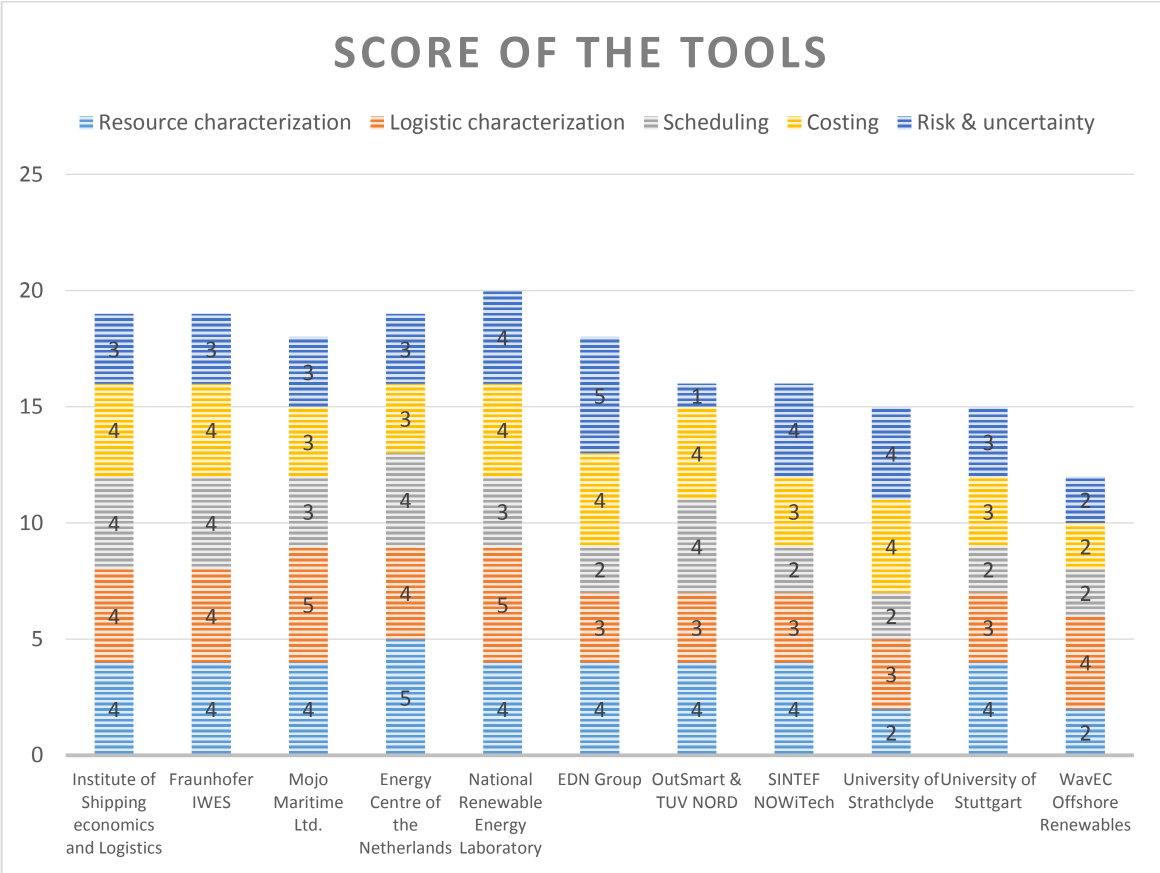

Figure 23. Cumulative bar plot of the results of the scoring systems for the review of the offshore logistic tools

APPENDIX B. REVIEW OF LOGISTIC PORT AND VESSEL DATABASES

To assess the level of details of the description of the maritime infrastructure characteristics, a scale has also been used. Below, the signification of each degree of the scale is given:

1. Only general information,

2. Include the main technical specifications or only some non-technical information,

3. Detailed technical description or detailed non-technical information,

4. Full technical specifications and some additional information such as experience, working conditions, access, availability and/or costs, and

5. Comprehensive listing of all characteristics.

In comparison with table 1, the databases corresponding to ports and vessels have been separately tabulated.

Table 3. List of existing databases of vessels potentially suitable for the MRE sector.

№	**Database provider**	**Database description**	**Format**	**Number of entries**	**Geographic coverage**	**Price**	**Level of details from 1 to 5**	**Source of information**
1	4COffshore	Offshore wind installation and construction vessels	Spreadsheet	370	EU	725 €	4	[24]
2	4COffshore	Offshore service vessels	Spreadsheet	390	EU	1.199 €	4	[24]
3	ORECCA	Offshore wind installation&servicing vessels	Spreadsheet	100	EU	Free on request	3	[23]
4	InField	Oil&Gas Specialist vessels	Spreadsheet	2400	World	2200 £	4	[47]
5	Eagle	Record of vessel with the ABS classification	Online search engine		World	Free	1	[48]
6	VTExplorer	Vessel tracking system using AIS data	Software	55000	South EU	480 €/year	3	[49]
7	FleetMom	Vessel database and tracking with AIS data	Online search engine	375000	World	Free up to 699 €/month	from 2 up to 4	[50]
8	Clarkson Research	Database of vessels and associated market study reports.	Report, spreadsheet and others		Mainly EU	Strict commercial use: variable fees	Up to 4	[51]

Table 4. List of existing databases of ports potentially suitable for the MRE sector.

№	Database provider	Database description	Format	Number of entries	Geographic coverage	Price	Level of details from 1 to 5	Source of information
1	4COffshore	Ports involved in offshore wind construction	Spreadsheet	46	EU	Free	4	[24]
2	ORECCA	Ports database	Spreadsheet	150	NorthSea	Free on request	3	[23]
3	SI Ocean	Ports database	GIS map	150	NorthSea	Free on request	3	[52]
4	IEA-OES	Ports database	GIS map	150	NorthSea	Free on request	3	[53]
5	WorldPortIndex	Ports and harbors database	PDF and software	3700	World	Free	4	[54]
6	WorldPortSource	World map of ports	Online search engine	4800	World	Free	1	[55]
7	FleetMom	Ports database	Online search engine	4350	World	Free up to 59 €/month	from 2 up to 4	[56]