Deliverable 5.5: Logistic model for ocean energy arrays

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Abstract

This report presents the Deliverable 5.5 (D5.5) of the DTOcean project – Logistic model for ocean energy arrays. D5.5 provides an introduction to the architecture of the installation module within the DTOcean global tool.

After contextualizing the role of the installation module within the global tool, the core sub-array components leading to the design of the most LCOE attractive installation plan in response to a given array of ocean energy converters are described.

D5.5 specifies the inputs required to run the installation module. Thus, the functions allowing the assessment of the least expensive logistic solutions for the installation phase are presented. Finally, all outputs generated by the installation module are listed.

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1 INTRODUCTION

Deliverable 5.5 – Logistic model for ocean energy arrays – consists of a computational module allowing the design of the most LCOE attractive installation plan in response to the design of all sub-array components (e.g. devices, moorings & foundations and electrical sub-systems). Along with a Python package, this report is delivered and serves as an introduction to the architecture and requirements associated with the installation DTOcean module (corresponding to the so-called "logistic model for ocean energy arrays").

In addition to setting the scope of the logistic model developed within the frame of the global DTOcean design tool, this report aims to describe the functional requirements of the different sub-modules forming the installation module. The flow of inputs-outputs circulating through the different steps of the algorithm are introduced. Key features specific to the installation module are highlighted while the core logistic functions are only briefly explained with reference to Deliverable 5.6 [1] for a reader interested in the details of the algorithms.

2 DTOCEAN GLOBAL TOOL

In order to situate the installation module within the global DTOcean tool, let us first present the architecture of the overall software package. DTOcean's core outcome is a suite of shared-access design tools developed in the Python programming language. One module (or design tool) should be a standalone application suited to continuous edition.

The global tool embraces a modular architecture in which coupling with other software may be done given the specifications of the replaced module are respected. Additional data or information should be readily absorbed by a module to grant significant flexibility for the end-user. The first official release of the DTOcean final software shall also feature a Graphical User Interface (GUI).

Figure 2-1 depicts the modular architecture of the global DTOcean tool. Five computational modules (on top) communicate through the core global design tool (blue box in the centre). Input-Output (I/O) connections are handled in the core through external functions. The global database (bottom) is also linked to the core. The left side of Figure 2-1 designates the end-user inputs and selections required to run the tool. Results are shown at the right side of the figure.

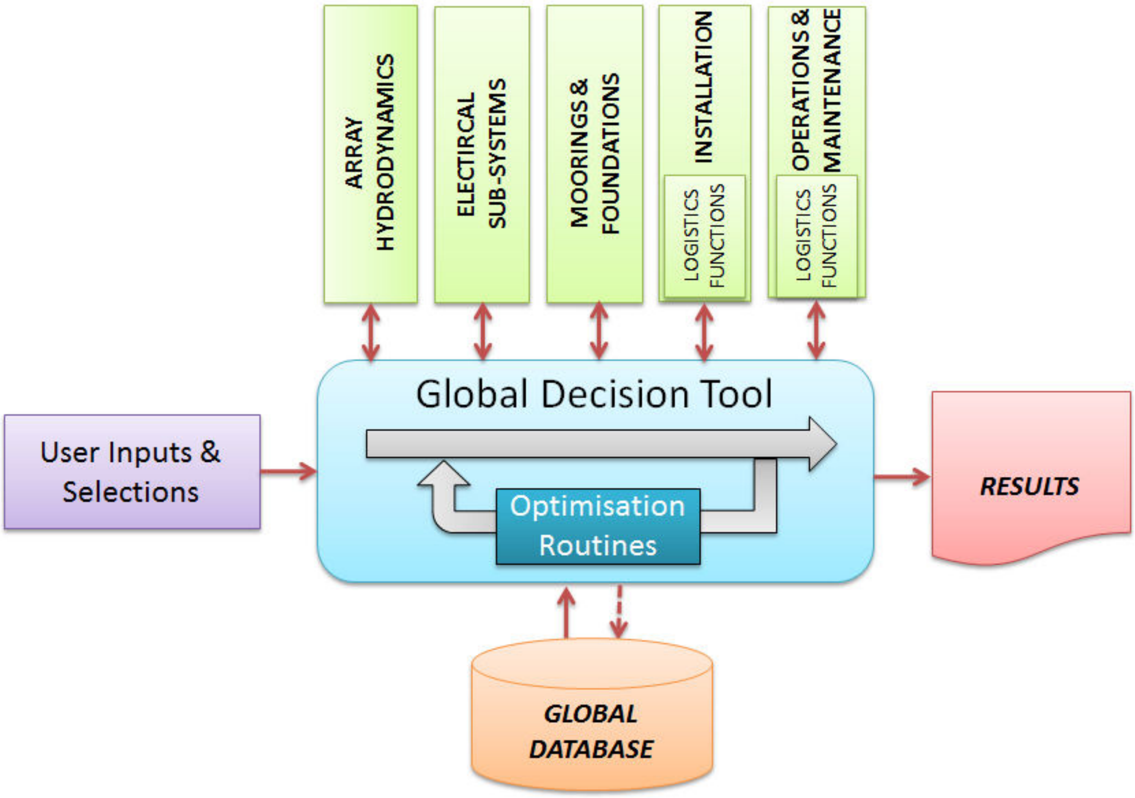

Figure 2-1 Functional structure of the global DTOcean design tool for ocean energy arrays

3 THE INSTALLATION MODULE IN THE DTOCEAN GLOBAL TOOL

In this software architecture, the installation module appears on the fourth position of the computational module when reading them from left-to-right. This somewhat reflects the background incremental logic path governing the design of ocean energy arrays in DTOcean. In fact, the installation module is seeking to optimise the cost of installation of all components/sub-systems chosen by the upstream modules.

In other words, the installation module covers the following elements:

- Installation of wave or tidal devices, as positioned by the array hydrodynamics module
- Installation of the electrical infrastructure components, as designed by the electrical sub-systems WP3 module
- Installation of the moorings & foundations, as arranged by the WP4 module

As with any other computational module, the WP5 installation module aims to solve a given physical problem and return new outputs. However, the nature of WP5 slightly differs from that of WP2, WP3 & WP4 in the sense that no physical array sub-component is selected nor designed as part of the bill of materials. In contrast, WP5 provides optimal logistic solutions by selecting feasible vessels, ports and equipment to accomplish the installation phase. These logistic solutions only intervene on a limited period of time of the project life cycle and do not directly affect the efficiency of the conversion chain transforming wave or tidal energy resource into useful electricity.

In addition to the simulation of logistic phases as described in chapter 2 of Deliverable 5.6 [1], the installation module comprises complementary features:

- A pre-defined logistic phase sub-module: this is where the operation sequences and vessels & equipment combinations are defined for all logistic phases
- An installation procedure definition sub-module: it is divided into two functions, one defining the scheduling rules to determine the sequence of the logistic phases and another function selecting the base installation port
- An optimization routine: the most inexpensive feasible logistic solutions are chosen

Figure 3-2 gives a high level schematic of the structure of the installation module. From left-to-right, one progresses through the analysis undertaken in the installation module. After loading all required inputs, the pre-defined logistic phase and the installation procedure definition sub-modules run sequentially.

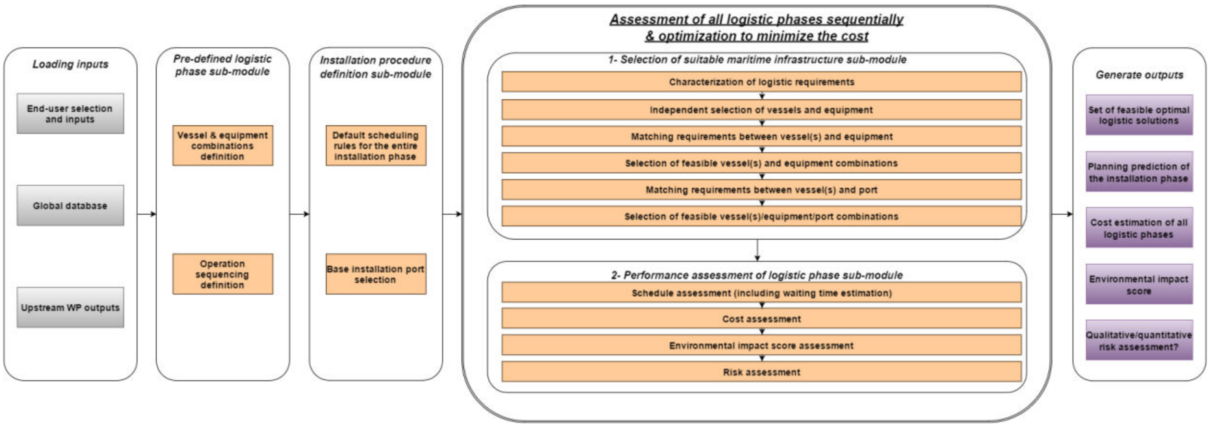

Figure 3-1 High level flow chart of the installation module.

Having the information of the Gantt chart planning of all logistic phases, the assessment of these is performed in three stages (for details of the feasibility, performance, risk and environmental functions, please refer to Deliverable 5.6[1]):

- STEP 1 “selection of suitable maritime infrastructure sub-module”: characterization of the logistic requirements relating the array physical parameters to the characteristics of the maritime infrastructure (ports, vessels and equipment). This step is followed with the matching of the logistic requirements previously determined with the database of vessels, ports and equipment purposely built-in for the DTOcean tool. To avoid unnecessary verification, the selection of the individual vessel(s), port and equipment is constrained by the pre-defined type of vessels and equipment. Ultimately, the end-user shall have the opportunity to specify a set of types of vessel(s) and equipment he would like to assess. This feature adds significant flexibility to the WP5 module.
- STEP 2 “performance assessment of logistic phase sub-module”: this assessment is four fold:
    - First, an estimation of the schedule of the marine operation is conducted. The mobilization time associated with the availability of the maritime infrastructure (vessels and equipment) is straightforwardly evaluated, based on average values in the database. Similarly, the transportation times are readily computed through the average speed values along with an assessment of the distance from port to site. By combining various methods for time assessment, the expected waiting time associated with the marine operation can be predicted. In essence, the weather window function requires the requested starting time and the duration of the marine operation to return an estimate of the waiting time.
    - Secondly, the cost functions produce estimates of the costs incurred by the utilization of the maritime infrastructure. Both fixed and variable costs are accounted for by making use of relevant economic parameters available in the database of ports, vessels and equipment.
    - Thirdly, a qualitative assessment of the environmental impact associated with the use of the vessel and equipment returns an environmental score for five potential impacts. The implementation of these functions is done in collaboration with France Energies Marines.

- A risk assessment which will attempt to quantify the uncertainty of four core categories of logistic liabilities. Note that this feature will not be available in the first release of the DTOcean tool.

- STEP 3 "optimization routine": in WP5, the objective function is to find the feasible logistic solutions which minimize the total cost (C_{lp}) for a given logistic phase.

At the end of this process, the outputs of the installation module are sorted and formatted in the most convenient way for future results presentations. The outputs include a set of optimal feasible logistic solutions along with their schedule, cost, risk and environmental impact assessment.

To-date, a total of nine logistic functions Excel sheets have been developed in response to the scope of the DTOcean tool. Details of these functions can be accessed in both Deliverable 5.4 [2]. In turn, any array configuration that can possibly be proposed to the installation module should fit the nine logistic phases characterized. In other words, the installation of all array sub-components can be appraised from a time, cost and environmental perspective. Below is the list of the nine logistic phases, split within the 3 main groups:

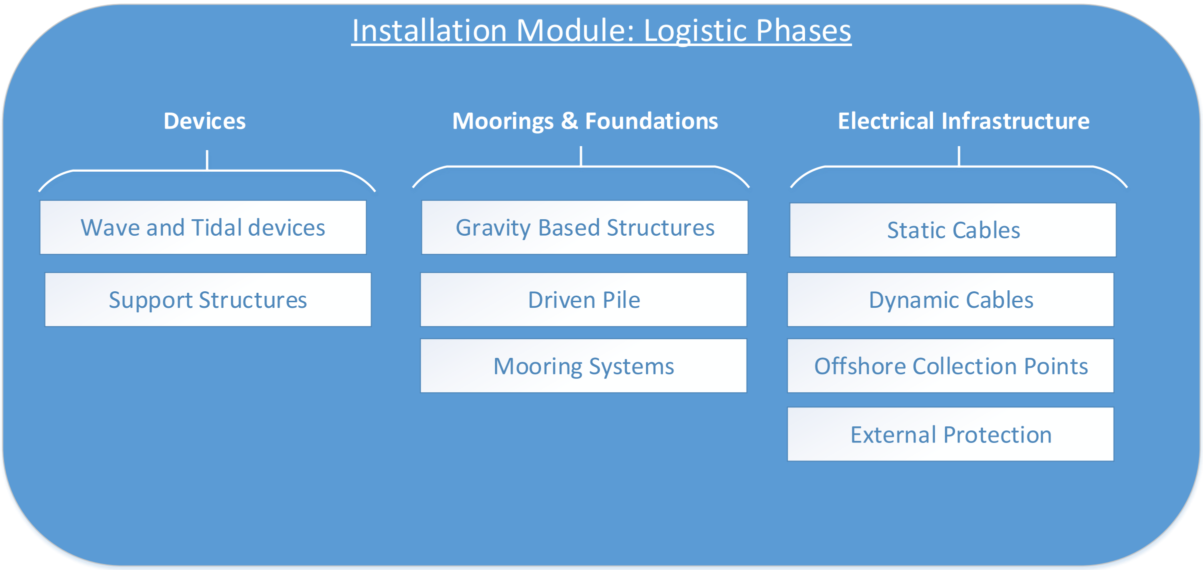

Figure 3-2 Scope of the logistic phases considered for the installation module

3.1.1 MOORINGS AND FOUNDATIONS SCOPE

Figure 3-3 to Figure 3-8 capture the options outlined in Figure 3-2 and illustrate the combinations of components that may be used to provide foundations or moorings for a marine energy device.

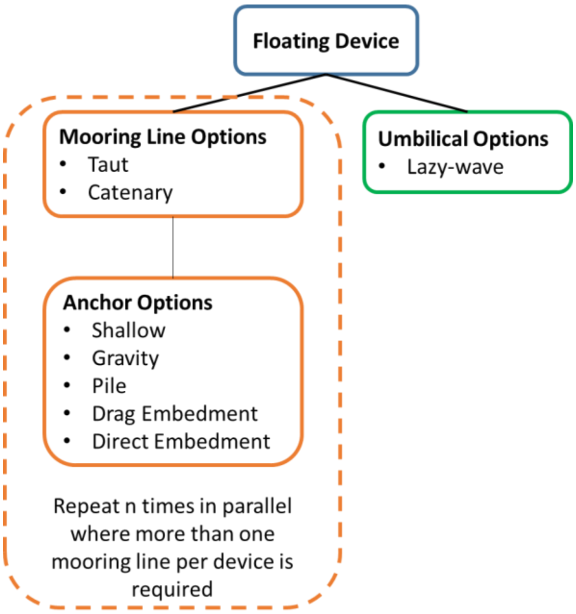

Figure 3-3 Mooring options for a floating marine energy device

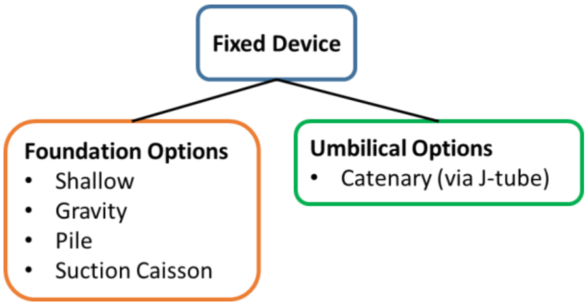

Figure 3-4 Foundation options for a fixed marine energy device

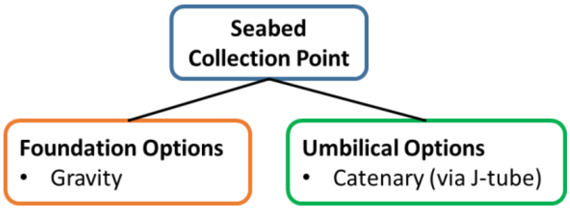

Figure 3-5 Foundation options for a seabed collection point

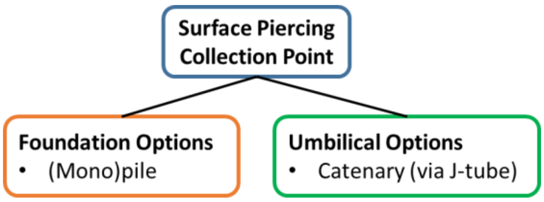

Figure 3-6 Foundation options for a surface piercing collection point

Mooring lines, whether taut or catenary, will be formed by one of the two patterns of components outlined in Figure 3-7 and Figure 3-8.

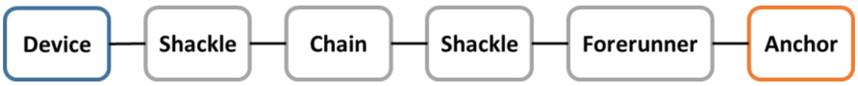

Figure 3-7 Components of a chain based mooring line

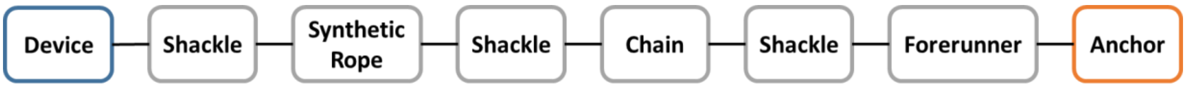

Figure 3-8 Components of a chain and synthetic rope based mooring line

3.1.2 ELECTRICAL INFRASTRUCTURE SCOPE

Figure 3-9 captures the options outlined in Figure 3-2 and illustrates the patterns of these components that may be used to form a marine energy array. Options for a given component are given as bullet points (e.g. a device can be of type floating or fixed). Branches in the diagram represent decisions to be made regarding routing of power from device to export.

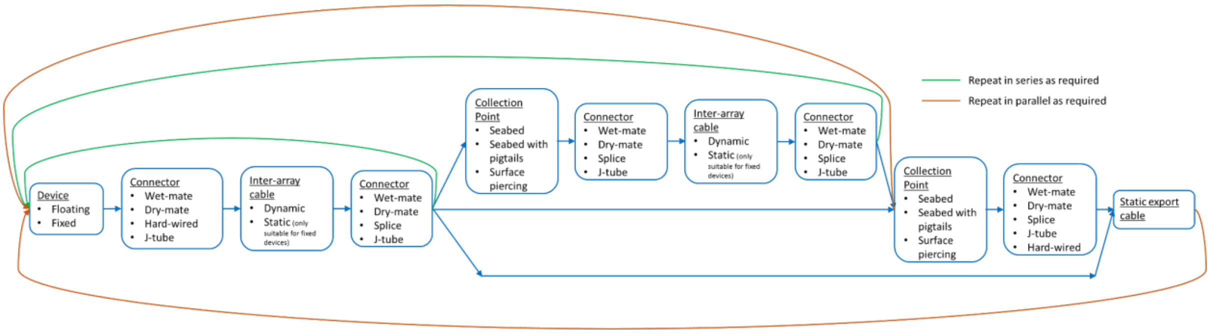

Figure 3-9 Allowable patterns of electrical components forming an array

Note that static inter-array cables are only suitable for use with fixed marine energy devices.

Figure 3-9 presents a number of ways in which arrays of devices may be connected, allowing output from numerous devices to be collected and exported.

1. A single device may be installed using the pattern device -> connector -> inter-array cable -> connector -> static export cable.
2. A number of devices may be installed in series by repeating the pattern device -> connector -> inter-array cable -> connector, before feeding down to a collection point or export cable.
3. Collection points may be inserted into a string as described in point 2 using the pattern collection point -> connector -> inter-array cable -> connector.
4. A number of strings as described in points 2 or 3 may be installed in parallel, all connecting down to a common collection point prior to a static export cable.
5. Any of the options described in points 1-4 may be repeated in parallel if more than one static export cable is to be used.

Three types of terminal can be highlighted in Figure 3-9 namely: device; collection point; and static export cable. Allowable patterns of connection between two terminals are:

1. Device to device
2. Device to static export cable
3. Device to collection point
4. Collection point to collection point
5. Collection Point to static export cable

3.2 INPUTS TO THE INSTALLATION MODULE

3.2.1 REQUIREMENTS FOR THE END-USER

Any data that the user is required to enter into the system for the functionality of the installation module have been previously labelled as WP1. In short the type of inputs falling into this category can be enumerated as follows (see details in Appendix 6.1):

- Site data: information about the bathymetry, the soil conditions at each grid point of the lease area characterized,
- Metocean data: time-series values of significant wave height, peak wave period, wind speed and current speed,
- Device data: device and device sub-systems specifications such as dimensions, weight, assembly strategy, load out strategy, transportation method.

Each category of inputs will be treated as panda DataFrame tables within the installation module. Although not compulsory requirements, the end-user is strongly advised to override the default values (e.g average fixed duration of logistic operations, vertical and horizontal progress rates, OLC, safety factor, day-rates and other cost input values) if more accurate data is available.

3.2.2 INTERACTIONS WITH THE GLOBAL DATABASE

As explained in Deliverable 7.2 [3], the global database is the amalgamation of all data that is required for the operation of the computational packages that can be provided without direct input from the user. Figure 3-1 shows that the database information is fed into the global design tool and not into the computational packages directly. This allows the user to override the results from the global database and also removes some ambiguities and inefficiencies that can occur when several modules require the same data or where some data that has originated from the database has been modified by one of the computational packages.

Among the large set of data available in this global database, the installation module essentially extracts the following parameters:

- Port database: detailed information about European ports with the following parameter categories:
    - General Information *(13 parameters),*
    - Port Terminal Specification *(17 parameters),*
    - Port Cranes, Support, Accessibilities and Certifications *(16 parameters),*
    - Manufacturing capabilities *(8 parameters),*
    - Economic Assessment *(8 parameters),*
    - Contact details *(4 parameters),*
- Vessel database: detailed information about each vessel types considered in DTOcean (see Deliverable 5.3 for details [4]) with the following parameter categories:
    - General Information *(9 parameters),*
    - Main Dimensions and Technical Capabilities *(18 parameters),*
    - Maximum Operational Working Conditions *(8 parameters),*
    - On-board Equipment Specifications *(~34 parameters),*
    - Economic Assessment *(4 parameters),*

- Equipment database: detailed information about each equipment types considered in DTOcean (see Deliverable 5.3 for details [4]) with the following parameter categories (the number of parameters varies from one equipment type to another):
    - Metrology *(min. 4 parameters),*
    - Performance *(min. 2 parameters),*
    - Support systems *(min. 2 parameters),*
    - Economic Assessment *(min. 2 parameters),*
- Installation default values:
    - Average fixed duration values of individual logistic operations (see tables at the end of each logistic phase description in Deliverable 5.6[1]),
    - Vertical penetration rates in all DTOcean soil types for all piling equipment (see Table 6-15),
    - Horizontal progress rates in all DTOcean soil types for all cable trenching/laying equipment (see Table 6-14),
    - Safety factors to apply on selected feasibility functions (see Table 6-16Table 6-17Table 6-18),
    - OLC values for specific individual logistic operations (see tables at the end of each logistic phase description in chapter 2 of Deliverable 5.6 [1]),
    - Default Gantt chart rules for the installation planning (see section 3.3).

Strictly, the global database is to provide inputs to the installation module as well as other computational modules, not to store outputs. However, it is important to facilitate a means for the user to update the database with contemporary information or site and technology specific data, prior to the operation of the tools.

In addition to updating the default values, the end-user has the opportunity to manipulate the maritime infrastructure database (port/vessel/equipment) so that, for example, new vessel(s) or equipment are incorporated or negotiated chartered day-rates values are applied instead of the pre-defined values. This feature is particularly pertinent for an end-user which would already know which port(s) should be considered for the installation and O&M phases.

3.2.3 INTERACTIONS WITH UPSTREAM WPS

The last interaction of the installation module copes with the results of upstream computational module. In other words, these inputs to WP5 correspond to outputs from other WPs (details of the parameters can be found in Appendix 6.1.2), as listed below:

- Array hydrodynamic WP2: number and position of the devices in the UTM grid coordinate system formatted in one panda DataFrame table.
- Electrical sub-system WP3: specifications of six sub-systems, namely: the collection points, the dynamic cables, the static cables together with the cable routing information (one panda DataFrame for each), the external protection and the connectors. This gives six panda DataFrames tables.
- Moorings & foundations WP4: specifications of two sub-systems, namely the foundations (which can be anchors in the case of mooring systems) and the mooring lines. This gives two panda DataFrame tables.

3.3 INTER-LOGISTC PHASES SCHEDULING

Among the nine logistic phases considered for the complete installation phase of an ocean energy array, it is clear that there exist scheduling relationships to plan them sequentially from a project developer standpoint. Therefore, "Gantt chart" rules to determine the sequence of the logistic phases forming the installation module have been created. For this purpose, it is necessary to first identify all possible scenarios that can reach the installation module. The definition of a scenario here is an array layout configuration which leads to a singular Gantt chart ruling system.

For instance, a Gantt chart rule can be the requirement to install the inter-array static power cables after the installation of the offshore collection point. Clearly, such rules are deeply project specific. Still, based on the literature review engaged in D5.2, some trends have been identified which are reported below:

- STEP 1 “Moorings & foundations”: any installation of moorings and/or foundations is likely to be completed before any other installation.
- STEP 2 “Electrical infrastructure”: all logistic phases associated with the installation of electrical infrastructure can be done simultaneously and should be conducted after the moorings and/or foundations and before the device installation.
- STEP 3 “Wave or tidal devices”: devices should be installed at last after completion of the installation of all electrical sub-systems.

These trends will be refined in the future through the construction of summary "Gantt chart rules tables" covering any possible array configuration scenario. DTOcean end-users should have the opportunity to override these default rules.

3.4 INSTALLATION BASE PORT SELECTION

The experience of offshore wind shows that one unique installation base port is mutualizing all logistic activities during the assembly, transportation and installation phase. There are obvious benefits in concentrating such complex organizational issues into one place, such as:

- Mutualisation of resources; in particular personnel and tools,
- Simplification of administrative/legal/regulatory issues; fewer authorities to confront,
- Cost reductions potential; minimization of transportation for procurement and mobilization, stronger negotiation process, etc.

For large offshore projects, the management team usually sets up a site office in/near the port area (or rent some offices nearby). From this office the daily operations are managed, operating from several ports would require additional offices and complicate coordination and logistics.

For all the above reasons, the installation module will select one unique base installation port in a two steps procedure:

- STEP 1 “minimum requirements”: verify that the port capabilities satisfy a set of minimum requirements that are:

- the availability of a suitable dry-dock for device assembly and loadout depending on the loadout strategy indicated by the end-user
- the presence of at least one terminal suitable to accommodate (in terms of quay area and quay bearing) one of the largest elements to be installed (the device or one of the elements of the electrical sub-systems or moorings/foundations)

- STEP 2 "nearest port selection": the nearest port to the installation site conforming with the minimum requirements is selected. For this step, the distance algorithm previously described determines the distances between all ports satisfying the minimum requirements and the first device appearing in the "layout" panda table generated by WP2 (see Table 6-5). This would reduce the distances, and in turn, the voyage costs.

Alternatively, the end-user may opt for the option to prescribe the base installation port himself/herself. In this case, either one of the ports available in the database is selected or a new one is fully characterized.

3.5 OUTPUTS OF THE INSTALLATION MODULE

This section describes the outputs generated by the installation module by providing an exhaustive list of the outputs. At the end of the installation module, the outputs generated by the logistic functions of all logistic phases that were under consideration are aggregated into a dictionary.

Assuming all upstream computational modules have successfully generated the outputs required to feed the installation module, no intervention from the user is required other than inputting the aforementioned four tables. The installation module terminates with the formatting of the outputs. Results obtained through the feasibility, scheduling, economic and environmental functions for all considered logistic phases convene in a predicted installation plan which contains:

- The starting and ending dates & times of all sub-array components installation phases together with the estimated waiting time,
- The list of all logistic requirements associated with the logistic phase,
- The selected suitable combinations of port/vessel(s)/equipment associated with the logistic phase (list filtered and extracted from the maritime infrastructure database)
- The schedule assessment (including the total time T_{lp}) of each feasible logistic solution associated with the logistic phase. This comprises the duration of all elements forming T_{lp},
- The cost assessment (including the total cost C_{lp}) of each feasible logistic solution associated with the logistic phase. This comprises the cost of all elements forming C_{lp},
- The environmental impact assessment (including the final score of the five environmental functions concerned with the logistic functions) of each feasible logistic solution associated with the logistic phase.

The parameter name, description, unit, format and some additional comments produced by each run of the logistic functions for a given logistic phase are compiled in Table 3-1.

Table 3-1 Dictionary output generated by the logistic functions for a given logistic phase

Dictionary name	Output number	Parameter description	Python key	Unit	Format	Additional comments
log_phase	0	Port selected	port	[-]	Panda series dataframe	Extracted row from the port database containing all parameters collected about the port
	1	Logistic requirements	requirement	[-]	several	Minimum or maximum values or Boolean and the corresponding parameters of the port/vessel(s)/equipment which should be satisfied. These are calculated in the feasibility functions
	2	Equipment selected	eq_select	[-]	Panda series dataframe	Extracted row(s) from the equipment database containing all parameters about the equipment satisfying the logistic requirements
	3	Vessels selected	ve_select	[-]	Panda series dataframe	Extracted row(s) from the vessel database containing all parameters about the vessels satisfying the logistic requirements
	4	Feasible combination port/vessel(s)/equipment	combi_select	[-]	several	Set of feasible combinations of port/vessel(s)/equipment compatible between each other
	5	Results from the scheduling functions	schedule	[-]	several	Starting & ending date/time stamp + duration assessment of all individual logistic operations for each feasible combination of port/vessel(s)/equipment. This includes all ingredients forming T_{port}, T_{sea} & T_{wait}
	6	Results from the cost functions	cost	[-]	several	Cost assessment for each feasible combination of port/vessel(s)/equipment. This includes all ingredients forming C_{port} & C_{sea}
	7	Results from the risk functions	risk	[-]	several	In preparation for the implementation of risk functions in future release of the logistic functions[1]
	8	Results from the environmental functions	envir	[-]	several	Environmental impact scores associated with each of the five environmental functions for each feasible combination of port/vessel(s)/equipment
	9	Status message	status	[-]	string	Text message stating whether the logistic

[1] It was decided not to develop the proposed risk functions iin D5.6 at this stage as it would imply significant work and addition in the database which would jeopardize the advancement in the integration of all computational modules. It should be noted, however, that some key risks (e.g the weather risk) are already inherently taken into account to a large extent in the available version of the logistic functions.

						functions have terminated successfully or not. May be removed after integration
	10	Log messages	log	[-]	several	List of error and warning messages relevant to the debugging and to inform the user on the key assumptions or uncompleted calculation (due to missing inputs)

Ultimately, the installation module outputs consist of a dictionary containing as many dictionaries presented in Table 3-1 as there are logistic phases to be considered.

3.6 OPTIMISATION ROUTINE IN THE INSTALLATION MODULE

As explained in D5.6, all feasible logistic solutions can be discriminated in terms of time efficiency, cost and environmental impact score. Since the LCOE is the chosen objective metric for the global optimization of the DTOcean tool, the installation module adopts a straightforward and yet coherent approach in trying to reach the most LCOE attractive installation plan. To this extent, the optimization routine within the installation module consists of always opting for the least costly logistic phase among the feasible solutions.

In mathematical terms, this reads:

$$\min_{\text{solution}=1:S} C_{lp} \; with \; C_{lp} = C_{port} + C_{sea} \tag{3-1}$$

C_{lp} represents the total cost of a given feasible logistic solution for a particular logistic phase. Details of the calculation to obtain C_{port} and C_{sea} are formulated in Deliverable 5.6 [1]

4 CONCLUSIONS

With regards to the high level flow chart shown in Figure 3-1, the status of the version of the module sent along with this report is summarized in the following points:

- Regarding the *loading input*:
    - Internally developed inputs are stored in Excel spreadsheets and are being imported into dataframes
    - These inputs match with the updated version of inputs shown in Appendix 6.1
    - In turn, there will be no import of inputs in the installation module since this task will be managed by the core of the DTOcean global tool as illustrated in Figure 2-1
- Regarding the *pre-defined logistic phase sub-module*:
    - The operations sequence definition has been completed for 9 logistic phases covering the entire scope presented in this document
    - The vessel and equipment combination definition has been completed for 9 logistic phases covering the entire scope presented in this document
    - Additional logistic phases can be relatively straightforwardly incorporated or existing ones can be modified for a user literate in Python
- Regarding the *Installation procedure definition sub-module*:
    - The default scheduling rules have been implemented with the simplified assessment proposed in section 3.3. More sophisticated inter-logistic phases rules may be added until release of the candidate version of the DTOcean global tool
    - The selection of the Installation port is implemented and was tested with the latest version of the database containing 77 entries
- Regarding the *Assessment of logistic phases & optimization:*
    - Characterization of the logistic requirements associated with the nine logistic phases was completed
    - The selection algorithm, which selects the suitable vessels based on the logistic requirements calculated by the feasibility functions has been implemented
    - The compatibility check between port/vessel, vessel/equipment has also been implemented
    - The scheduling functions to estimate the time per logistic operation is up and running for the 9 logistic phases featuring an alpha version of the weather window function which will be further tested and upgraded before the release candidate version of the global DTOcean tool
    - Similarly, the cost functions are working as they have been described in Deliverable 5.6 [1]
    - Risk functions were not coded mainly due to the significant modifications it would have required on the global database which needed to be frozen to allow progress of all developers and integrators of the global tool
    - Environmental functions were externally developed and are not currently linked to the installation module. The DTOcean core module developers will perform this task

5 REFERENCES

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[2] B. Teillant, P. Chainho, C. Vrousos, K. Charbonier, and S. Ybert, "DTOcean Deliverable 5.4 - Logistic functions for ocean energy arrays," 2015.

[3] Tecnalia Research & Innovation, WavEC Offshore Renewables, University of Exeter, The University of Edinburgh, University College Cork, IWES Fraunhofer, Aalborg University, France Energies Marines, Sandia Coorporation, and Joint Research Centre, "DTOcean Deliverable 7.2 - Specification and architecture of a global software tool for ocean energy arrays, with performance models and characteristics curves."

[4] WavEC Offshore Renewables, "DTOcean Deliverable 5.3 - Database of maritime infrastructure," 2015.

6 APPENDICES

6.1 LIST OF INPUTS TO THE INSTALLATION MODULE

6.1.1 END-USER INPUTS LIST

Table 6-1 Panda DataFrame containing all required "site" input data to WP5

DataFrame name	Input number	Parameter description	Python name	Unit	Format	Additional comments
site	0	Points of the grid UTM coordinate system in the lease area	x coord	[m]	float	UTM grid coordinate system - Spatial resolution: ΔX≤50 m ; Δy≤50 m
	1		y coord	[m]	float	
	2		zone	[-]	string	
	3	Bathymetry	bathymetry	m	float	Water depth at each point previously defined in 'points'. Water depth must be sufficient for the vessels and some operations are constrained by water depth
	4	Seabed Conditions - Geophysics/Geotechnics	soilt type	[-]	string	Soil type at each point previously defined in 'points' - Soil type list: Cohesionless (sands) -(loose sand; medium sand; dense sand) Cohesive (clays) - (very soft clay; soft clay; firm clay; stiff clay) Others - (hard glacial till; cemented; soft rock coral; hard rock; gravel cobble)

Table 6-2 Panda DataFrame containing all required "metocean" input data to WP5

DataFrame name	Input number	Parameter description	Python name	Unit	Format	Additional comments
metocean	0	Date and time of the measure metocean historical data	year	[-]	integer	
	1		month	[-]	integer	
	2		day	[-]	integer	
	3		hour	[-]	integer	
	4	Resource metocean data (wave): (Hs, Tp)	wave Hs	[m]	float	Weather window calculation - Time series of Hs, Tp, wind speed and current speed - One point only in the lease area but must be the same for all dataset - 1 hour resolution minimum - 1 year length minimum
	5		wave Tp	[s]	float	
	6	Resource metocean data (wind): wind speed	wind speed	[m/s]	float	
	7	Resource metocean data (tide): tidal speed	tide speed	[m/s]	float	

Table 6-3 Panda DataFrame containing all required "device" input data to WP5

DataFrame name	Input number	Parameter description	Python name	Unit	Format	Additional comments
device	0	Device type	type	[-]	string	List of device types: (float WEC; fixed WEC; float TEC; fixed TEC)
	1	Device dimensions	dimensions	[m]	float	Three main dimensions of the device such as length, width and height
	2	Device dry mass	dry mass	[kg]	float	
	3	Sub-system list	sub system list	[-]	string	List of the device sub-systems should always be: (A - hydro; B - PTO; C - control; D - support)
	6	Assembly Strategy of the sub-systems of one device	assembly strategy	[-]	text	Sequence and location (port or site) of assembly of the device sub-systems. Under square bracket = sub-systems installed at port. Under parenthesis = sub-systems installed at site. Example: ([A,B,C], D) = Hydro & PTO & control assembled together at port and this sub-assembly is assembled to the support structure at site
	7	Estimated assembly duration of one device	assembly duration	[hour]	float	Time required to complete the assembly at port of one device
	8	Load-out strategy	load out	[-]	string	Load out type list: (skidded; trailer; float away; lift away) This defines what port characteristics are relevant for the load-out operation of the devices (e.g. dry-dock required, lifting capacities, etc.)
	9	Device and/or sub-assembly transportation method	transportation method	[-]	string	Transportation method list: (deck; tow) If all device sub-systems are assembled at port it is the full device transportation method otherwise it is the sub-assembly transportation method
	10	Required towing bollard pull of the device/sub-assembly	bollard pull	[ton]	float	Relevant only for towed device/sub-assembly

	11	Estimated overall duration of positioning and connection to moorings/foundations	connect duration	[hour]	float	This parameter defines the average on-site time required to position, hook up the device and connect it electrically
	12	Estimated overall duration of disconnection	disconnect duration	[hour]	float	This parameter defines the average on-site time required to disconnect the device for retrieval
	13	Operational Limit Conditions during the device positioning and connecting/disconnecting operation	max Hs	[m]	float	These parameters are used for the weather window calculation
	14		max Tp	[s]	float	
	15		max wind speed	[m/s]	float	
	16		max current speed	[m/s]	float	

Table 6-4 Panda DataFrame containing all required "sub_device" input data to WP5

DataFrame name	Input number	Parameter description	Python name	Unit	Format	Additional comment
Sub_device	0	Device sub-system ID	id	[-]	string	List of the device sub-systems should always be: (A - hydro; B - PTO; C - control; D - support structure)
	1	Device sub-system dimensions	length	[m]	float	Three main dimensions of each device sub-system such as length, width and height
	2		width	[m]	float	
	3		height	[m]	float	
	4	Device sub-system dry mass	sub system dry mass	[kg]	float	Dry mass of each device sub-system
	5	Assembly location of the device sub-system	assembly location	[-]	string	assembly location can be either: port (must take place at the installation port) ; site (must take place at the exploitation site); elsewhere (takes place before installation somewhere afar the port and the site)
	6	Estimated assembly duration of the device sub-system	assembly duration	[hour]	float	Time required to complete the assembly of one device sub-system

6.1.2 UPSTREAM WPS INPUTS

Table 6-5 Panda DataFrame containing all required input data generated by WP2 to WP5

DataFrame name	Input number	Parameter description	Python name	Unit	Format	Additional comment
layout	0	Device number	units	[-]	integer	
	1	Device ID number	device	[-]	string	Should be consistent with device ID used by all other WPs
	2	Position of devices in the UTM grid coordinate system	x coord	[m]	float	UTM grid coordinate system (x coord, y coord, zone)
	3		y coord	[m]	float	
	4		zone	[-]	string	

Table 6-6 Panda DataFrame containing all required input data "collection point" generated by WP3 to WP5

DataFrame name	Input number	Parameter description	Python name	Unit	Format	Additional comments
collection point	0	Collection point id number	id	[-]	integer	Identification number of the collection point
	1	Collection point type	type	[-]	string	Type list: (Seabed; Seabed with pigtails; Surface Piercing)
	2	Position of collection points	x coord	[m]	float	UTM grid coordinate system (x coord, y coord, zone)
	3		y coord	[m]	float	
	4		zone	[-]	string	
	5	Collection point dry mass	dry mass	[kg]	float	
	6	Collection point dimensions	width	[m]	float	
	7		length	[m]	float	
	8		height	[m]	float	
	9	Collection point electrical interfaces parameters	upstream ei type	[-]	string	- Type list: (wet-mate connector / dry-mate connector / splice / j-tube) - Depending on the Collection Point type, these assume: <u>Seabed</u>: onboard connectors (wet-mate/dry-mate) <u>Seabed with pigtails</u>: pigtails connectors (wet-mate/dry-mate/splice) <u>Surface Piercing</u>: J-tube interfaces (j-tube)

	10		upstream ei id	[-]	integer	Identification number of the upstream electrical interface of the collection point. If type == (wet-mate connector || dry-mate connector || splice): id should point to the 'connectors' dataframe if type == j-tube: id should point to the 'collection point' dataframe
	11		downstream ei type	[-]	string	- Type list: (wet-mate connector / dry-mate connector / j-tube / hard-wired cable) - Depending on the Collection Point type, these assume: <u>Seabed</u>: onboard connectors (wet-mate/dry-mate) or hard-wired interfaces (hard-wired cable) <u>Seabed with pigtails</u>: onboard connectors (wet-mate/dry-mate) or hard-wired interfaces (hard-wired cable) <u>Surface Piercing</u>: J-tube interfaces (j-tube)

	12		downstream ei id	[-]	integer	Identification number of the upstream electrical interface of the collection point.
						
						If type == (wet-mate connector || dry-mate connector):
						id should point to the 'connectors' dataframe
						if type == j-tube:
						id should be empty
						if type == hard-wired cable:
						id should point to the 'static cable' dataframe

	14	Number of Pigtails	nr pigtails	[-]	integer	
	15	Pigtails length	pigtail lenght	[m]	float	
	16	Pigtails diameter	pigtail diameter	[mm]	float	
	17	Pigtails cable dry mass	pigtail cable dry mass	[kg/m]	float	Cable dry mass per meter
	18	Pigtails total dry mass	pigtail total dry mass	[kg]	float	Dry mass of Individual pigtail cable plus the connector halve with end cap

Table 6-7 Panda DataFrame containing all required input data "dynamic cable" generated by WP3 to WP5

DataFrame name	Input number	Parameter description	Python name	Unit	Format	Additional comments
dynamic cable	0	Umbilical id number	id	[-]	integer	Identification number of the umbilical
	1	Umbilical dry mass	dry mass	[kg/m]	float	Umbilical dry mass per meter
	2	Umbilical total dry mass	total dry mass	[kg/m]	float	Dry mass of umbilical cable plus connector halves
	3	Umbilical length	length	[m]	float	
	4	Umbilical diameter	diameter	[mm]	float	
	5	Umbilical minimum bend radius (MBR)	MBR	[m]	float	
	6	Umbilical minimum breaking load (MBL)	MBL	[N]	float	
	7	Umbilical termination parameters	upstream termination type	[-]	string	Type list: (Device / Collection Point)
	8		upstream termination id	[-]	integer	Identification number of the upstream termination element of the umbilical. If type == device: id should point to the 'device' dataframe if type == collection point: id should point to the 'collection point' dataframe
	9		upstream termination x coord	[-]	float	UTM grid coordinate corresponding to the upstream termination of the umbilical
	10		upstream termination y coord	[-]	float	
	11		upstream termination zone	[-]	string	
	12		downstream termination type	[-]	string	Type list: (Device / Static Cable / Collection Point)

	13		downstream termination id	[-]	integer	Identification number of the downstream termination element of the umbilical.
						If type == device:
						id should point to the 'device' dataframe
						if type == static cable:
						id should point to the 'static cable' dataframe
						if type == collection point:
						id should point to the 'collection point' dataframe

	14		downstream termination x coord	[-]	float	UTM grid coordinate corresponding to the downstream termination of the umbilical
	15		downstream termination y coord	[-]	float	
	16		downstream termination zone	[-]	string	
	17	Umbilical electrical interface parameter	upstream ei type	[-]	string	Type list: (wet-mate connector / dry-mate connector / j-tube / hard-wired) - Depending on the downstream termination type, these assume: Device: onboard connectors (wet-mate/dry-mate) or a hard-wired umbilical Collection Point: onboard connectors (wet-mate/dry-mate) or (J-tube) interfaces for surface piercing collection points
	18		upstream ei id	[-]	integer	Identification number of the upstream electrical interface of the umbilical. If type == (wet-mate connector || dry-mate connector): id should point to the 'connectors' dataframe if type == hard-wired: id should point to the 'device' dataframe
	19		downstream ei type	[-]	string	Type list: (wet-mate connector / dry-mate connector / splice / j-tube) - Depending on the downstream termination type, these assume: Device: onboard connectors (wet-mate/dry-mate) Static Cable: seabed connector (wet-mate/dry-mate/splice) Collection Point: onboard connectors (wet-mate/dry-mate), pigtail connectors (wet-mate/dry-mate/splice) or (J-tube) interfaces for surface piercing collection points

	20		downstream ei id	[-]	integer	Identification number of the downstream electrical interface of the umbilical. If type == (wet-mate connector || dry-mate connector || splice): id should point to the 'connectors' dataframe if type == j-tube: id should point to the 'collection point' dataframe
	21	Buoyancy modules number	buoyancy number	[-]	integer	
	22	Buoyancy modules dimensions	buoyancy diameter	[m]	float	
	23		buoyancy length	[m]	float	
	24	Buoyancy modules weight	buoyancy weigth	[kg]	float	

Table 6-8 Panda DataFrame containing all required input data "static cable" generated by WP3 to WP5

DataFrame name	Input number	Parameter description	Python name	Unit	Format	Additional comments
static cable	0	Static cable id number	id	[-]	string	Identification number of the umbilical
	1	Static cable type	type	[-]	string	Type list: (array / export)
	2	Static cable dry mass	dry mass	[kg/m]	float	Umbilical dry mass per meter
	3	Static cable total dry mass	total dry mass	[kg]	float	Dry mass of static cable plus connector halves
	4	Static cable length	length	[m]	float	
	5	Static cable diameter	diameter	[mm]	float	
	6	Static cable minimum bend radius (MBR)	MBR	[m]	float	
	7	Static cable minimum breaking load (MBL)	MBL	[N]	float	
	8	Static Cable termination parameters	upstream termination type	[-]	string	Type list: (Device / Dynamic Cable / Collection Point)

	9		upstream termination id	[-]	integer	Identification number of the upstream termination element of the static cable.
						If type == device:
						id should point to the 'device' dataframe
						if type == static cable:
						id should point to the 'static cable' dataframe
						if type == collection point:
						id should point to the 'collection point' dataframe

	10		downstream termination type	[-]	string	Type list: (Device / Dynamic Cable / Collection Point / Landing Point)

	11		downstream termination id	[-]	integer	Identification number of the downstream termination element of the static cable.
						If type == device:
						id should point to the 'device' dataframe
						if type == dynamic cable:
						id should point to the 'dynamic cable' dataframe
						if type == collection point:
						id should point to the 'collection point' dataframe
						if type == landing point:
						id should be N/A

	12	Static Cable electrical interface parameters	upstream ei type	[-]	string	Type list: (wet-mate connector / dry-mate connector / splice / j-tube / hard-wired) Depending on the upstream termination type, the ei types can assume: Device: onboard connectors (wet-mate/dry-mate/ J-tube) Dynamic Cable: seabed connector (wet-mate/dry-mate/splice) Collection Point: onboard connectors (wet-mate/dry-mate) or (hard-wired) for seabed collection points and (J-tube) interfaces for surface piercing collection points

	13		upstream ei id	[-]	integer	Identification number of the upstream electrical interface of the static cable.
						
						If type == (wet-mate connector || dry-mate connector || Splice):
						id should point to the 'connectors' dataframe
						if type == hard-wired:
						id should point to the 'device' dataframe
						if type == j-tube:
						id should point to N/A

	15		downstream ei type	[-]	string	Type list: (wet-mate connector / dry-mate connector / splice / j-tube / NA) Depending on the upstream termination type, these assume: Device: onboard connectors (wet-mate/dry-mate/ J-tube) Dynamic Cable: seabed connector (wet-mate/dry-mate/splice) Collection Point: onboard connectors (wet-mate/dry-mate) or hard-wired for seabed collection points and J-tube interfaces (j-tube) for surface piercing collection points Landing Point: Electrical interfaces are not applicable (NA) for this termination

	16		downstream ei id	[-]	integer	Identification number of the downstream electrical interface of the static cable.
						
						If type == (wet-mate connector || dry-mate connector || Splice):
						id should point to the 'connectors' dataframe
						if type == j-tube:
						id should point to N/A
						if type == NA:
						id should point to N/A

Table 6-9 Panda DataFrame containing all required input data "cable route" generated by WP3 to WP5

DataFrame name	Input number	Parameter description	Python name	Unit	Format	Additional comments
cable route	0	Static cable id number	static cable id	[-]	integer	Identification number of the static cable
	1	Cable route UTM coordinates	x coord	[m]	float	UTM grid coordinate system (x coord, y coord, zone)
	2		y coord	[m]	float	
	3		zone	[-]	string	
	4	Soil type	soil type	[-]	string	Soil type corresponding to the UTM grid coordinate
	5	Soil bathymetry	bathymetry	[m]	float	Bathymetry corresponding to the UTM grid coordinate

	6	Burial depth	burial depth	[m]	float	The burial depth is defined from this cable grid coordinate until the next on the route.
	7	Split pipe required	split pipe	[-]	boolean	(Yes/No) : If the cable section starting from this grid point until the next requires the installation of split pipes

Table 6-10 Panda DataFrame containing all required input data "external protection" generated by WP3 to WP5

DataFrame name	Input number	Parameter description	Python name	Unit	Format	Additional comments
external protection	0	Type of protection element	type	[-]	string	Type list: (concrete matress / rock filter bag)
	1	Position of protection element	x coord	[m]	float	UTM grid coordinate system (x coord, y coord, zone)
	2		y coord	[m]	float	
	3		zone	[-]	string	

Table 6-11 Panda DataFrame containing all required input data "connectors" generated by WP3 to WP5

DataFrame name	Input number	Parameter description	Python name	Unit	Format	Additional comments
connectors	0	Electrical connector id number	id	[-]	integer	Identification number of the connector
	1	Electrical connector type	type	[-]	string	Type list: (wet-mate connector / dry-mate connector / splice connector)
	2	Electrical connector dry mass	dry mass	[kg]	float	
	3	Electrical connector dimensions	lenght	[m]	float	
	4		width	[m]	float	
	5		height	[m]	float	
	6	Electrical connector required mating / de-mating force	mating force	[N]	float	For wet-mate connectors, this data corresponds to the mating force required for the ROV manipulators to plug the connector.
	7		demating force	[N]	float	For wet-mate connectors, this data corresponds to the demating force required for the ROV manipulators to unplug the connector.

Table 6-12 Panda DataFrame containing all required "foundation" input data generated by WP4 to WP5

DataFrame name	Input number	Parameter description	Python name	Unit	Format	Additional comment
foundation	0	Device ID number	devices	[-]	string	Should be consistent with device ID used by all other WPs
	1	Foundation ID number	foundations	[-]	string	
	2	Foundations/anchors type	type	[-]	string	Foundation type list: (shallow foundation; gravity; pile; suction caisson; direct-embedment anchor; drag-embedment anchor)
	3	Foundations/anchors subtype	subtype	[-]	string	Foundation subtype list: (shallow foundation; concrete/steel composite structure with shear keys or concrete/steel composite structure without shear keys, gravity; concrete/steel composite structure, pile; pin pile or pipe pile, suction caisson; closed top, direct-embedment anchor; hammer driven, drag-embedment anchor; <anchor model specified in database>)
	5	Foundations/anchors coordinates	x coord	[m]	float	UTM grid coordinate system
			y coord	[m]	float	
			zone	[-]	string	
	6	Foundations/anchors dimensions	width	[m]	float	For all foundation types apart from piles and suction caissons three dimensions are specified (length, width and height). For piles and suctions caissons width=length=diameter.
			length	[m]	float	
			height	[m]	float	
	7	Foundation penetration depth	depth	[m]	float	Installation depth will be specified for all foundation types except gravity and shallow foundations
	8	Foundations/anchors dry mass	dry mass	[kg]	float	
	9	Foundation grout type	grout type	[-]	string	grout type list: TBC
	10	Foundation grout volume	grout volume	[m3]	float	

Table 6-13 Panda DataFrame containing all required "line" input data generated by WP4 to WP5

DataFrame name	Input number	Parameter description	Python name	Unit	Format	Additional comment
line	0	Device ID number	device	[-]	string	Should be consistent with device ID used by all other WPs
	1	Mooring line ID number	lines	[-]	string	The ID number of the line should match with the foundation ID number, i.e line001 of (device001) is attached to foundation001 (device001)
	2	Component list of the mooring system	component list	[-]	string	Anything between anchoring point and fairlead. Only one component list per device meaning there would necessarily be one mooring line type per device
	3	Type of mooring system	mooring system type	[-]	string	Mooring system type list: (taut; catenary)
	4	Mooring line length	line length	[m]	float	Cumulated length of all elements from the anchoring point to the fairlead
	5	Mooring line dry mass	line dry mass	[kg]	float	Cumulated dry mass of all elements from the anchoring point to the fairlead

6.1.3 DEFAULT VALUES INPUTS

Table 6-14 Default values for the horizontal progress rates of four cable laying techniques across all DTOcean soil types

Technique	Soil Type											
	Cohesionless			Cohesive				Others				
	loose sand	medium sand	dense sand	very soft clay	soft clay	firm clay	stiff clay	hard glacial till	cemented	soft rock coral	hard rock	gravel cobble
Jetting [m/h]	100 - 400	100 - 300	0	350 - 600	350 - 600	150 - 350	0	0	0	0	0	0
Ploughing [m/h]	50 - 150	200 - 500	50 - 150	0	250 - 500	250 - 750	350 - 750	250 - 350	0	0	0	200 - 500
Cutting [m/h]	0	100 - 450	100 - 450	0	100 - 450	100 - 450	50 - 100	50 - 100	50 - 100	25 - 75	0	0
Dredging [m/h]	100 - 200	50 - 150	25 - 125	100 - 200	50 - 150	25 - 125	25 - 75	25 - 75	25 - 75	25 - 75	0	25 - 125

Table 6-15 Default values for the vertical penetration rates of four pile driving equipment across all DTOcean soil types

Equipment	Soil Type											
	Cohesionless			Cohesive				Others				
	loose sand	medium sand	dense sand	very soft clay	soft clay	firm clay	stiff clay	hard glacial till	cemented	soft rock coral	hard rock	gravel cobble
Drilling rig [m/h]	0	0	0	0	0	0.5 - 0.8	0.4 - 0.6	0.25	0.5	0.3 - 0.45	0.2 - 0.3	0
Hammer [m/h]	15 - 25	10 - 20	2.5 - 7.5	10 - 20	10 - 15	5 - 10	1.5 - 7.5	0	0	0	0	2.5 - 7.5
Vibro-driver [m/h]	300 - 450	200 - 300	50 - 100	150 - 200	50 - 100	0	0	0	0	0	0	50 - 100
Suction pump [m/h]	300 - 450	200 - 300	50 - 150	150 - 250	50 - 150	0	0	0	0	0	0	0
ROV with jetting [m/h]	100 - 400	100 - 300	0	350 - 600	350 - 600	150 - 350	0	0	0	0	0	0

Table 6-16 Port feasibility functions and safety factors

	Port parameter verified (unit)	Methodology	Safety factor (in %)
Terminal/Dock capabilities	Terminal dock size area (m²)	Ensure the largest sub-system can individually fit in the dock size area	20%
	Max. terminal load bearing (t/m²)	Ensure the maximum loading one individual sub-system can apply on the terminal does not exceed the max. terminal load bearing specified in the port database	20%
Load out capabilities	Marine slipway (yes/no)	Ensure the availability of the appropriate load-out equipment at port depending on the transportation method and load-out strategy of the device	N/A, 20% on the dimensions of the dry-dock
	Dry dock (yes/no and dimensions)		

Table 6-17 Vessel feasibility functions and safety factors

	Vessel parameter verified (unit)	Methodology	Safety factor (in %)
Deck capabilities	Deck size area (m^2)	Ensure that as many sub-systems as possible to be transported fit the deck size area	20%
	Max. Deck loading (t/m^2)	Ensure the loading of one sub-system does not exceed the one of the vessel deck	20%
	Maximum cargo (t)	Ensure the total weight on the deck does not exceed the maximum payload	20%
Lift capabilities	Onboard crane capacity (t)	Ensure the maximum weight of one individual sub-system does not exceed the on-board max. lifting capacity	20%
Towing capabilities	Bollard pull (t)	Verify that the mass of the element to be towed is inferior than the vessel bollard pull	20%
Turntable capabilities	Turntable/reel - loading capacity [t]	Ensure the turntable/reel loading capacity of the cable laying platform is sufficient for the sum of cable weights to be loaded	20%
	Turntable/reel - inner diameter [m]	Ensure the inner radius of the turntable/reel is higher than the cable minimum bending radius	20%
Dredging capabilities	Dredge Depth [m]	Ensure the dredging depth capabilities of the dredger vessels is higher than the bathymetry within the cable route	20%
Anchor handling capabilities	Winch rated pull [t]	Ensure the winch pulling capabilities of the anchor handling vessels are sufficient to perform the installation of the mooring systems	0%
	Winch drum capacity [m]	Ensure the winch drum capacity of the anchor handling vessels are sufficient to perform the installation of the mooring systems	0%
Jack-up capabilities	Maximum payload (t)	Ensure the total weight on the deck does not exceed the maximum payload	20%
	Leg max. operating water depth (m)	Ensure the leg max. operating depth is suitable for the working site bathymetry	20%

Table 6-18 Equipment feasibility functions and safety factors

	Equipment parameter verified (unit)	Methodology	Safety factor (in %)
ROV	ROV manipulator max. grip force (N)	Verify the suitability of the ROV arm manipulator for performing wet mate connections.	20%
	Depth rating (m)	Ensure the depth rating of the onboard ROV inspection class is superior to the maximum operating water depth.	0%
Diver team	Depth rating (m)	Ensure the depth rating of the diving team is superior to the maximum operating water depth	0%

Piling equipment	Max. pile sleeve diameter (m)	Ensure the piling equipment has a sleeve diameter exceeding the maximum diameters of ALL piles to be installed at site	20%
	Max. pile weight capacity (t)	Ensure the piling equipment has a weight capacity exceeding the maximum individual weight among ALL piles to be installed at site	20%
	Depth rating (m)	Ensure the depth rating of the piling equipment is superior to the maximum water depth of the foundations	0%
Cable Burial Tool	Max. Trench depth [m]	Ensure the max. trench depth of the cable burial tool is superior to the maximum burial depth within the cable route	0%
	Max. Cable diameter [mm]	Ensure the max. cable diameter of the cable burial tool is superior to the maximum cable cross section diameter	0%
	Min. Cable bending radius [m]	Ensure the min. bending radius of the cable burial tool is superior to the min. bending radius of the cable	0%
	Max. Operating depth [m]	Ensure the depth rating of the cable burial tool, is superior to the maximum water depth of the cable route with burial requirements	0%
Split Pipes	Max. Cable size [mm]	Ensure the max. cable size of the cast-iron pipes is superior to the maximum cable cross section diameter	0%
	Min. Bending radius [m]	Ensure the min. bending radius of the cast-iron pipes is superior to the min. bending radius of the cable	0%