Advanced Design Tools for Ocean Energy Systems Innovation, Development and Deployment

Deliverable D5.1

Technical Requirements for the Deployment Design Tools

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EXECUTIVE SUMMARY

This document, D5.1 Technical Requirements for the Deployment Design Tools, is a deliverable of the DTOceanPlus project, which is funded by the European Union's H2020 Programme under Grant Agreement №785921.

The overarching objective of the DTOceanPlus project is to develop and demonstrate an open source, integrated suite of 2nd generation design tools for ocean energy technologies that support the entire technology innovation process. The suite of design tools will be applicable to different levels of technology (from sub-systems, to devices and arrays) and across all stages (from concept, to development and deployment). DTOceanPlus will assist users in working towards an optimal solution based on information available at a stage. The DTOceanPlus suite of design tools can help accelerate the development of the ocean energy sector and reduce the technical and financial risks of devices and arrays to achieve the deployment of cost-competitive wave and tidal arrays.

A coherent set of functional and technical requirements have been developed for the DTOceanPlus suite of design tools based on analysis of gaps between the current state-of-the-art tools, learning from the original DTOcean project, and the stakeholder expectations identified in the user consultation survey. The technical requirements in this document are translated from the general requirements for the overall suite of tools, and specific requirements (functional, operational, user, interfacing, and data) for the Deployment design tool that will be developed as part of this project.

D5.1 includes a detailed description of the technical requirements of each of the Deployment design tools to be developed within the DTOceanPlus project; moreover, a full section is dedicated to the technical requirements for the integration of the Deployment design tools with the other sets of tools (Assessment design tools, Structured Innovation design tools and Stage Gate design tools), as well as for the integration with the underlying platform and the digital representations and for the interaction with the user.

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ABBREVIATIONS AND ACRONYMS

AEC	Annual Energy Captured
AET	Annual Energy Transformed
AEP	Annual Energy Production
API	Application Programming Interface
BEM	Boundary Element Method
BIM	Building Information Modelling
BoM	Bill of Materials
BV	Bureau Veritas
CAD	Computer Aided Drawing/Design software
CAPEX	Capital Expenditure
CFD	Computational Fluid Dynamics software
cFMEA	Concept-design Failure Modes and Effects Analysis
CMEMS	Copernicus Marine Environment Monitoring Service
CPU	Central Process Unit
CSV	Comma Separated Variables
dFMEA	Design Failure Modes and Effects Analysis
Dx.x	Deliverable x.x from a task or work package
DR	Digital Representation
DSM	Design Structure Matrix
EC	Energy Capture Module
ED	Energy Delivery Module
EDF	Electricite de France
EnFAIT	Enabling Future Arrays in Tidal
ESA	Environmental and Social Acceptance module
ESC	Energy Systems Catapult
FMEA	Failure Modes and Effects Analysis
GIS	Geographical Information Systems
GUI	Graphical User Interface
HoQ	House of Quality Matrix
I/O	Input/Output
IP	Intellectual Property
IRR	Internal Rate of Return
LCOE	Levelised Cost of Energy
LMO	Logistics and Marine Operation Planning module
MAP++	Mooring Analysis Program
MRE	Marine/Ocean Renewable Energy
NPV	Net Present Value
O&M	Operations and Maintenance
OEC	Offshore Energy Converter (aggregate term for WEC & TEC)
OEM	Original Equipment Manufacturer
OES	Ocean Energy System
OTPS/TPXO	OSU Tidal Prediction Software /
PE	Power Electronics
PTO	Power Take-Off
QFD	Quality Function Deployment
R&D	Research and development
RAMS	Reliability, Availability, Maintainability, Survivability

SC	Site Characterisation (module)
SCGI	Squirrel Cage Induction Generator
SG	Stage Gate (tool)
SI	Structured Innovation (tool)
SK	Station Keeping (module)
SLC	System Lifetime Cost assessment module
Tx.x	Task x.x within a work package
TEC	Tidal Energy Converter
TRIZ	*Teoriya Resheniya Izobretatelskikh Zadatch*, (theory of inventive problem solving)
TRL	Technology Readiness Level
UEDIN	University of Edinburgh
UI	User Interface
UML	Unified Modelling Language
WAM	Wave Model
WEC	Wave Energy Converter
WES	Wave Energy Scotland
WP	Work Package
WW3	WaveWatch III model

DTOCEANPLUS TERMINOLOGY

The following hierarchy is used to describe DTOceanPlus, illustrated in Figure 0.1:

Suite of Tools Over-arching term for all the tools in DTOceanPlus (shown as a dark blue dashed line in Figure 0.1).

Design Tools The DTOceanPlus suite comprises of four design tools (shown in blue): 'Structured Innovation', 'Stage Gate', 'Deployment', and 'Assessment'.

Modules The design tools (except Stage Gate) are split into modules e.g. 'QFD', 'Site Characterisation', 'Energy Capture', 'System RAMS (Reliability Availability Maintainability and Survivability)' (shown in light blue). This follows the terminology of the original DTOcean software.
These each contain multiple functions/processes/routines etc. that perform the calculation/assessment (not shown for clarity).

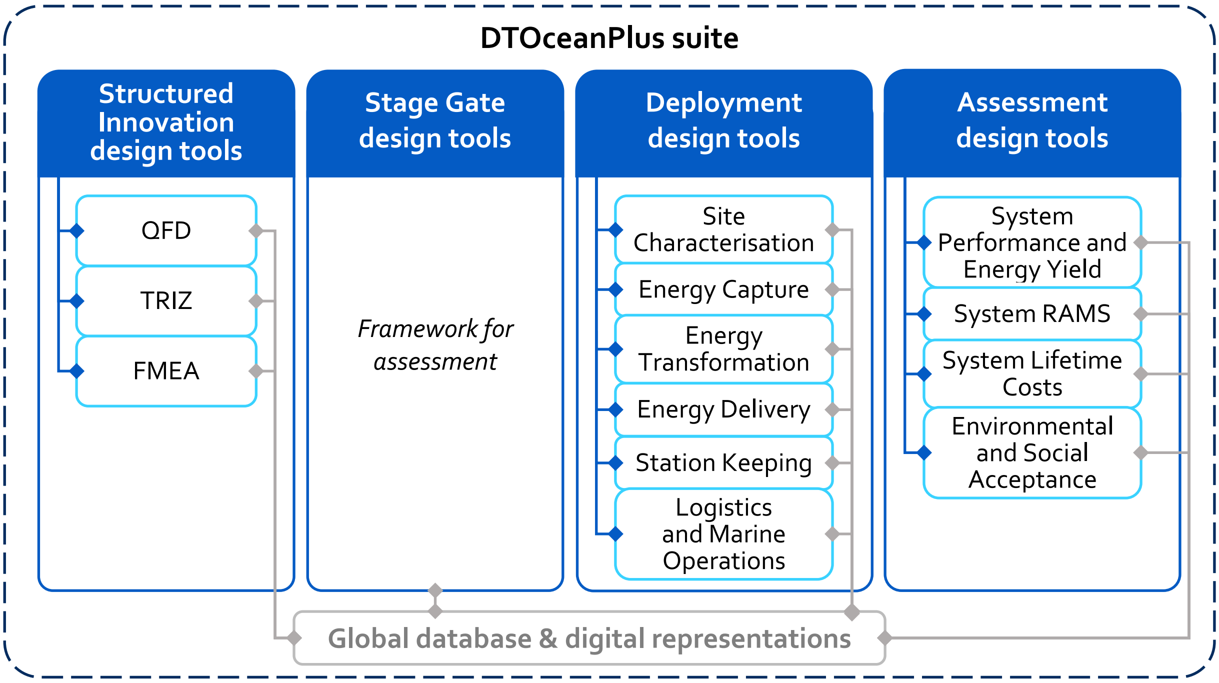


FIGURE 0.1 REPRESENTATION OF THE DTOCEANPLUS TOOLS HIERARCHY

In addition, there are a number of terms with a specific meaning generally or within DTOceanPlus.

Operational Requirements Define the major purpose of a system (i.e. what it fundamentally does; its capability) together with the key overarching constraints. The Operational Requirement(s) is a succinct clear and unambiguous statement as to what the system fundamentally does, including its key constraints.

Functional Requirements Specify what the system must do to achieve the Operational Requirements. A Functional Requirement does not define how it is done or how well it is done and should be implementation independent.

Technical requirements Factors that are required to deliver a desired function or behaviour from a system to satisfy a user's standards and needs. Specify how to implement what the

	system must do in order to get what is required. These include accessibility, adaptability, usability, auditability, maintainability, performance, etc.
Digital Representation	A complete description of the user's project at a given time. It can be seen as a digital version of the real project and therefore it should contain all the needed information to describe the project. It describes all the concepts defined in the DTOceanPlus application (concept creation, contradictions ...). Each of these concepts is handled by one of the tools of the application, so it means that the Digital Representation can be seen as an assembly of the extracted data from each tool, and as an export of the current project. This export will be done in a standard format, such as XML or JSON, with a documented structure so that it can be used by other applications. However, the Digital Representation is not a complete export of a DTOceanPlus project. Indeed, as this format is presented as a standard to represent an ocean energy system, it is important that it remains independent from the DTOceanPlus application. Therefore, not all the concepts that are internal to DTOceanPlus application should be exported in the Digital Representation.
Global database	A shared structured dataset containing input data, the digital representations of components to arrays, and accessed by all the design tools. It contains the Reference Database which is a package that contains a list of catalogues. These catalogues can be described as standard references that can be imported from organisations (e.g. list of devices or vessels) or can come from several databases (local or online), or even files (CSV or any format).
User Interface/ Graphical User Interface	"The user interface (UI), is the space where interactions between an end user and a machine occur to allow effective operation and control in order to achieve desired output(s). The graphical user interface (GUI) is a form of UI that allows users to interact with electronic devices through graphical icons and visual indicators, instead of text-based user interfaces[1]".
Local Storage	A structured dataset containing input data only relevant to the Structured Innovation modules. The DTOceanPlus modules can be developed in a way that they can be run independently in a standalone mode, or with the rest of the modules in the DTOceanPlus application. This can be useful for users who want to use one of the tools, and who won't need to install the full platform but only one tool. A standalone module can work independently with the required data saved in the local storage, but also use data from the database.
Quality Function Deployment (QFD)	A structured method used to identify, prioritise customers' requirements and translate them into suitable technical requirements for each stage of product development and production. It is achieved using the House of Quality (HoQ)

[1] https://en.wikipedia.org/wiki/Graphical_user_interface

	which is a matrix used to describe the most important product or service attributes or qualities [1].
Theory of Inventive Problem (TRIZ)	A systematic problem-solving approach based on universal principles of creativity, patents and research. The module looks to identify the generic concept problems and solutions, and to eliminate the technical and/or physical contradictions.
Failure Modes and Effects Analysis (FMEA)	A module used as a risk analysis and mitigation tool to improve development ventures. At concept and design phases, the concept or design FMEA mitigates risks associated with the various concept selections [2].
Stage Gate Metrics	The measures of success which define the performance of a technology. These are strongly linked to the Deployment and Assessment tools which calculate the required metrics.
Evaluation Areas	These are a list of the topics which are to be assessed. Examples of some of these are: Maintainability, Installability and Energy Capture.

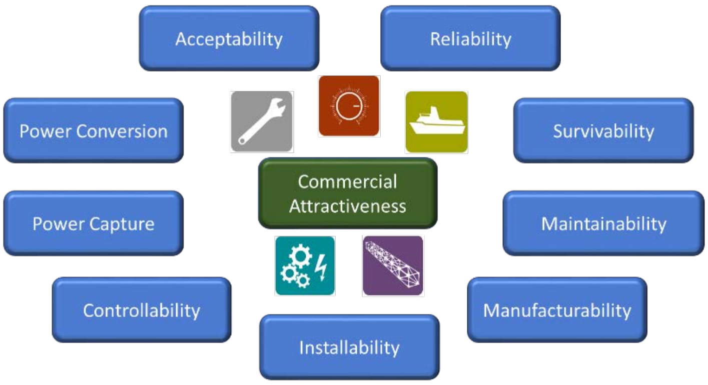


FIGURE 0.2 EXAMPLE OF EVALUATION AREAS IN THE ASSESSMENT OF THE COMMERCIAL ATTRACTIVENESS OF OCEAN ENERGY TECHNOLOGY

Stage gate metric thresholds	These are the user defined performance criteria which must have been achieved for a technology to "pass" a particular metric within a topic area. These may be defined by the users of the tool themselves, or they can be selected from a list of default values. For example, Metric: Mean Time To Failure, MTTF (hours), Threshold: 50000 hours
Stage Activities	These are the activities which have taken place in the development of a technology. For example, this includes "Numerical models have been completed and validated against tank test data", "Small scale physical testing is complete in realistic wave conditions".
Stage Gate Metrics Framework	The structure which defines what to assess, in what level of detail, and against which benchmarks for success for technologies in a technology development process.

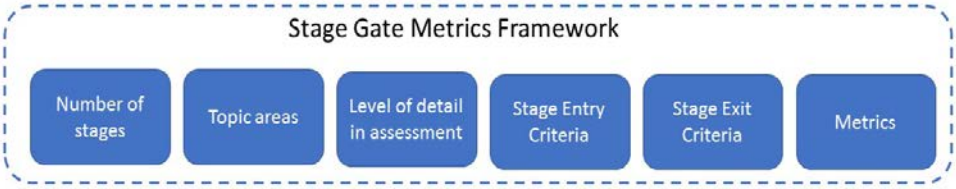


FIGURE 0.3: REPRESENTATION OF A STAGE GATE METRICS FRAMEWORK

Within a stage gate metrics framework, the following is defined:

- Number of stages within the stage gate metrics framework
- Stage entry and stage exit criteria Topic areas: These are a list of the topics which are to be assessed and are linked to the Deployment and Assessment tools. Examples of some of these are: Maintainability, Installability and Energy Capture.
- Level of detail for each stage and topic area: At lower TRL (lower maturity), technologies are likely to have less data supporting their performance and therefore will be assessed at a higher and less detailed level. At higher TRL (higher maturity), there may be more data available and therefore the level of assessment can be more complex and detailed.
- Metrics: The measures of success, these are the measures which define the performance of a technology.

Stage Entry Criteria Defined activities which have taken place in the development of a technology – but not the results of such activities (i.e. It is not a measure of performance). For example, Entry to Wave Energy Scotland (WES) Stage 2 includes "Numerical models have been completed and validated against tank test data" or "Small scale physical testing is complete in realistic wave conditions".

Stage Exit Criteria The thresholds of performance which must have been achieved for a technology to "pass" a stage which it is being assessed against. These may be defined by the users of the tool themselves, or they can be selected from a list of default values.

Power Take-Off Subsystem to convert mechanical energy (from Hydrodynamic subsystem) to useful electrical energy. It is composed of at least of prime mover, an electrical generator and a power converter.

Annual Energy Production (AEP) Average annual electricity production, in MWh, of a device or array.

Bill of Materials List of components, sub-assemblies and/or logistical actions that are associated with a project, technology or subsystem under analysis, with associated quantities

Discount Rate The discount rate is a measure of time-value, which is the price put on the time that an investor waits for a return on an investment. Furthermore, the discount rate is also used to account for the risks and uncertainties of an investment. It is used for present value calculations.

Capital Expenditure (CAPEX) Initial costs for setting up a project, including project development, site preparation, procurement, construction and installation.

Internal Rate of Return (IRR)	Discount Rate that sets the net present value of all cash flows at zero. It is the rate at which the project will reach the break-even point at end.
Levelised Cost of Energy (LCOE)	Economic assessment of the energy-generating system costs over its lifetime, accounting for the time-value of money and risk.
Net Present Value (NPV)	Sum of the present values of the individual cash flows of the same entity. It is a measure of the profitability of a project.
Operational Expenditure (OPEX)	All the cost incurred during the operational lifetime of the project.
Development Expenditure (DEVEX)	All the cost incurred from initiation to implementation of a project.
Payback time	The payback period is the time needed for the project to break even. It can be simple, i.e. not accounting for time-value, or discounted, i.e., using a discount rate.
Present value	The value of a future quantity at the present time, accounting for time-value and risk.
Weighted Average Cost of Capital (WACC)	The rate obtained by combining the rates on investment and/or interest rates of the different financing options, weighted by the contribution to financing.
Receptor	A receptor is the entity that is potentially sensitive to a stressor (see definition of stressor below) related to an ocean energy project. Receptors can be for instance *marine mammals or birds* (sensitive to stressors such as collision risks with vessels or underwater noise due to operation and maintenance); *seabed habitat and associated communities* that can be degraded due to anchoring systems or; *fish and invertebrates* that can be impacted by chemical pollution such as oil or lubricants used by vessels and marine infrastructures. In DTOceanPlus, social acceptance will also be considered as a receptor. Estimating carbon footprint for manufacturing materials, producing energy or operation and maintenance activities can have an impact on *social acceptability*.
Stressor	A stressor is any physical, chemical, or biological entity that can generate a pressure or an environmental/ social impact. Stressors create a pressure on the environment such as *collision risk* (i.e. interaction between wildlife – e.g. mammals and birds – and vessels that may result in physical injuries); *footprint* (i.e. seabed that can be degraded by operation and maintenance activities - e.g. anchoring systems) or *carbon footprint* for manufacturing materials, producing energy or operation and maintenance activities.
Structured Innovation	A technique to stimulate rigour, organised and consistent innovative thinking, technology selection and impact assessment. This technique combines functions such as understanding the mission, the future vision, the market (including the potential for commercial exploitation, competition, differentiation, social value

Methodology

etc.) and the development of potential solutions. This is broadly described in British Standard BS7000-1, "Design Management Systems, Part 1 – Guide to Managing Innovation" amongst others [3]. The methodology is to be developed in accordance with the concept shown in Figure 0.4:

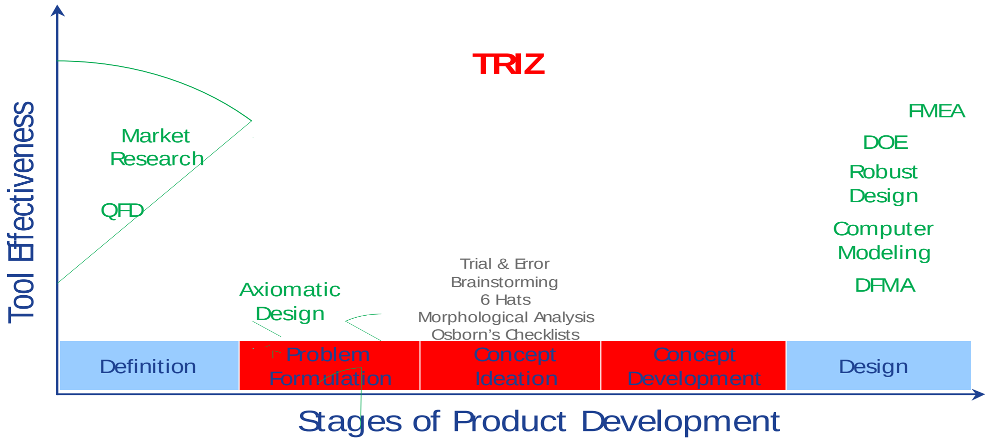


FIGURE 0.4: TOOL EFFECT VS PRODUCT DEVELOPMENT STAGE [4]

1. INTRODUCTION

The DTOceanPlus project will develop an open-source integrated suite of 2nd generation tools for ocean energy technologies [5]. The tools will support the entire technology innovation and advancement process from concept, through development, to deployment, and will be applicable at a range of aggregation levels: sub-system, device, and array.

The proposed tools are covered in more detail in section 1.4. At a high level, these will include:

- **Structured Innovation tool**, for concept creation, selection, and design.
- **Stage Gate tool**, using metrics to measure, assess and guide technology development.
- **Deployment tool**, supporting optimal device and array deployment.
- **Assessment tool**, used by the other tools to quantify key parameters.

1.1 SCOPE OF REPORT

This report is the outcome of Task 5.1 'Technical requirements for ocean energy deployment tool'. It is one of four concurrent deliverables to produce detailed specifications for the DTOceanPlus software tool development in conjunction with tasks T3.1, T4.1, T6.1, and T7.1 of work packages 3–7, as shown in figure 1-1.

These deliverables document the current understanding of the requirements at the time of writing. It is inevitable however that some of the specific details of implementation will change over the course of the software development. The full description of the technical specifications of the tools will be published in the technical manuals to accompany the final software release.

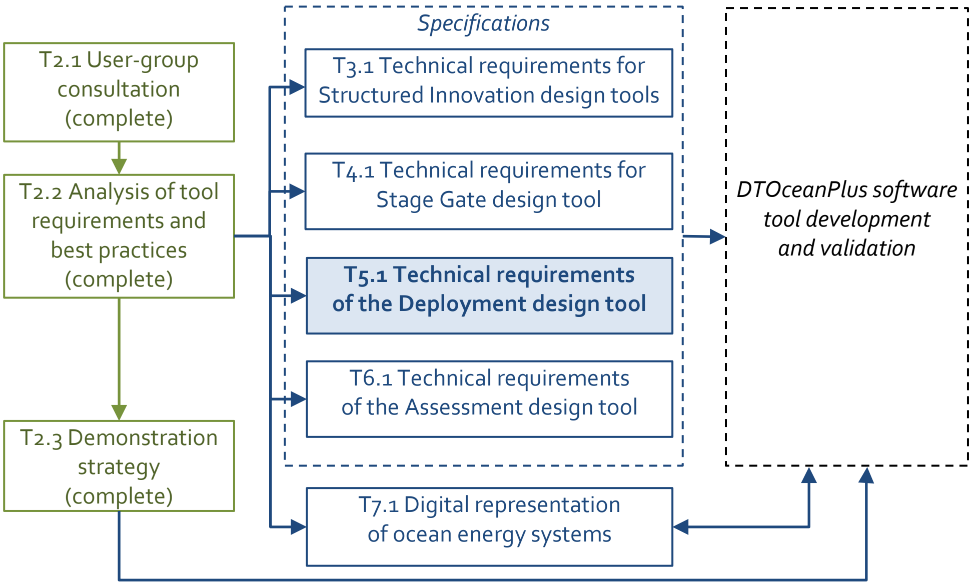


FIGURE 1-1: GRAPHICAL SUMMARY OF SOFTWARE SPECIFICATION TASKS (EXTRACTED FROM GRAPHICAL PRESENTATION OF THE PROJECT [6])

1.2 OUTLINE OF REPORT

This report specifies the detailed requirements (functional, operational, user, interfacing, and data) for the DTOceanPlus suite of tools.

The remainder of the report is laid out as follows:

- Section 2 sets out the technical requirements of the Deployment design tool.
- Section 3 sets out the technical specifications for the integration of the Deployment design tool in the DTOceanPlus suite of tools.
- Finally, section 4 gives conclusions and summarises the next steps.

1.3 TECHNICAL SPECIFICATIONS OF DTOCEAN

The original DTOcean Project produced a first generation of freely-available open-source design tools for wave and tidal energy arrays. The project built an integrated suite of tools [7] split into five modules or stages:

- **Hydrodynamics**: designs the layout of converters in a chosen region and calculates their power output.
- **Electrical sub-systems**: designs an electrical layout for the given converter locations and calculates the electrical energy exported to shore.
- **Moorings and foundations**: designs the foundations and moorings required to secure the converters at their given locations.
- **Installation**: designs the installation plan for the energy converters and the components required to satisfy the electrical sub-system and moorings and foundations designs.
- **Operations and maintenance**: calculates the required maintenance actions and power losses resulting from the operation of the converters over the lifetime of the array.

These were brought together by a global decision tool containing optimisation routines, as shown in Figure 1-2. These routines evaluate each stage of the design, and the design as a whole, using three thematic assessments:

- **Economics**: produces economic indicators for the design, in particular the Levelised Cost of Energy

  (LCOE).
- **Reliability**: assesses the reliability of the components in the design over the array lifetime.
- **Environmental**: assesses the environmental impact of each stage of the design.

The original DTOcean suite of tools is currently considered to be at TRL 4, having been validated in a research (laboratory) setting.

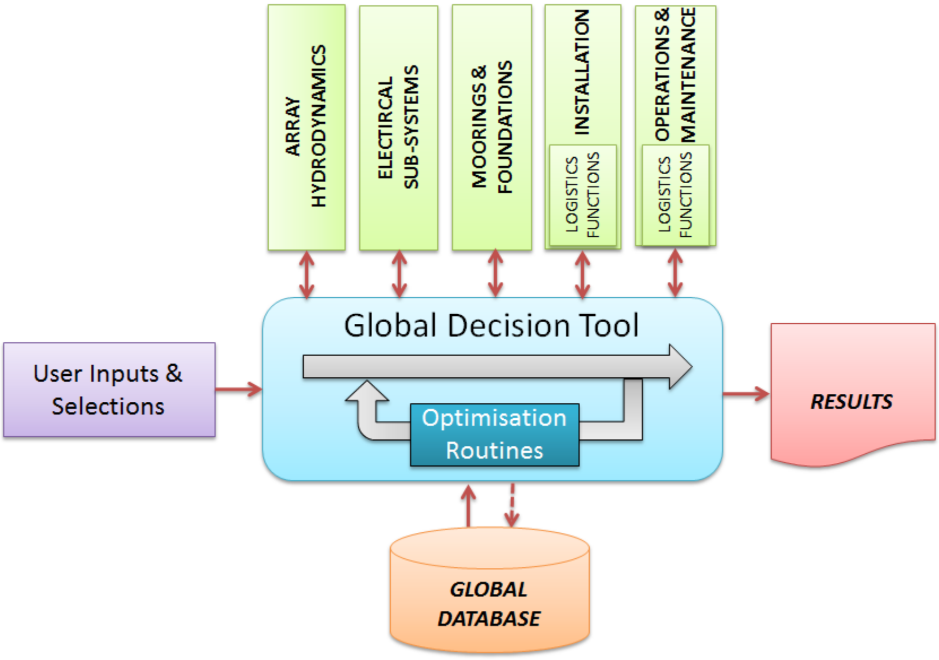


FIGURE 1-2: FUNCTIONAL STRUCTURE OF ORIGINAL DTOCEAN SOFTWARE [7]

1.4 OUTLINE OF THE DTOCEANPLUS SUITE OF TOOLS

The DTOceanPlus software will comprise an integrated suite of 2nd generation design tools, which are summarised below and illustrated at a high level in Figure 1-3. These build upon the tools originally developed in the DTOcean project[2] between 2013 and 2016, and the latest release of DTOcean 2.0[3].

- The Structured Innovation and Stage Gate design tools are new to DTOceanPlus. Based on best practices from the ocean energy and other sectors, they will provide structured methods for concept creation and assessing the progress of technology development through defined stages and stage gates. The Deployment and Assessment Design Tools will be significantly improved from the original DTOcean versions. The whole suite of design tools will be designed to assess various levels of complexity and to be used throughout the project lifecycle.
- **Structured Innovation design tool**, for concept creation, selection, and design, with three modules:
  - Quality Function Deployment (QFD).
  - Theory of Inventive Problem Solving (TRIZ).
  - Failure Modes and Effects Analysis (FMEA).
- **Stage Gate design tool**, using metrics to measure, assess and guide technology development. As part of this, the DTOceanPlus project will develop:
  - A stage-gate structure.
  - Metrics.

[2] Funded under EU FP7 framework Grant Agreement № 60859
[3] https://www.dtoceanplus.eu/Tools/DTOcean-Version-2.0

  - Tools for measuring success and analysing performance against metrics and thresholds.
  - Stage gates and metrics graded to the relevant stage in through the technology development process.
- **Deployment design tools**, supporting optimal device and array deployment. These will improve and expand on the capabilities of the original DTOcean software to consider the main functionalities of ocean energy technologies and systems, split into six modules:
  - Site Characterisation (e.g. metocean, geotechnical, and environmental conditions), a new module within DTOceanPlus.
  - Energy Capture at an array level.
  - Energy Transformation (PTO and control), also a new module within DTOceanPlus.
  - Energy Delivery (electrical and grid issues).
  - Station Keeping (moorings and foundations).
  - Logistics and Marine Operations (installation, operation, maintenance, and decommissioning), with expanded scope beyond just O&M in DTOcean.
- **Assessment design tools**, will provide objective information to the developer or investor on the suitability of a technology and project, and will also support the other DTOceanPlus design tools, split into four modules:
  - System Performance and Energy Yield.
  - System Lifetime Costs.
  - System Reliability, Availability, Maintainability, Survivability (RAMS), with significantly expanded scope beyond just reliability in DTOcean.
  - Environmental and Social Acceptance, with expanded scope from DTOcean to also include social aspects.
- Underlying these will be **common digital models** and a **global database**.
  - A digital representation will be developed to provide a standard framework for the description of sub-systems, devices and arrays. This will be a common digital language for the entire sector.
  - The global database will contain catalogues of reference data from various sources.

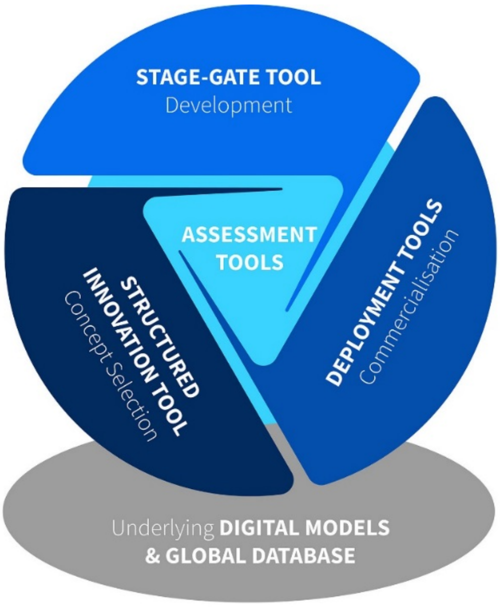


FIGURE 1-3: REPRESENTATION OF DTOCEANPLUS TOOLS.

The technical requirements for the Stage Gate design tool are set out in this document. Accompanying deliverables set out the technical requirements for the other design tools as follows: D3.1 Structured Innovation, D5.1 Deployment, and D6.1 Assessment. Further details of the common digital models or digital representation will be proposed in D7.1 'Standard data formats for the Ocean Energy Sector' due to be published in autumn 2019.

USE AT DIFFERENT LEVELS OF COMPLEXITY

DTOceanPlus will support the development of ocean energy technologies at all stages of the project lifecycle — from concept creation through design development to commercial deployment — with increasing level of data available and detail required at each. It will also be designed to support users with differing requirements in terms of detail; from investors wishing for a high-level overview of a technology or project, to developers performing more detailed technical assessments, e.g. for project consenting.

The project lifecycle can be seen from two complementary perspectives:

- The chronological phases of a project: namely conception, design, procurement, construction, installation, operation (including maintenance), and decommissioning.
- The project development and/or the technology deployment can be split into three stages for clarity (Early, Mid, and Late), as described in Table 1-1. These can broadly be linked to the widely-used TRL scale [8]. Those three stages address all the phases described above, with different levels of complexity accounted for in the project definition.

TABLE 1-1. INDICATIVE STAGES OF PROJECT DEVELOPMENT LINKED TO TRL AND DEVELOPMENT PROGRESS USED WHEN DEFINING DTOCEANPLUS REQUIREMENTS.

STAGE	APPROX. TRL	DEVELOPMENT PROGRESS	DESCRIPTION

Early	1-3	Concept definition	Early stage analysis of potential device or site. Gives an overview of capabilities and next development steps, but may be based on limited data.
Mid	4-6	Feasibility	Includes an in-depth study of the topics covered in the concept definition. More accurate than previous stage, with additional data requirements.
Late	7-9	Design and deployment	Key project features are planned in this stage, informed by the previous phases. Makes use of detailed information about the project.
Note that while three stages are shown here to guide the functional requirements and ensure the varying level of complexity throughout the project lifecycle is being addressed appropriately, the number and scope of stages used in DTOceanPlus will be configurable by the user as required.			

As well as being used at different stages in the project development lifecycle, DTOceanPlus will also be applicable to three different levels of aggregation, specifically:

- **Sub-system**, e.g. PTO, or moorings and foundations that form part of a device.
- **Device**, i.e. one complete system that can be deployed individually or to make up an array.
- **Array** of multiple devices deployed in a farm.

Where applicable, the design tools will consider details of assemblies and components, however they will not be designed to assess technologies at this level.

The design tools within the DTOceanPlus suite can be summarised as follows:

- The Structured Innovation design tool generates new concepts; including novel concepts for wave and tidal energy devices, or an improvement of a sub-system, device, or array at higher maturity level. The tool also provides the ability to assess technologies at the early concept stages when there is minimal data available and will inform part of the inputs for the Stage Gate design tool.
- The Stage Gate design tool supports the objective assessment of technologies in the development process, ensuring a fair assessment of sub-systems, devices and arrays from early stage concepts up to commercial deployment.
- The Deployment design tools provide optimised solutions and layouts for the deployment of ocean energy technologies, and define all the technical design specification to run the Assessment design tools for the evaluation of metrics.
- Finally, the Assessment design tools execute the key calculations to measure the vital parameters at all stages of the project lifecycle, and ultimately support the Stage Gate design tool by delivering these fundamental computations.

Therefore, an important functionality of DTOceanPlus is the ability to assess the performance of technologies throughout the project lifecycle, as a technology matures; when there is little to no data available about a technology at the concept definition stage, and more data from testing and simulations at the design and deployment stage.

Table 1-2 below outlines how the assessment method changes through these different stages, depending on the data available. This assessment is a key functional requirement of the software, and will have consistency in the approach through integration of the tools provided by the Digital Representation. As a running theme throughout the project lifecycle, assessment of sub-systems, devices and arrays must be flexible to the users' requirements depending on the particular user type, the maturity of the technology and the amount of data available. This is highlighted in the use cases described in section 2.2 of D2.2 Functional requirements and metrics of 2nd generation design tools [9].

TABLE 1-2 INCREASING TOOL COMPLEXITY FOR DIFFERENT DEVELOPMENT STAGES.

Stage & approx.TRL	Data availability	Assessment method
Early stage (TRL 1–3)	Little quantitative data available; overview of capabilities and operating modes	Assessment through the Structured Innovation and Stage Gate design tools by utilising the earliest level assessments of technologies; these may use: ▫ Fundamental physics, engineering and economic relationships. ▫ High-level quantitative assessments from the Assessment and Deployment design tools. ▫ Scoring of a technology by qualitative assessment from an expert assessor.
Mid stage (TRL 4–6)	Low complexity; limited data available	High-level 'basic' quantitative assessments through the Deployment and Assessment design tools. These can be the same as the detailed 'advanced' tools but with simple parameters and/or default values used.
Late stage (TRL 7-9)	Full complexity; makes use of detailed information about the project.	More detailed 'advanced' quantitative assessments through the Deployment and Assessment design tools.

2. TECHNICAL REQUIREMENTS OF THE TOOL

In this section, the technical requirements for all the modules of the Deployment design tool developed in DTOceanPlus will be described.

As part of the Agile Modelling approach [10], the technical requirements include a set of non-functional requirements that the software should be able to satisfy in order to accomplish the specific functions to be carried out. Essentially, these involve performance, reliability, and availability issues. In the following sections, the discussion is focused on not-pure technical requirements, rather than specific technologies. This prevents requirements from becoming obsolete as technologies change. Indeed, the following sections make reference to the data requirements and the main classes of technologies such as the GUI, the global database, each tool local storage, etc…

The technical requirements are numbered following a "business rule", i.e. TR-XXX-YY, where YY is the sequential number of the technical requirement of tool XXX indicated by the acronym of the tool.

The following sections 2.1–2.6 will be organised in four sub-sections:

1. FROM FUNCTIONAL TO TECHNICAL REQUIREMENTS: in this subsection, the transition from functional requirements identified in D2.2 Functional Requirements [9] towards the technical requirements is described as well the connection between them;
2. ARCHITECTURE OF THE TOOL: in this subsection, the main architecture of the tool is described. A diagram for each tool will illustrate the flow of the actions that the tool will carry out when running, the functions that are implemented and the interactions with other modules of the tool;
3. MAIN FUNCTIONS AND MODELS: in this subsection, the main functions are described;
4. DATA REQUIREMENTS: in this subsection, a brief overview of the requirements in terms of data and their internal-to-the-tool organisation into classes.

Following this, sections 2.7 and 2.8 will collect general technical requirements, applicable to all or most of the set of tools, covering:

- INTERFACES/COMPATIBILITY/PORTABILITY: in this section, the possibility of connecting the tool to other software (commercial, open-source, in-house) through the use of interfaces is described, as well as the ability to import inputs and export outputs.
- MAINTENANCE: in this section, the management of extensions and updates in the future is briefly discussed.

2.1 SITE CHARACTERISATION

The Site Characterisation (SC) module will process the resource information and prepare the environmental constraints for the definition of an ocean energy project. The module will cover a wide spectrum of use cases, from the development of a project for a specific site to the treatment of more generic environmental conditions to evaluate a machine performance, for example for comparing different sites.

2.1.1 FROM FUNCTIONAL TO TECHNICAL REQUIREMENTS

The following tables Table 2-1 and Table 2-2 summarise the functional requirements of the Site Characterisation (SC) module and the corresponding technical requirements.

TABLE 2-1: FUNCTIONAL AND TECHNICAL REQUIREMENTS FOR THE SITE CHARACTERISATION MODULE.

Functional Requirements	
FR-SC-1.	Select the site location
FR-SC-2.	Import the project site data
FR-SC-3.	Edit site data
FR-SC-4.	Generate characterised site data (Run current prediction solver or wave propagation solver on project area)
FR-SC-5.	Export characterised data
FR-SC-6.	Visualise site data
Technical Requirements	
TR-SC-1.	Use a geo-referenced interface (global to DTOceanPlus) to load project location
TR-SC-2.	Load the lease area
-2.a.	Enable the user to draw a polygon (area of interest for characterisation) around their project
-2.b.	Load a shapefile of the area of their project
-2.c.	Ask the user to define the lease area
-2.d.	Ask the user to define the electrical collection point (optional, if not performed in Energy Delivery module)
-2.e.	Enable the user to define specific exclusion areas such as no-go, boundary padding, cable corridor areas…
TR-SC-3.	Enable the user to load layers
-3.a.	Coastline
-3.b.	Bathymetry
-3.c.	Seabed properties (superficial sediment characteristics, equivalent roughness length, …)
TR-SC-4.	Compute statistics (and selected time series) for wind, waves and currents
-4.a.	from local DTOceanPlus database (Level 1)
-4.b.	from downloadable finer databases (Level 2)
-4.c.	from a dedicated numerical modelling (wave and current only) (Level 3).
TR-SC-5.	Export statistics (and selected time series) and loaded layers values to other tools
TR-SC-6.	Visualise statistics value on the interface at selected points
TR-SC-7.	Visualise statistics values on the interface in 2D.

TABLE 2-2: FUNCTIONAL REQUIREMENTS / TECHNICAL REQUIREMENTS RELATION MATRIX FOR THE SITE CHARACTERISATION MODULE.

		Functional Requirements					
		FR-SC-1	FR-SC-2	FR-SC-3	FR-SC-4	FR-SC-5	FR-SC-6
Technical Requirements	TR-SC-1	X					
	TR-SC-2	X					
	TR-SC-3		X	X			
	TR-SC-4				X		
	TR-SC-5					X	
	TR-SC-6						X
	TR-SC-7						X

2.1.2 ARCHITECTURE OF THE TOOL

The following UML diagram offers an overview of the Site Characterisation module displaying the flow of actions when running the design tool.

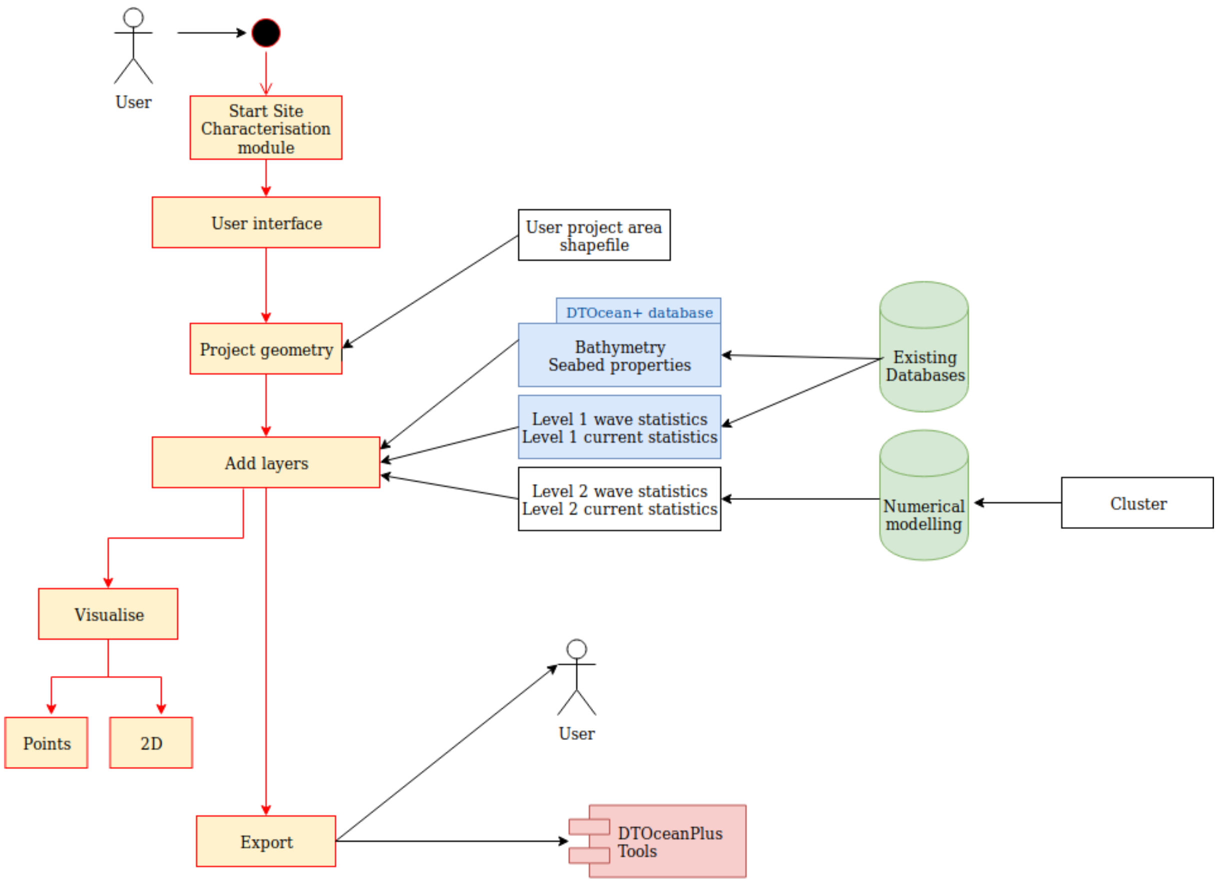


FIGURE 2-1. GENERAL ARCHITECTURE OF THE SITE CHARACTERISATION MODULE.

The Site Characterisation module will tackle three levels of complexity:

1. Level 1 "**Lower level**" => A local database will come with DTOceanPlus.

Points that are representative of the average conditions of currents, waves and wind will be chosen based on global energy atlases. At these points , statistics (scatter diagrams, quartiles, extrema...) and time series of tidal currents, waves and wind (extracted from public databases) will be provided, as well as the bathymetry and the seabed nature. At other locations (approximately 1/4° grid resolution) only the bathymetry, the seabed nature and simplified statistics will be provided, allowing the user to perform an approximate transformation of the results of the nearest representative point.

2. Level 2 "**Intermediate level**" => Local databases can be downloaded.

Databases (extracted from public database) with statistical (and selected time series) data for the most common places in Europe/the World will be prepared and can be downloaded in the Site Characterisation module.

These databases (spatial resolution of approximately 1/12° or finer) will provide bathymetry, soil properties as well as statistics and time series of tidal currents, waves and wind.

3. Level 3 "**Higher level**" => Tailored numerical runs.

The Site Characterisation module will interact and be interfaced with physical oceanography models (WW3 and Telemac 2D) at high spatial resolution on a remote cluster will be used in order to get precise statistics and selected time series at a requested site.

2.1.3 MAIN FUNCTIONS AND MODELS/USE CASES

The list of the **main functions** to be implemented in the Site Characterisation module are:

- Geo-referenced interface and all linked functions (background layer visualisation, active buttons for actions, ...) => used by SC tool but not in the scope of SC module.
- Add a geometry: user can create a polygon representing their project area
- Add a shapefile layer: user can load a shapefile of their project area
- Add a raster layer: for data (seabed properties, bathymetry, ...) layers
- Functions to compute statistics from existing databases
- Functions to select, extract and format selected time series
- Functions to create a geometry mesh file for the numerical modelling
- Pre-processing functions to create inputs for the numerical modelling
- Processing functions to launch the numerical modelling on a cluster
- Post-processing functions to format and to compute statistics from the numerical modelling
- Functions to export values from the Site Characterisation module to other DTOceanPlus tools and modules
- Visualisation functions to visualise values in the interface
- Visualisation 2D functions to visualise values in 2 dimensions on the interface

Use cases based on the various module users

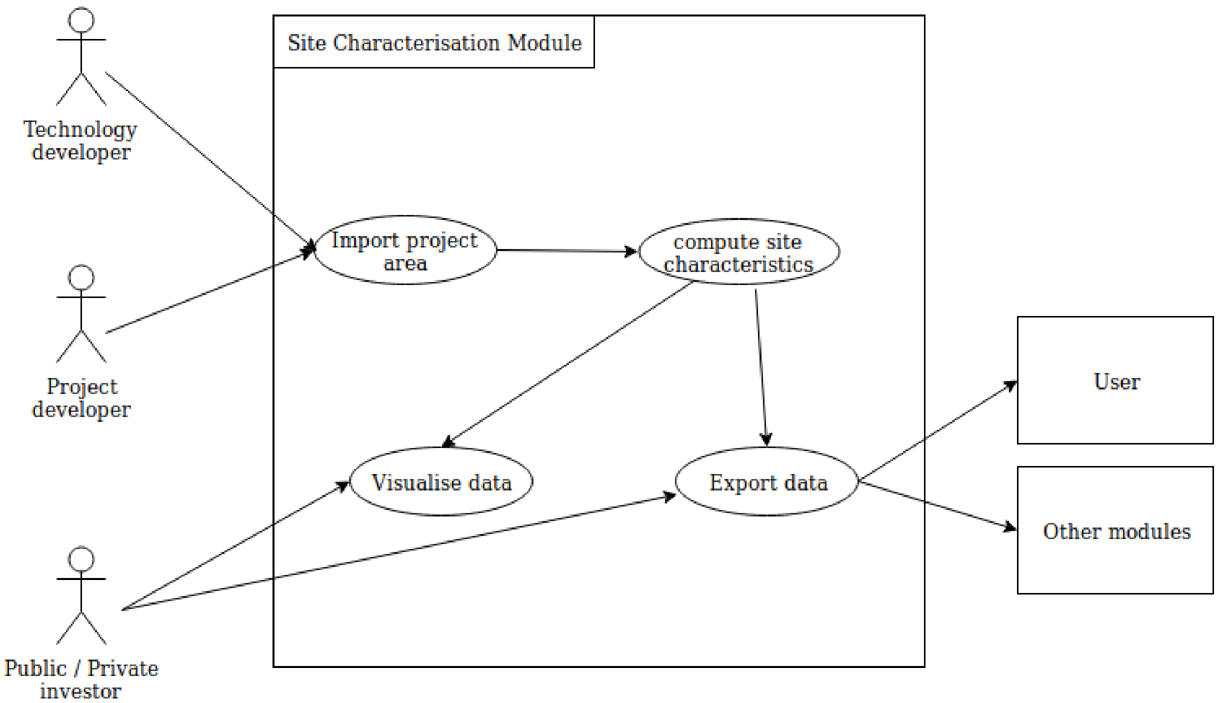


FIGURE 2-2. USE CASES FOR THE SITE CHARACTERISATION MODULE.

For the technical requirements TR-SC-4a and TR-SC-4b, three existing databases will be used (note that the presented databases are global, could be others only for European coasts):

- **CMEMS Waves:** CMEMS Waves is the operational global ocean analysis and forecast system of Météo-France with a resolution of 1/12 degree. This system provides daily analysis and 5 days forecasts for the global ocean sea surface waves.

- **OTPS/TPXO:** The harmonic (tidal) component of the current will come from the TPXO/OTPS (Oregon State University (OSU) Tidal Prediction Software) solution.

- **ERA 5:** ERA5 is the fifth generation ECMWF atmospheric reanalysis of the global climate. Reanalysis combines model data with observations from across the world into a globally complete and consistent dataset using the laws of physics.

ERA5 provides estimates for each hour of the day, worldwide, with a 0.25° horizontal resolution.

In order to address the technical requirement TR-SC-4c, two models will be adopted to compute statistics (and selected time series) for wind, waves and currents:

- **Telemac2D**: This numerical flow model is part of the OpenTELEMAC suite developed by the LNHE (Laboratoire National d'Hydraulique et Environnement) of EDF R&D (Hervouët, 2000).

Telemac2D is a two-dimensional (2D) model that uses unstructured meshes and a finite-element method to solve 2D Navier-Stokes equations as well as transport and diffusion equations.

- **WaveWatch III**: WaveWatch III is a third-generation wave model developed at NOAA/NCEP in the spirit of the Wave Model WAM model. WaveWatch III solves the random phase spectral action density balance equation for wavenumber-direction spectra.

2.1.4 DATA REQUIREMENTS

The class diagram for the data in the site characterisation module is presented in Figure 2-3, and the requested inputs and outputs are described below :

The Site Characterisation module requires the following input data (green box):

- Coastline in a shapefile format
- Bathymetry in a raster format
- Seabed properties in a raster format
- Geometry of the user project (shapefile or user selection)
- Wave statistics in a raster format (from existing databases or from numerical modelling)
- Ocean current statistics in a raster format (from existing databases or from numerical modelling).

All these required inputs (except for numerical modelling) will be saved in a local storage that will come with DTOceanPlus (red boxes).

For numerical modelling and wave propagation, the data will come from existing databases (red boxes).

Outputs to other tools and modules (blue box):

- Bathymetry
- Seabed properties (at minimum: superficial sediment typology and macroscopic roughness length)
- Geometries (lease area, exclusion zones, ...)
- Waves (at representative points for level 1): statistics (scatter diagrams, ...), spectrum, extreme values and 1-year time series.
- Tidal current (at representative points for level 1): statistics (scatter diagrams, ...), extreme values and 1-year time series.
- Wind (at representative points for level 1): statistics (scatter diagrams, ...), extreme values and 1-year time series.

The yellow boxes represent the core of the module, where the main functions are implemented.

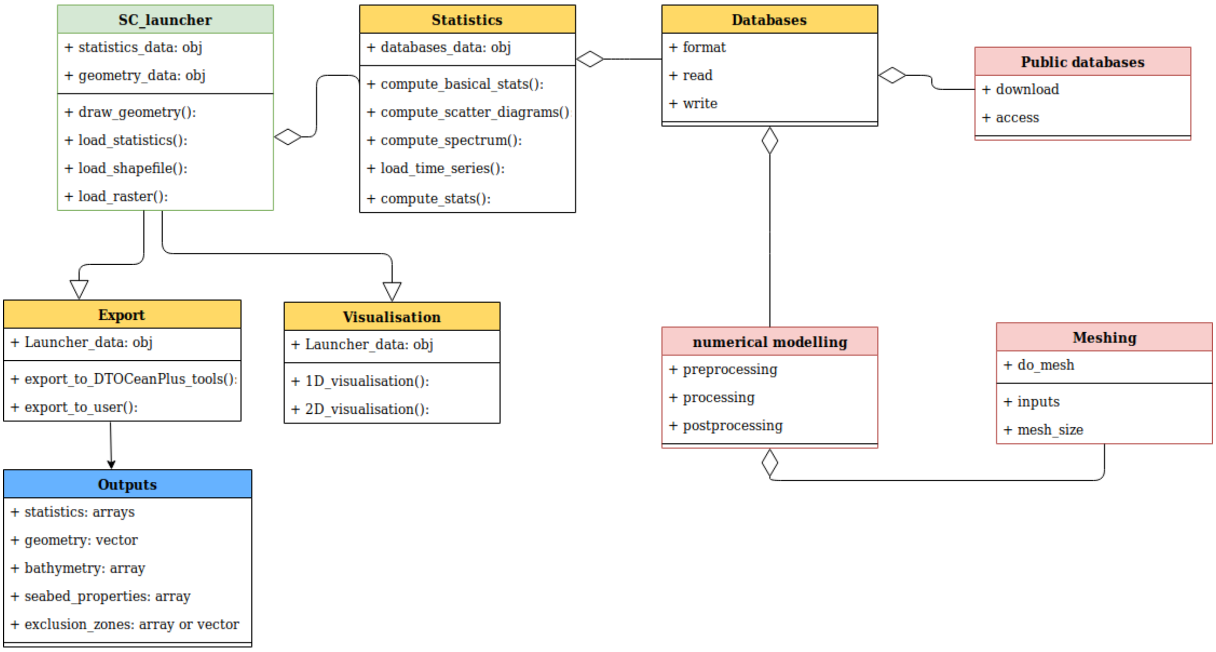


FIGURE 2-3. CLASS DIAGRAM FOR THE DATA IN THE SITE CHARACTERISATION MODULE.

2.2 ENERGY CAPTURE

The Energy Capture (EC) module assesses and designs optimal solutions for array of wave or tidal wave energy converters. The Energy Capture module has two main modes of operations: i) assessment of a user specified array layout and ii) identification of the optimal array layout. In the present context, array layout refers to the spatial location of the machines within the specified lease area, while the term "optimal array layout" refers to a layout that maximises the total mechanical energy absorbed by the converters throughout the year.

The captured power estimated by the Energy Capture module will be used as inputs for the Energy Transformation and the Energy Delivery modules.

The array annual energy production (AEP) constitutes one of the contributions for the project cost-of-energy estimation. The AEP is estimated by solving the hydrodynamic interaction between the converters within the array and the related mechanical problem.

2.2.1 FROM FUNCTIONAL TO TECHNICAL REQUIREMENTS

The identification of the technical requirements from the functional requirements specified in D2.2, is summarised in the following tables Table 2-3. and Table 2-4..

TABLE 2-3. FUNCTIONAL AND TECHNICAL REQUIREMENTS OF THE ENERGY CAPTURE MODULE.

Functional Requirements	
FR-EC-1.	Process user inputs and default values
FR-EC-2.	Solve the hydrodynamic interaction problem between converters (Tidal or Waves) in a limited time
FR-EC-3.	Find the best spatial placement of the converters in a limited time.
Technical Requirements	
TR-EC-1.	Produce outputs within a few seconds for early stage analysis, using look-up tables or simplified performance metrics to estimate farm interactions.
TR-EC-2.	Produce outputs within a few minutes/hours for medium/late stage analysis, using validated simplified numerical models to estimate the farm interactions.
TR-EC-3.	Produce outputs within a few hours /days for the late stage analysis, using validated numerical model or link to high-fidelity external numerical toolsets to estimate the farm interactions.
TR-EC-4.	Produce homogeneous results across the different project stages, using accurate models with increasingly higher precision.
TR-EC-5.	Run with incomplete input datasets, using default values, look-up tables and analytical functions for non-critical inputs.
TR-EC-6.	Produce an optimised solution if requested, using different optimisation strategies. The accuracy of the optimisation strategies will increase with the computational cost of the method.
TR-EC-7.	Usage of low computation/medium accuracy models to estimate the array energy output and layout. Due to computational cost constraints the system cannot utilise high accuracy and high precision models to solve the hydrodynamic problem. The implementation of high CPU-demanding models, such as non-linear propagation models, CFD, SPH or similar, is hindered by the excessive CPU requirement.
TR-EC-8.	Require a minimal input dataset to perform any analysis. Critical input cannot be replaced by default values or guessed, in order to not compromise the output accuracy.
TR-EC-9.	Produce an output data structure compliant with the I/O framework.
TR-EC-10.	The use of predefined structure class with embedded data type, guarantees the production of outputs compliant with the specified data format.
TR-EC-11.	Run 95% of the time if the minimum dataset of input is given. Perform input data sanity check with a dedicated interface in order to guarantee the successful run of the module. Utilisation of fixed input class with embedded data type checks on the inputs. Abort the computation if violation of the main modelling assumptions is notified. The system should be capable to abort the computation or/and inform the user if the modelling assumptions are violated in order to have a high percentage of successful run.
TR-EC-12.	Allow a user or a higher-level module to input project data and launch project simulation. A dedicated UI will be built to allow the user to interact with the EC module. The UI will have a project data section, a visualization section and a load, save section.
TR-EC-13.	Merge the project output to the Digital Representation using a dedicated interface.

Each technical requirement will be used to achieve the functional requirements. The TRs required to achieve each FR are represented in the table below:

TABLE 2-4. FUNCTIONAL REQUIREMENTS / TECHNICAL REQUIREMENTS RELATION MATRIX FOR THE ENERGY CAPTURE MODULE.

		Functional Requirements		
		FR-EC-1	FR-EC-2	FR-EC-3
Technical Requirements	TR-EC-1	X	X	X
	TR-EC-2	X	X	X
	TR-EC-3	X	X	X
	TR-EC-4	X	X	X
	TR-EC-5	X	X	X
	TR-EC-6			X
	TR-EC-7		X	
	TR-EC-8		X	
	TR-EC-9		X	X
	TR-EC-10	X		
	TR-EC-11	X		
	TR-EC-12	X		
	TR-EC-13	X		

2.2.2 ARCHITECTURE OF THE TOOL

The main code structure of the Energy Capture module resembles the hydrodynamic package proposed in the previous DTOcean project. The module comprises of an input element, delegated to perform the tasks such as input checks and input formatting, a main element and an output element. The main element uses the formatted inputs, pushing the project results to the output element and is composed at a high level of two functions.

An Array Layout Designer function generates array layouts, if not specified by the user or by the optimiser and estimates the hydrodynamic interaction between single devices within the array layout, for the given environmental conditions. This function contains two sub-functions, one to solve the hydrodynamic interaction and one to quantify the energy absorbed by the array.

The Search Optimum function identifies the array layout that maximises the annual energy output, using three methods, Brute-Force Search, Monte-Carlo Optimisation, and CMA-ES Optimisation.

The project results are then pushed to the UI or to the interfaced modules and the Digital Representation.

The overall module functionality is represented in the figure Figure 2-4.using a block diagram. The blocks represent the main logic steps that subdivide the module.

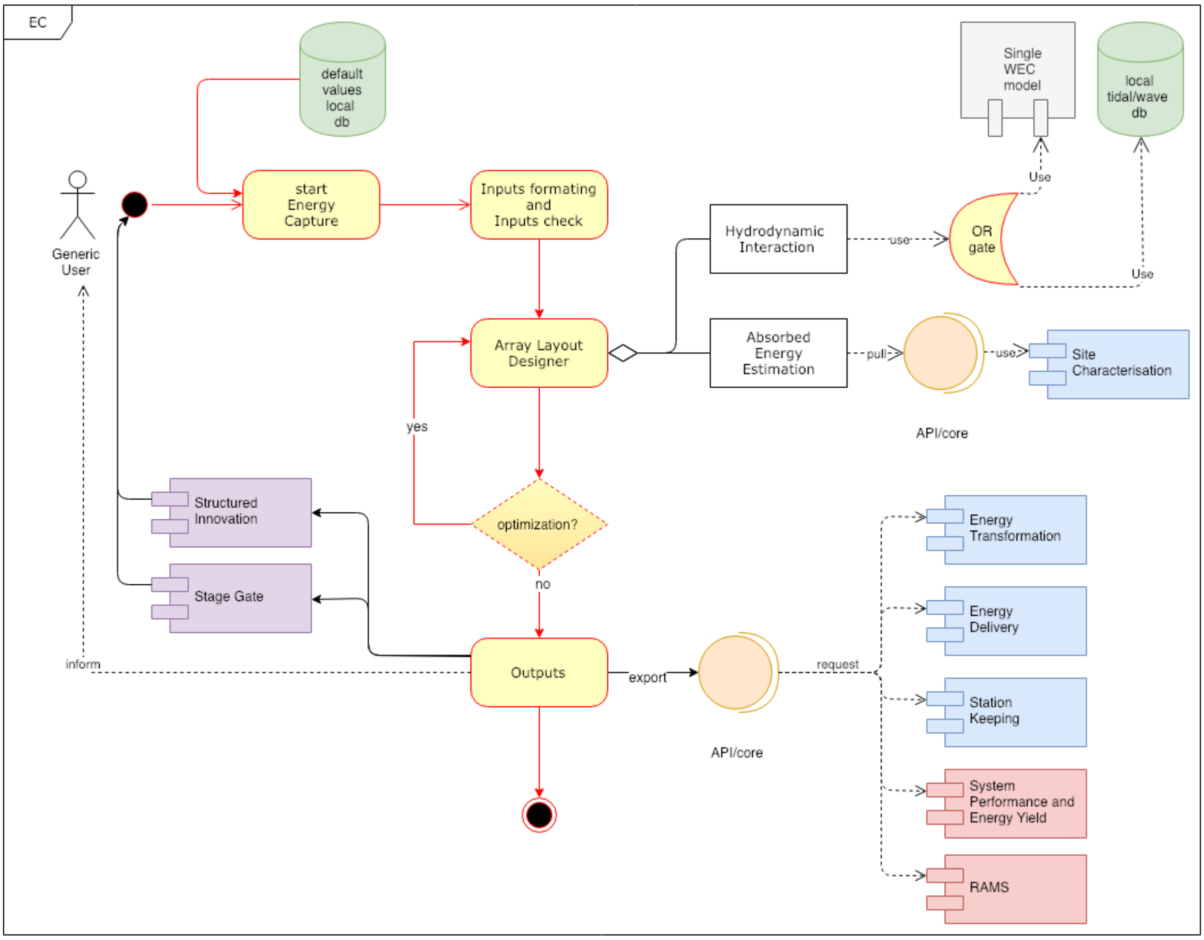


FIGURE 2-4. GENERAL ARCHITECTURE OF THE ENERGY CAPTURE MODULE.

2.2.3 MAIN FUNCTIONS AND MODELS/USE CASES

As previously mentioned in Section 2.2.2, the Energy Capture module will have two distinct operational modes;

1. The first mode assesses the array layout AEP . This is considered the base case.
2. The second mode estimates the array layout: this is considered the advanced case. "Optimal" refers to the array layout that maximises the mechanical AEP of the project.

The second model is an extension of the first mode since the optimizer generates a series of array layouts to be assessed, acting as a user.

Based on the output of the user consultation and the functional specification, ref D2.1 and D2.2, it is possible to identify the most relevant user cases. The Energy Capture module will have a potential impact in the User Cases UC3.X, UC6.X and UC9.X, which represent technology developers, project developers and public and private investors respectively.

For most User Cases, the operational model 2 will be used, and less use of the operational mode 2 is foreseen. However, the main difference in the tool usage is by project stage. For example, a public investor will probably use the tool at an early project stage, while a project developer at a late project stage.

Figure 2-5. gives a generic representation of two User Cases, in specific

- UC9.1. Assist in investment decisions
- UC6.1. Assess how a device/technology performs/behaves with different locations & balance of plant (either for single device or an array)

In both cases, the operational mode selected is number 2, and is early to mid-project stage. Only a rough estimation of the AEP is required, since a selection of site or technology is yet to be made.

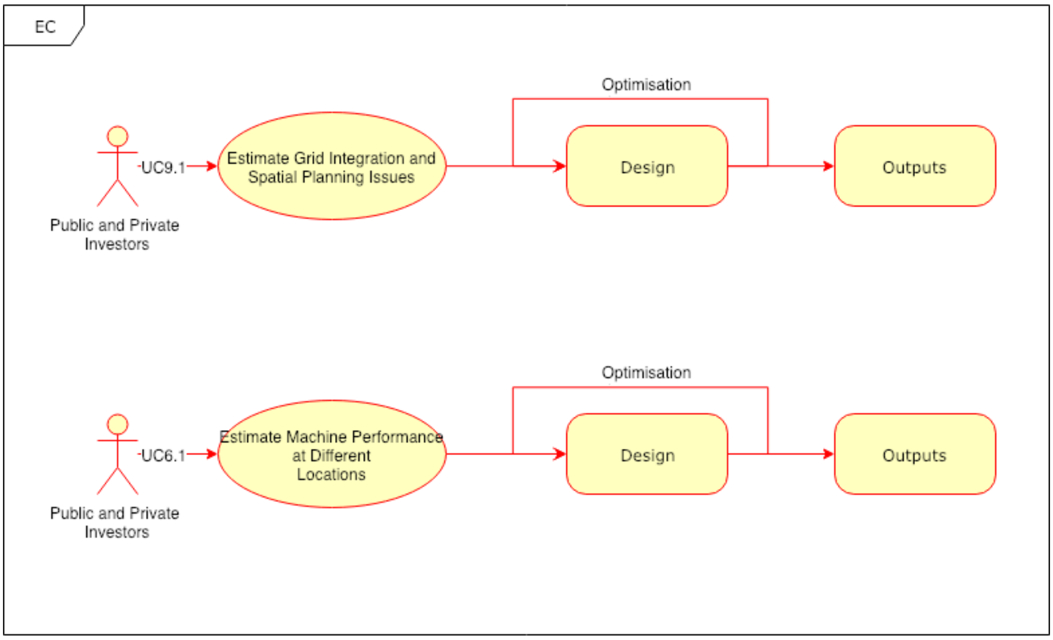


FIGURE 2-5. COMMON FUNCTIONAL BASE CASES FOR DIFFERENT USE CASE EXAMPLES.

2.2.4 DATA REQUIREMENTS

In Figure 2-6, the Data Transfer Objects used for both inputs and outputs of the Energy Capture module are shown, as well as its main components are represented.

The Energy Capture module input data comprises;

- Site description
- Device description

The Site Description includes all inputs describing the site conditions, such as wave and tidal resources, bathymetry and seabed properties, lease area, exclusion zones, etc.

The Device Description comprises the machine and array features, such as characteristic length, single machine numerical model, parametrized array, constraints, etc.

Although the Input Data Transfer Object has consistent structure throughout the development stages, the input types will vary for changes in levels of complexity. This is done in order to accommodate the need for different analysis modes related to the dissimilar user type identified in the previous section.

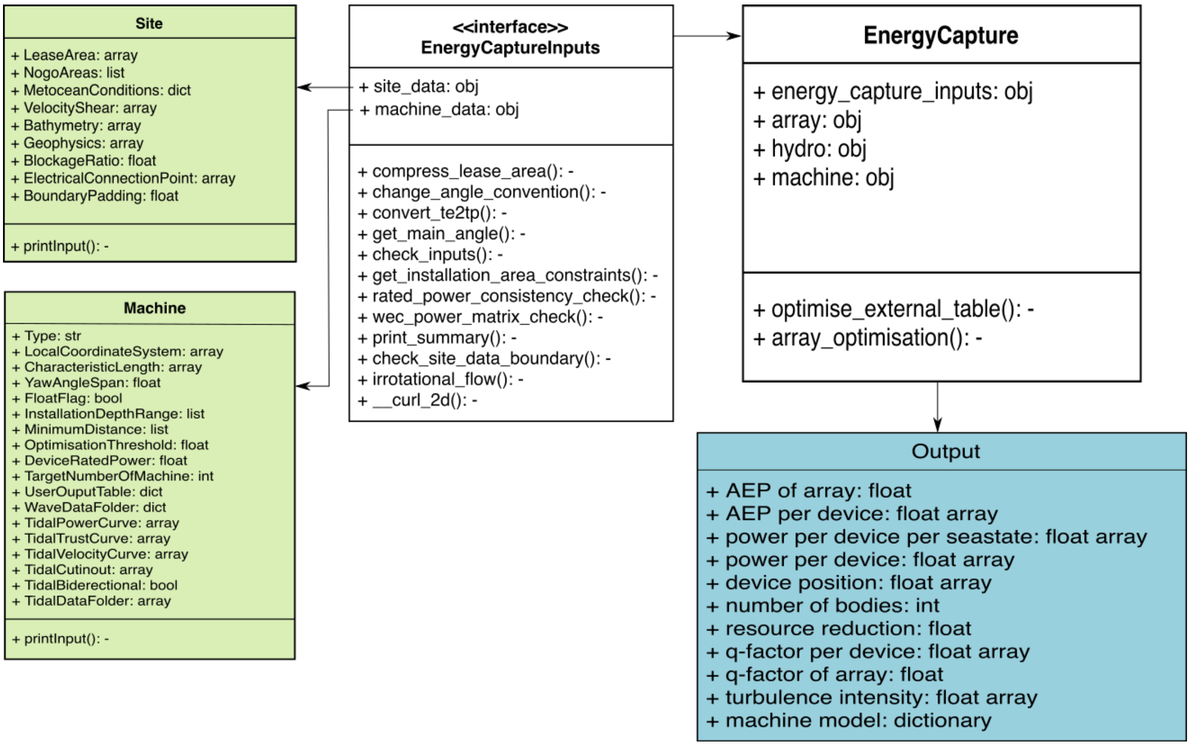


FIGURE 2-6: ENERGY CAPTURE DATA REQUIREMENTS (INPUTS ARE HIGHLIGHTED IN GREEN, OUTPUTS IN BLUE, AND WHITE IS USED FOR THE MODULE INTERFACE AND CORE).

2.3 ENERGY TRANSFORMATION

The Energy Transformation (ET) design module computes the transformation of energy from the power captured to the electrical output of each device in an array of Ocean Energy Systems (OES). In the energy conversion chain, it is situated in between the Energy Capture and Energy Delivery modules. It allows the study of several PTO systems both for tidal and wave energy converters focusing on the effect of various configurations, not only in terms of performance and costs but also informs of the impacts on reliability, logistics and operation as well as environmental issues. It has two main use modes, whether the user wants to assess a specific technology in a specific development stage and under a control strategy; or a design mode where the main PTO characteristics are functionally optimised for a selected criterion (for example, cost, performance and reliability).

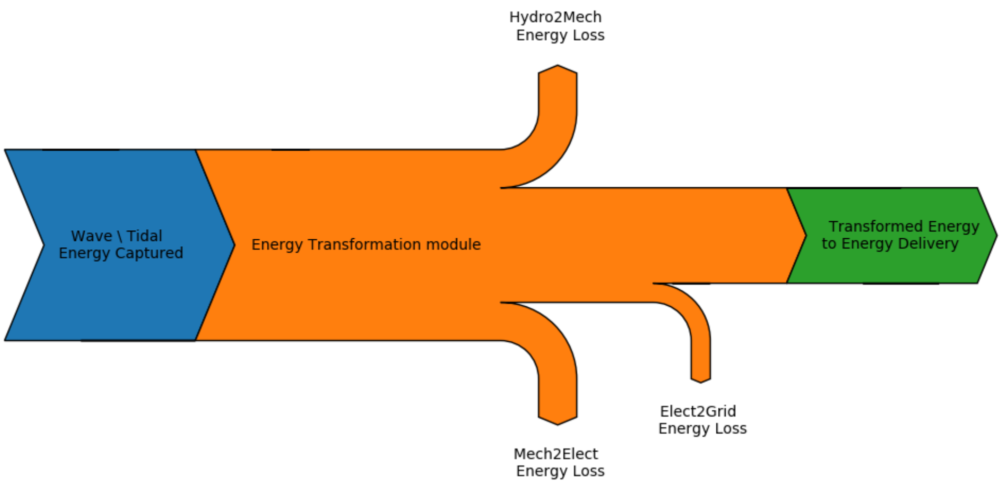


FIGURE 2-7. ENERGY FLOW REPRESENTATION IN THE ENERGY TRANSFORMATION MODULE

2.3.1 FROM FUNCTIONAL TO TECHNICAL REQUIREMENTS

The technical requirements are identified as the actions to be carried out by the Energy Transformation module to meet the functional requirements. The identification of the technical requirement from the functional requirement specified in D2.2, is summarised in the following tables Table 2-5. and Table 2-6..

TABLE 2-5. FUNCTIONAL AND TECHNICAL REQUIREMENTS OF THE ENERGY TRANFORMATION TOOL

Functional Requirements	
FR-ET-1.	Assess the performance of common (and eventually user-defined) PTO systems and control strategies for a specific OES
FR-ET-2.	Assess component costs and loadings
FR-ET-3.	Define two different use modes: analysis and design
FR-ET-4.	Operate with different levels of complexity depending on the development stage (early-mid-late)
FR-ET-5.	Interact with the user through a Graphical User Interface
Technical Requirements	
TR-ET-1.	Read the corresponding motion distributions to the selected control strategy
TR-ET-2.	Use of control strategy motion distributions to be considered in the mechanical efficiency module
TR-ET-3.	Read site characterization attributes corresponding to resource occurrence
TR-ET-4.	Read EC attributes corresponding to the captured energy from the waves and the PTO settings considered to obtain it

TR-ET-5.	Read selected mechanical transformation device performance properties
TR-ET-6.	Use of Mechanical Energy transformation module to define its motions and the mechanical efficiency. Operational Conditions are represented through equivalent PTO settings
TR-ET-7.	Read selected electrical transformation device (generator) performance properties
TR-ET-8.	Use of Electrical transformation module to define its annual average efficiency
TR-ET-9.	Read Electrical power grid conditioning performance properties of the selected Power Electronics device
TR-ET-10.	Use of Grid Conditioning module to compute the electrical energy conversion efficiency
TR-ET-11.	Use Mechanical Efficiency module to compute loads on the device
TR-ET-12.	Use Mechanical to Electrical efficiency module to compute loads on the components connecting it with the Mechanical Efficiency Module components
TR-ET-13.	Read costs of all components of all transformation stages
TR-ET-14.	Call of common internal functions (TRs) by the optimisation process
TR-ET-15.	Allow the user to select the use mode when initiating the tool: analyse and assess (for a specific OES and selected parameters) and design (component optimisation)
TR-ET-16.	Allow the user to fill in mandatory information for the WEC or TEC (PTO type, control strategy, analysis or design) and optional data with the level of detail corresponding to the stage.
TR-ET-17.	Use default components and linear models at early stage
TR-ET-18.	Allow the user to select the main parts with custom parameters and the proper tools functions at mid stage.
TR-ET-19.	Allow the user to introduce user defined functions, if needed, to substitute to the ones present on the tool
TR-ET-20.	Use default values from the component database in case a set of data is not filled by the user
TR-ET-21.	Input parameters corresponding to the necessary assessment criteria (performance, reliability, environmental, …) from the database (unless given by the user)
TR-ET-22.	Select different optimisation cost functions, based on performance, cost reduction, highest reliability, …

Each technical requirement will be used to achieve the functional requirements. The TRs required to achieve each FR are represented in the table below:

TABLE 2-6. FUNCTIONAL REQUIREMENTS / TECHNICAL REQUIREMENTS RELATION MATRIX FOR THE ENERGY TRANSFORMATION MODULE.

		Functional Requirements				
		FR-SC-1	FR-SC-2	FR-SC-3	FR-SC-4	FR-SC-5
Technical Requirements	TR-ET-1	X				
	TR-ET-2	X				
	TR-ET-3	X				
	TR-ET-4	X				
	TR-ET-5	X				
	TR-ET-6	X				
	TR-ET-7	X				
	TR-ET-8	X				
	TR-ET-9	X				
	TR-ET-10	X				
	TR-ET-11		X			
	TR-ET-12		X			
	TR-ET-13		X			
	TR-ET-14			X		
	TR-ET-15			X		X
	TR-ET-16	X				X
	TR-ET-17				X	
	TR-ET-18				X	
	TR-ET-19				X	
	TR-ET-20					X
	TR-ET-21				X	
	TR-ET-22				X	

Most of the listed requirements are related with the main function of the module, dedicated to the assessment and analysis of a specific PTO system, already sized. Additionally, and in order to optimise the PTO design, the activation of a design mode initiates an optimisation routine to guide the sizing process in function of one of the objective criteria (performance, costs, reliability, ...)

2.3.2 ARCHITECTURE OF THE TOOL

In Figure 2-8. General architecture of the Energy Transformation module.below , an overview of the Energy Transformation module is shown, displaying the flow of actions. It can be used in two ways:

- Analysis and assessment: Using defined, known technology and its main components (either user defined or defaults), the tool gives a component list with all the attributes needed for the assessment tools, such as performance, reliability, or environmental.
- Design and optimisation: For cost optimisation, the device PTO components are optimally selected and the tool gives the same output format as above.

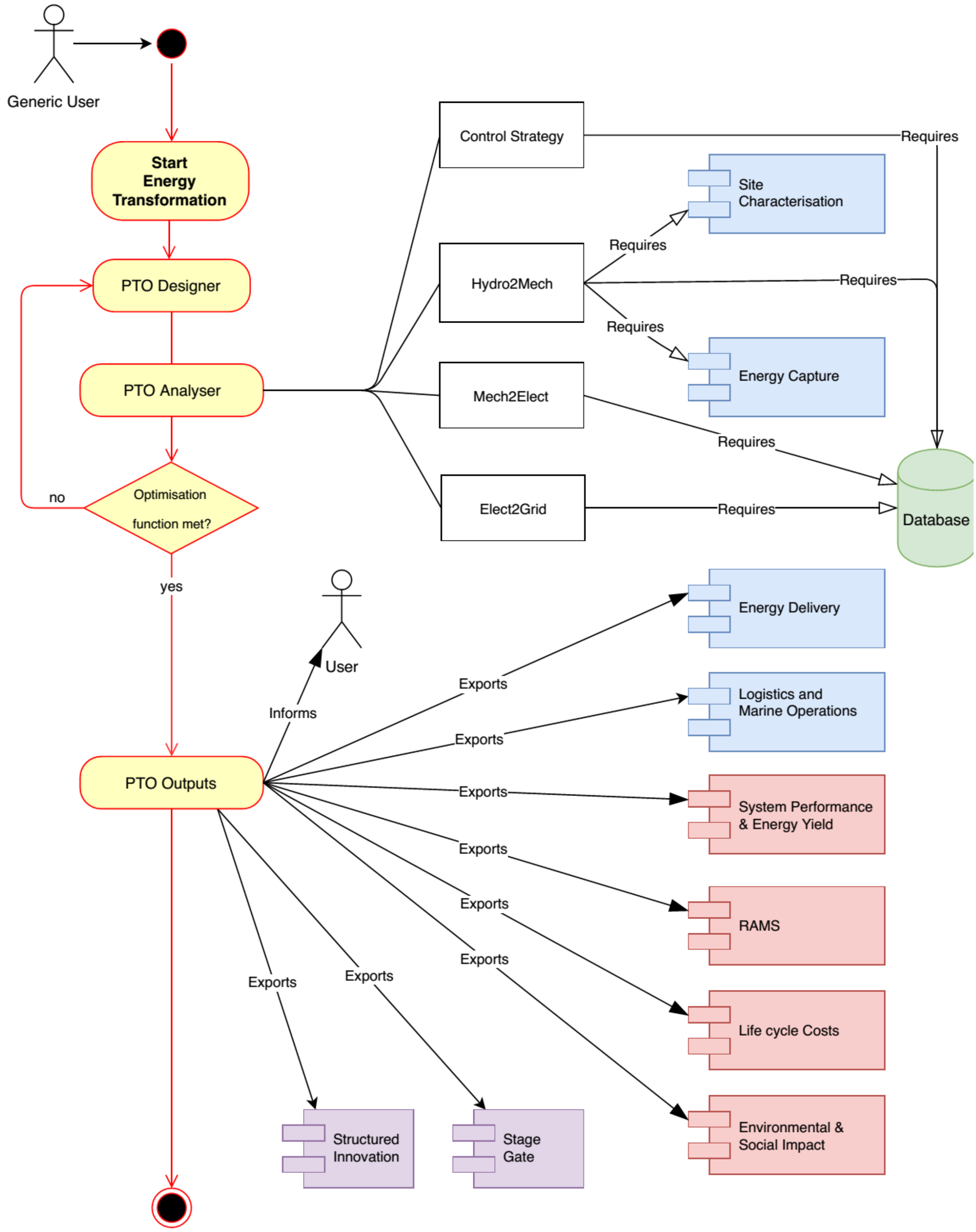


FIGURE 2-8. GENERAL ARCHITECTURE OF THE ENERGY TRANSFORMATION MODULE.

Figure 2-8 details the three main functions representing each stage of the power transformation used in the PTO analyser:

- Hydro2Mech: Mechanical design: performs the PTO mechanical efficiency and loads calculations, using;
    - The PTO technology from the User
    - The resource from the Site Characterisation module
    - The absorbed energy and the device motion from the Energy Capture module
    - The control strategy
    - The component database
- Mech2Elect: Electrical Design: computes the generator efficiency and loads, knowing the mechanical PTO power and operation range.
- Elect2Grid: Component Design for grid compatible electrical power: Power Converter selection and computes its efficiency and electrical power output.

Additionally, the Control Strategy function converts device motions and loadings to specific velocity distributions to be accounted for in the conversion chain.

The main objective is the PTO design, and this module is capable of finding the optimal sizing of the PTO components depending on user's objectives, for example, performance optimisation and cost reduction.

Finally, the module sends a series of outputs to two deployment tools and four assessment tools:

- Energy Delivery: the output power, as well as reactive power, generator-convertor topology
- Logistics and Marine operations: the components physical characteristics
- System performance and energy yield: the output power, partial and total PTO efficiencies
- Lifecycle costs: the components costs
- RAMS: the components loadings and bill of material
- Environmental and social impacts: PTO environmental impact

2.3.3 MAIN FUNCTIONS AND MODELS/USE CASES

Use cases depend on the user type and objectives. The main targeted users of DTOceanPlus have been identified in deliverable D2.1 [11] to be:

- Funders & Investors
- Innovators & Developers
- Project Developers
- Policy makers and regulators

From the Energy Transformation module perspective, eight examples of use cases have been identified:

TABLE 2-7. USE CASE IDENTIFIER

Use Case ID	User Type	Objective	Stage	Mode of Operation	Objective Function
1	Funders & Investors	Looking for a Technology	Early	Design	Cost
2	Funders & Investors	Assess specific technology	Mid	Analysis	
3	Innovators & Developers	Test a novel PTO	Late	Design	Performance
4	Innovators & Developers	Look for improvement areas	Mid	Design	Cost
5	Project Developers	Assess a PTO in a device	Mid	Design	Performance
6	Project Developers	Assess O&M implications of a PTO	Early	Analysis	
7	Policy makers & Regulators	Impact of a technology on the energy mix	Early	Design	Performance
8	Policy & Regulators	Environmental impact of a specific technology/site	Mid	Analysis	

The Energy Transformation module architecture does not change with the mode of operation, the objective function, or the development stage associated with the use case. However, the module input types are expected to change for different development stages and modes of operation.

A set of 6 different common base cases considered to illustrate the various tool possibilities:

1- Early stage & Analysis
2- Early stage & Design
3- Mid stage & Analysis
4- Mid stage & Design
5- Late stage & Analysis
6- Late stage & Design

Figure 2-9. shows how the 6 common base cases can represent all 8 use cases:

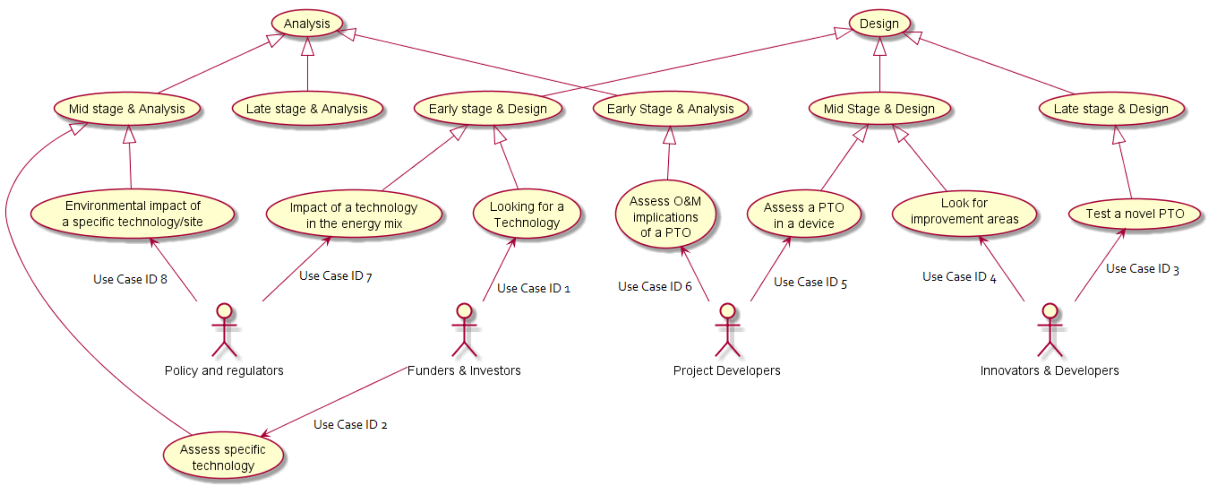


FIGURE 2-9. Common Base Cases in function of different Use Case examples.

Any use case defined in Table 2-7. can then be represented as one of the 6 common base cases. Each scenario will need specific input data so that the *PTO Designer* can decide how the module is used. It should be noted that when no objective function is provided, the *PTO Analyser* will be run only once. Afterwards the *PTO Designer* will consider that no further evaluations are needed and will provide *PTO Analyser* outputs as the module outputs.

- Base Case 1: In this case, no objective function is provided to the module and all components are selected to be idealized. However, global component inputs should be provided as, for example, linear conversion system rated powers and the ideal generator.

A use case example is provided for ID6 from Table 2-7. Use case identifier in Figure 2-10. Use case ID6:

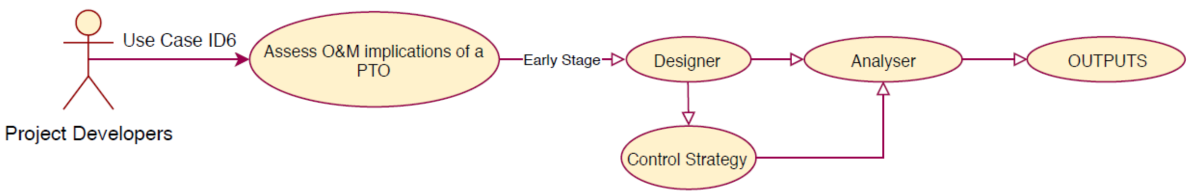


FIGURE 2-10. USE CASE ID6

- Base Case 2: This case considers the same settings as Base Case 1, except that it is not necessary to provide rated powers, but an objective function instead. The PTO designer will look for the main characteristics of different conversion chains to meet the requirements of the objective function.

A use case example is provided for ID1 and 7 from Table 2-7. Use case identifier in Figure 2-11 below:

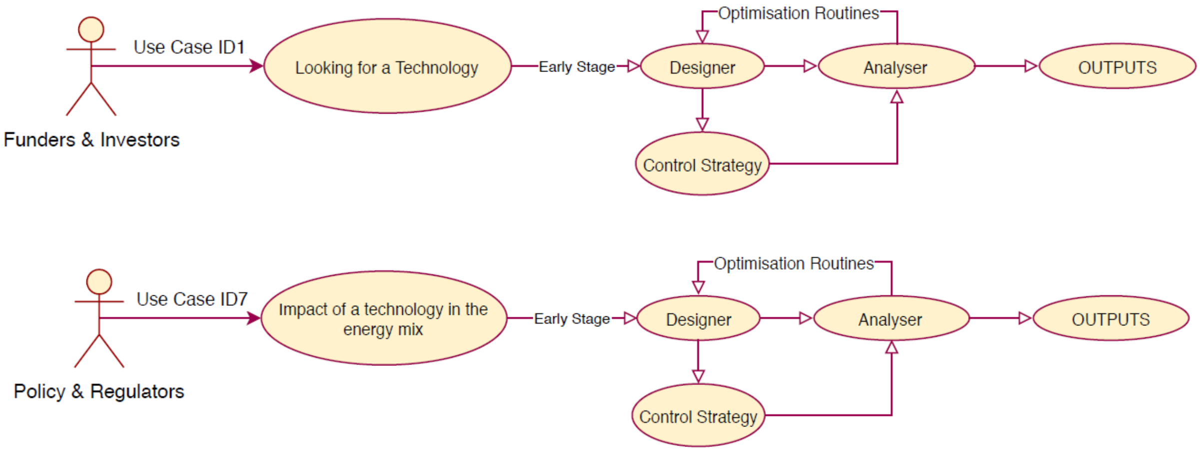


FIGURE 2-11. USE CASES ID1 & 7

- Base Case 3: Base case 3 corresponds to a mid-stage of development and, as such, no component can be ideal. In the example below, a hydraulic system with a SCIG and a realistic PE is selected with a latching control strategy. Additionally, this case corresponds to an analysis mode of operation and components sizes shall be provided.

A use case example is provided for ID2 and 8 from Table 2-7. Use case identifier in Figure 2-12 below:

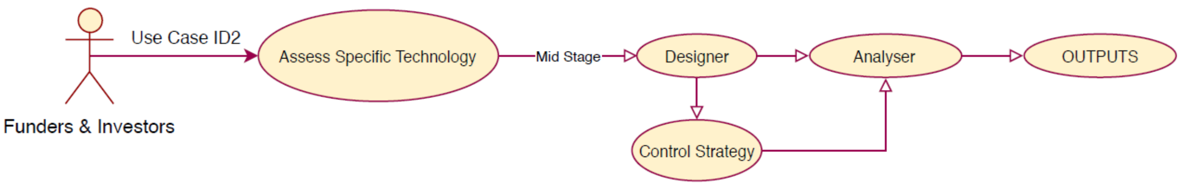
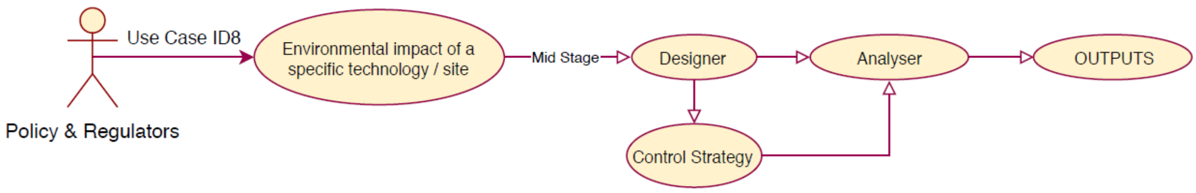


FIGURE 2-11. USE CASES ID2 AND ID8



- Base Case 4: This case uses the same inputs as the previous case except those input connected to component dimensions. In exchange, an objective function is to be provided so that the module can determine the best component dimensions to meet its requirements.

A use case example is provided for ID1 and 7 from Table 2-7. Use case identifier in Figure 2-12. Use cases ID4 and ID5:

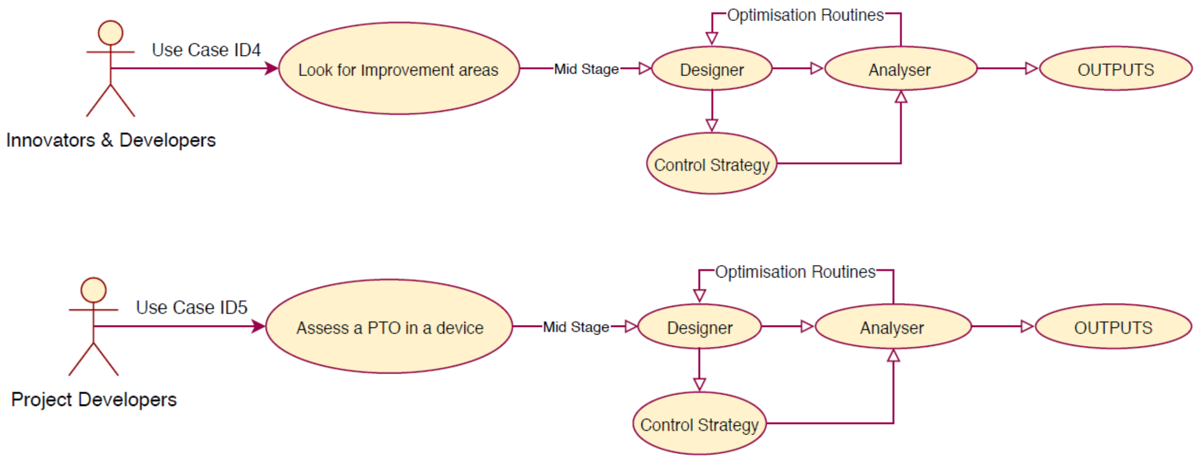


FIGURE 2-12. USE CASES ID4 AND ID5

- Base Case 5: The mode of operation of this case is "analysis", therefore sizes of components shall be provided. As it corresponds to a later stage of development, at least one component shall be user defined with its main properties.

- Base Case 6: This is the most advanced or detailed mode of analysis. In addition to requiring user defined properties, the optimisation function is activated with a given criterion so that the module can determine the most suitable sizing of all components.

A use case example is provided for ID3 from Table 2-7. Use case identifier in Figure 2-13. Use case ID3 below:

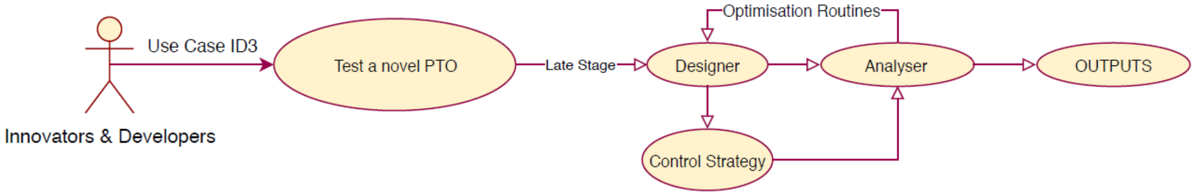


FIGURE 2-13. USE CASE ID3

2.3.4 DATA REQUIREMENTS

In the Energy Transformation module architecture definition, several objects are to be generated during its execution. Therefore, data requirements are represented in terms of attributes and method of internal module objects.

Module global inputs and outputs are shown in Figure 2-14. and Figure 2-15;

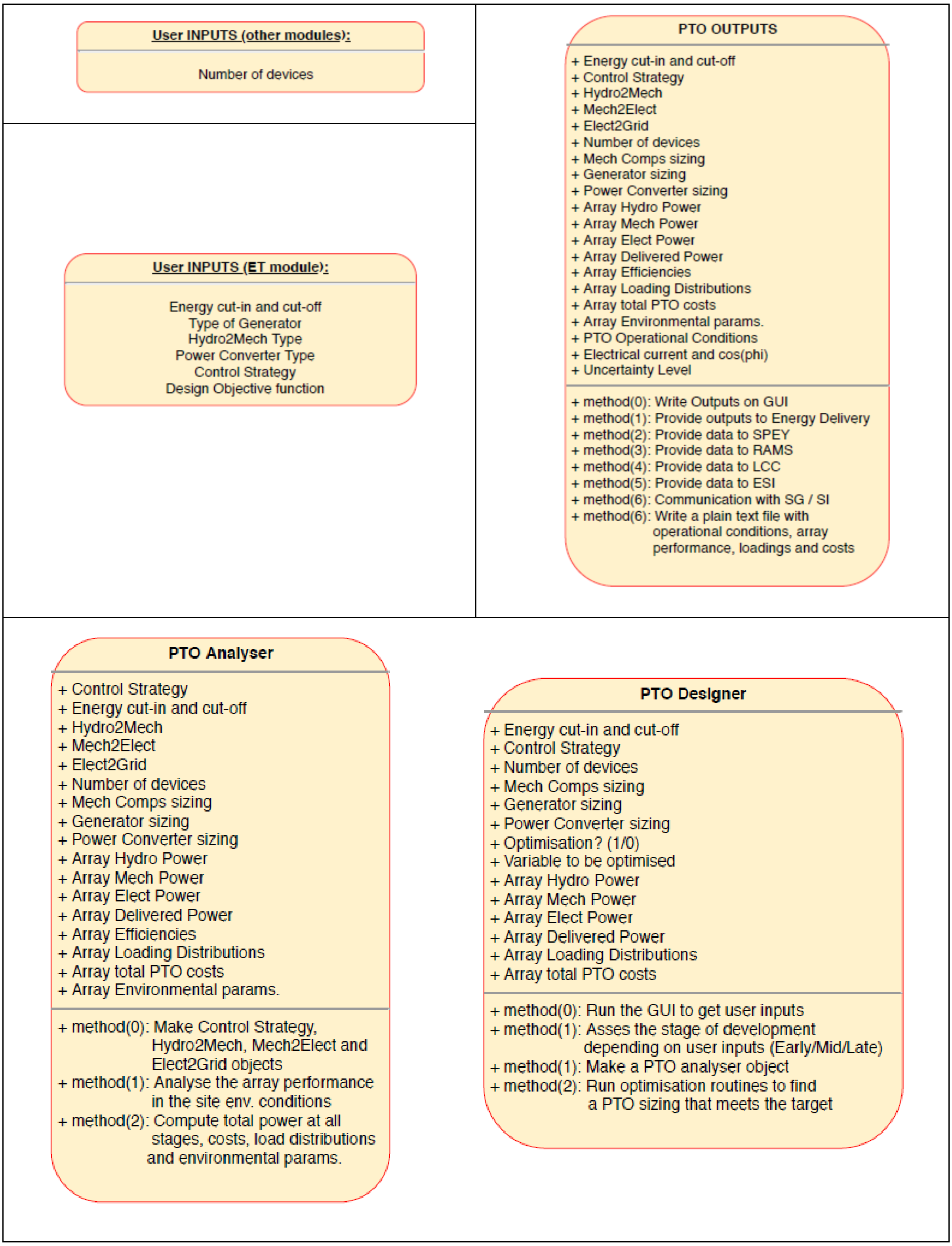


FIGURE 2-14. DATA STRUCTURE OF MAIN FUNCTIONS OF THE ENERGY TRANSFORMATION MODULE

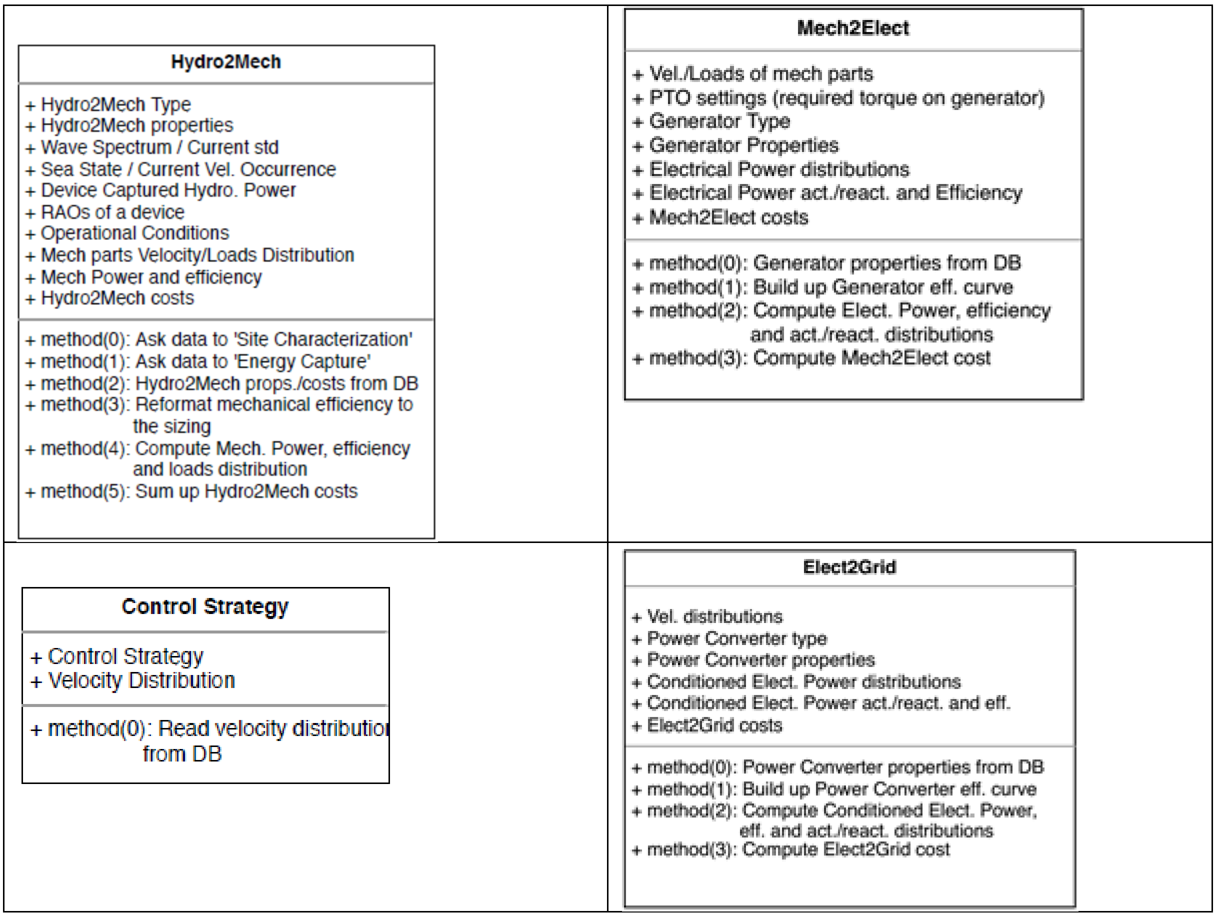


FIGURE 2-15. DATA STRUCTURE OF INTERNAL OBJECTS OF THE ENERGY TRANSFORMATION MODULE.

2.4 ENERGY DELIVERY

The Energy Delivery (ED) design module designs and assembles optimal solutions for the electrical infrastructure. This delivers electrical power to the onshore distribution network, for a given sub-system, device, array and site. The module design objective is to maximise the level and quality of the delivered power considering the cost and value of the solution proposed, as well as to ensure overall grid compliance. The Energy Delivery module will have two main functionalities: firstly, designing the energy delivery system, and secondly, evaluating parameters of network design.

The term 'electrical infrastructure' includes all the key electrical components such as the umbilical cable, static subsea intra-array cables, electrical connectors, offshore collection points, and the transmission cables to the onshore grid. Figure 2-16 shows the scope of the Energy Delivery module and shows the typical electrical infrastructure components required by ocean energy converters and arrays.

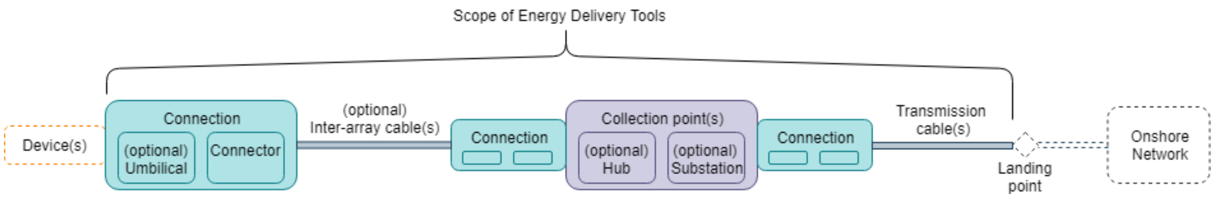


FIGURE 2-16 SCOPE OF ENERGY DELIVERY TOOLS

2.4.1 FROM FUNCTIONAL TO TECHNICAL REQUIREMENTS

TABLE 2-8: FUNCTIONAL AND TECHNICAL REQUIREMENTS FOR THE ENERGY DELIVERY MODULE.

Functional Requirements	
FR-ED-1.	Process the seabed information (lease area & cable corridor)
FR-ED-2.	Design the transmission system – including cable routing and collection point design
FR-ED-3.	Design the intra-array network – including connector(s), umbilical(s), cable routing and collection point design
FR-ED-4.	Select and identify appropriate components based on the designs
FR-ED-5.	Evaluate technically feasible solutions using a techno-economic model
Technical Requirements	
TR-ED-1.	Use simplifications and default values to facilitate design at earlier stages when not all details are available or for high level assessment
-1.a.	Inform user about increased uncertainty
TR-ED-2.	Accept user inputs and design choices with appropriate data validation through the GUI
TR-ED-3.	Load properties from the data storage
TR-ED-4.	Save properties and results
TR-ED-5.	Analyse seabed properties of the lease area & cable corridor
-5.a.	Map properties to the grid points
-5.b.	Calculate seabed slope from bathymetry
TR-ED-6.	Remove marine exclusion zones from the grid
TR-ED-7.	Obtain electrical properties/constraints [User input or from database]
TR-ED-8.	Obtain network topology type from user
-8.a.	Number and type of transmission system collection point(s) E.g. 2 subsea hubs, or 1 surface piercing, 3 direct to shore without CP
-8.b.	Obtain the intra-array network type from user (radial/star/hybrid)
TR-ED-9.	Design transmission system to shore
-9.a.	Obtain transmission system collection point location(s)
-9.b.	Determine transmission voltage options
-9.c.	Design transmission system collection point (electrical), E.g. number and capacity of transformers, switchgear, etc.
-9.d.	Design transmission system collection point (mechanical),

E.g. indicative costs and mechanical design of foundation in the assessment
-9.e. Identify options of export cable number and capacity
-9.f. Identify feasible/optimal cable route(s) for transmission cable to shore
-9.g. Consider indicative costs of different cable installation methods and cable protection requirements in the assessment

TR-ED-10. Design connector(s) and umbilical(s)
-10.a. Determine requirement of static or dynamic umbilical
-10.b. Design the static or dynamic umbilical (electrical)
-10.b.i. Determine length of umbilical required
-10.b.ii. Identify options of umbilical
-10.c. Design the dynamic umbilical (mechanical)
-10.c.i. Consider indicative costs and mechanical design of dynamic umbilical in the assessment
-10.d. Obtain connector type
-10.e. Design the connector (electrical)

TR-ED-11. Design intra-array network
-11.a. Determine requirement of intra-array network collection point(s)
-11.b. Obtain intra-array network collection point location(s)
-11.c. Determine intra-array network voltage options
-11.d. Design intra-array network collection point (electrical)
E.g. number and capacity of transformers, switchgear, etc.
-11.e. Design intra-array network collection point (mechanical)
E.g. indicative costs and mechanical design of foundation/mooring in the assessment
-11.f. Use clustering algorithm to determine intra-array network topology
-11.g. Determine feasible/optimal cable routes(s) for intra-array network
-11.h. Consider indicative costs of different installation methods and protection requirements in the assessment

TR-ED-12. Output representation of the electrical network(s)
-12.a. Hierarchical data structure
-12.b. Graphical visualisation

TR-ED-13. Identify component options for the network design(s)
-13.a. Select appropriate components of the network design(s)
-13.b. Output table with x, y coordinates of all the components with quantity/length values
-13.c. Access component cost, installation cost, failure rates and mean repair times for the network design options

TR-ED-14. Provide a summary of network design option(s)
-14.a. Output list of connections between different sub-systems
-14.b. Output summary table of cable routes
-14.c. Output summary table of collection point data
-14.d. Output summary table of umbilical and connector designs
-14.e. Output a summary of the economic data (bill of material) – component quantity, cost and details including installed failure rates

TR-ED-15. Evaluate impact of component failure
-15.a. Obtain components (s) of interest from the user
-15.b. Evaluate loss of production capacity due to selected component failures

TR-ED-16. Techno-economic evaluation of the network design options
-16.a. Run power flow solver (using power time-series/histogram) for the network design options

created
-16.b. Evaluate network voltages and power losses for the network design options
-16.c. Evaluate reactive power requirement on the offshore transmission system collection point and on the onshore substation
-16.d. Include the quantity of reactive power required in the summary of network design options
-16.e. Update summary of the economic data (bill of material)
-16.f. Check technical feasibility of the network design options based on grid compliance etc.
-16.g. Output summary of technically feasible PF solver results, including network efficiency, AEP at onshore landing point etc.
-16.h. Output summary of total cost (including component and installation) and failure rates and mean repair times for each network design option

TR-ED-17. Display results and outputs through the GUI and save report

TABLE 2-9: FUNCTIONAL REQUIREMENTS / TECHNICAL REQUIREMENTS RELATION MATRIX FOR THE ENERGY DELIVERY TOOLS

		Functional Requirements				
		FR-ED-1	FR-ED-2	FR-ED-3	FR-ED-4	FR-ED-5
Technical Requirements	TR-ED-1	X	X	X	X	X
	TR-ED-2	X	X	X	X	X
	TR-ED-3	X	X	X	X	X
	TR-ED-4	X	X	X	X	X
	TR-ED-5	X				
	TR-ED-6	X				
	TR-ED-7		X	X		
	TR-ED-8		X	X		
	TR-ED-9		X			
	TR-ED-10		X	X		
	TR-ED-11			X		
	TR-ED-12		X	X		
	TR-ED-13				X	
	TR-ED-14				X	
	TR-ED-15					X
	TR-ED-16					X
	TR-ED-17		X	X	X	X

2.4.2 ARCHITECTURE OF THE TOOL

The Energy Delivery module will comprise two main functionalities or operation modes, namely designing and evaluating the electrical network options, as shown in Figure 2-17.

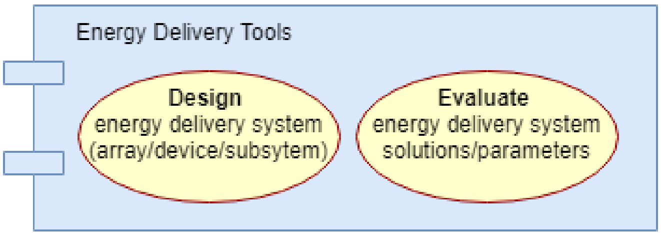


FIGURE 2-17: TWO MAIN FUNCTIONALITIES OF THE ENERGY DELIVERY DESIGN TOOLS

The main operation modes of the Energy Delivery module are shown in Figure 2-18 and Figure 2-19 for the network design and network evaluation functionalities respectively. Note that multiple design options may be produced for the electrical network by the design functionality of the tool. After being evaluated, the user can select the 'best' option to be taken forward to other modules for the remainder of the analysis.

The network designs may be a user input for those users only using the evaluation functionality of the tool. The impacts of the various parameters of these network designs are assessed by the evaluation functionality of the tool.

The Structured Innovation and Stage Gate design tools will exploit the functionalities and functions of the Energy Delivery module in a similar fashion to an informed user.

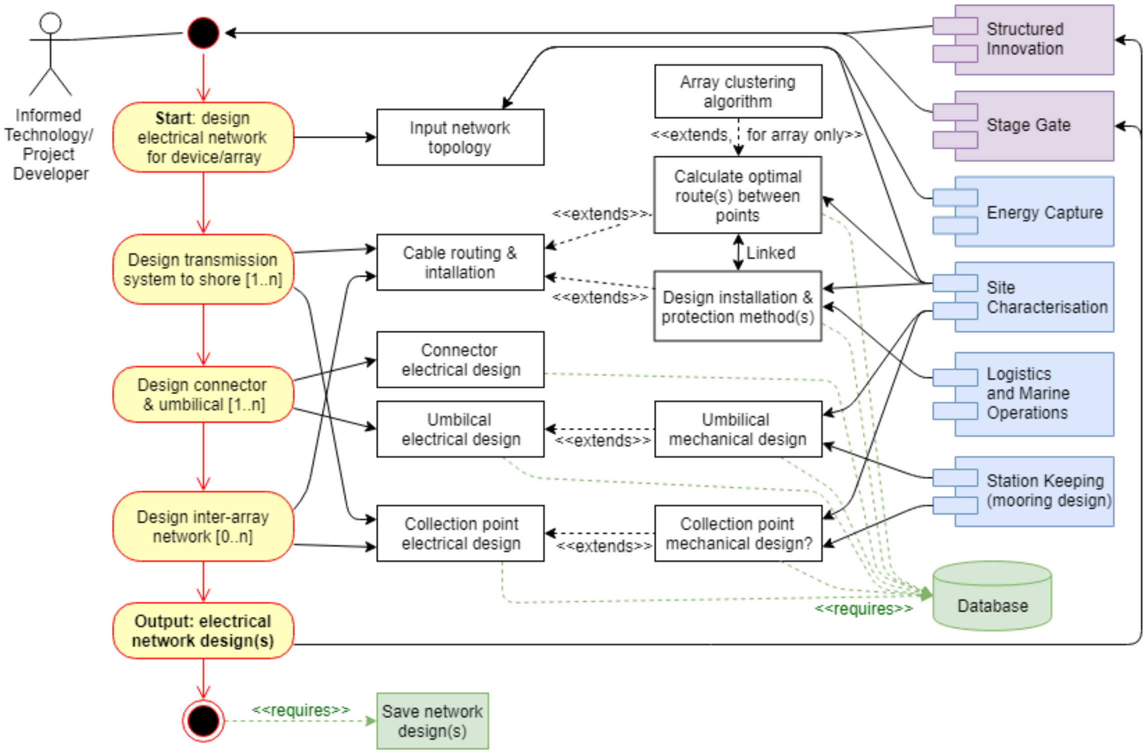


FIGURE 2-18: MAIN FUNCTIONS OF THE ENERGY DELIVERY DESIGN MODULE – DESIGN OF NETWORK

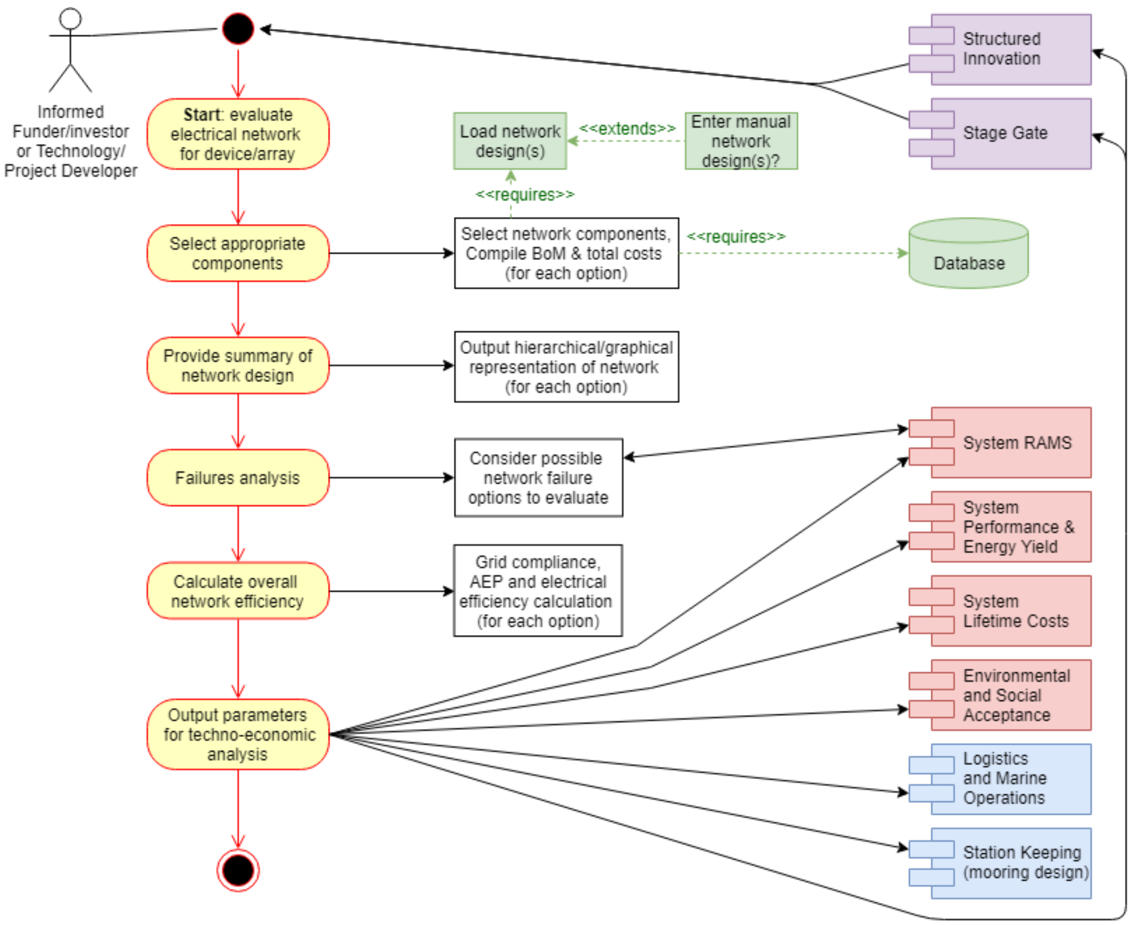


FIGURE 2-19: MAIN FUNCTIONS OF THE ENERGY DELIVERY DESIGN TOOLS – EVALUATE NETWORK(S)

2.4.3 MAIN FUNCTIONS AND MODELS/USE CASES

use cases are split by three main types of user (Technology Developers, Project Developers, and Funders/Investors). An extension to these is a user wishing to consider only a specific part/ subsystem of the energy delivery system. These use cases can be summarised as follows, and shown graphically in the figures below.

1. Designing the energy delivery system (Figure 2-20)
   a. Either for the whole system: for a single device or an array of multiple devices
   b. Or detailed design of an individual component within the system
2. Evaluating solutions for a given network (Figure 2-21)

The tool is designed to be used by an informed user, i.e. one with an understanding of the issues and complexities involved in designing the energy delivery network of an ocean energy array.

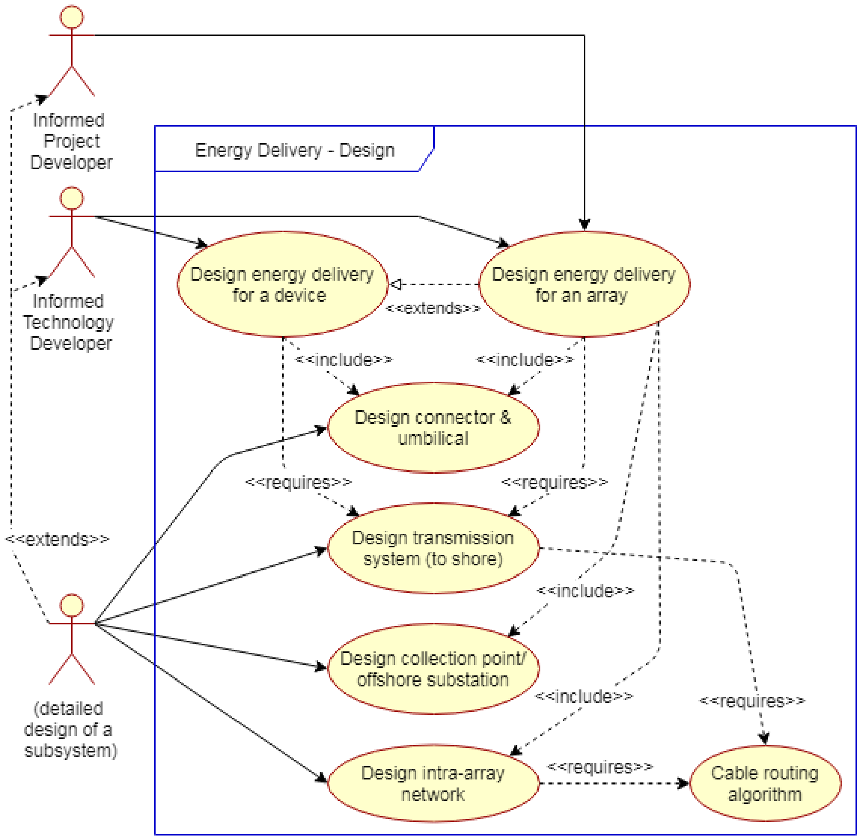


FIGURE 2-20: USE CASES FOR DESIGN OF A SINGLE DEVICE, ARRAY OF MULTIPLE DEVICES, OR AN INDIVIDUAL COMPONENT/SUBSYSTEM

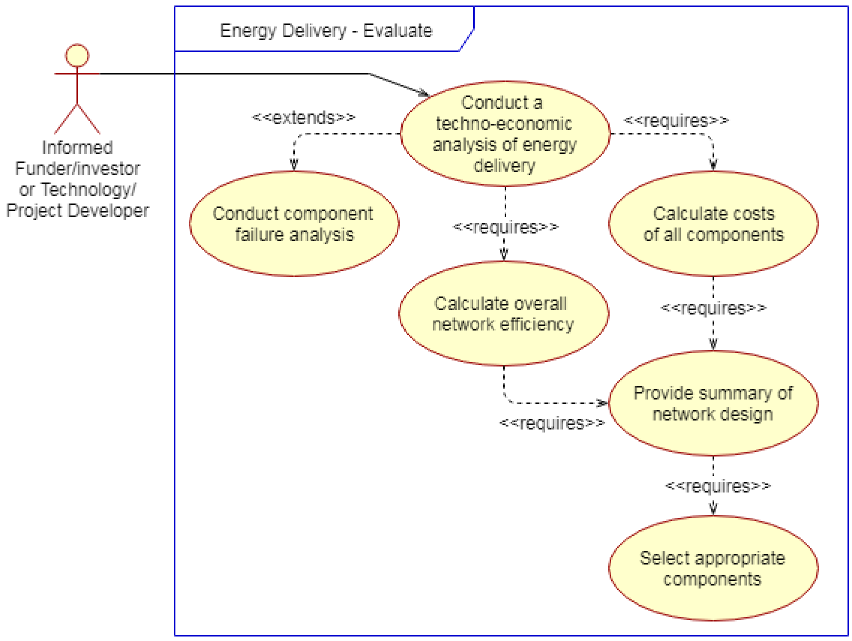


FIGURE 2-21: USE CASES FOR EVALUATING NETWORK SOLUTIONS

2.4.4 DATA REQUIREMENTS

The Energy Delivery module requires the following input data, some of which may be default values at the earliest stages of development:

- Details about the site, including:
  - Bathymetry and seabed properties, exclusion zones, from the Site Characterisation module.
  - User inputs for onshore network capacity and landing point(s).
- Details about the array, including:
  - Number of devices[4] and their positions, from the EC module.
  - User inputs to define the network topology and redundancy requirements.
- Details about the device, including:
  - Power generated, rated capacity, rated voltage etc., from the Energy Transformation module.
  - Type of device – whether wave or tidal, and if floating or fixed.
- Other information including:
  - Cost rates for various installation methods from the Logistics and Marine Operation module
  - User design choices for parameters (for example user choice on cable installation/protection methods etc.).

The main classes of data for the Energy Delivery module are shown in Figure 2-22. Note that this diagram shows only the higher complexity version of the Energy Delivery module. The module will also allow low and medium complexity versions of network design and evaluation to be run using simplifications and default values for parameters. The integration of the Energy Delivery module with the other modules is described in Section 3.

The Energy Delivery module will also allow user to input design choices without following the standard design process provided in the tool. This feature will allow analysis of these alternative options and the incorporation of other constraints or factors beyond the energy delivery module.

[4] Can be a single device

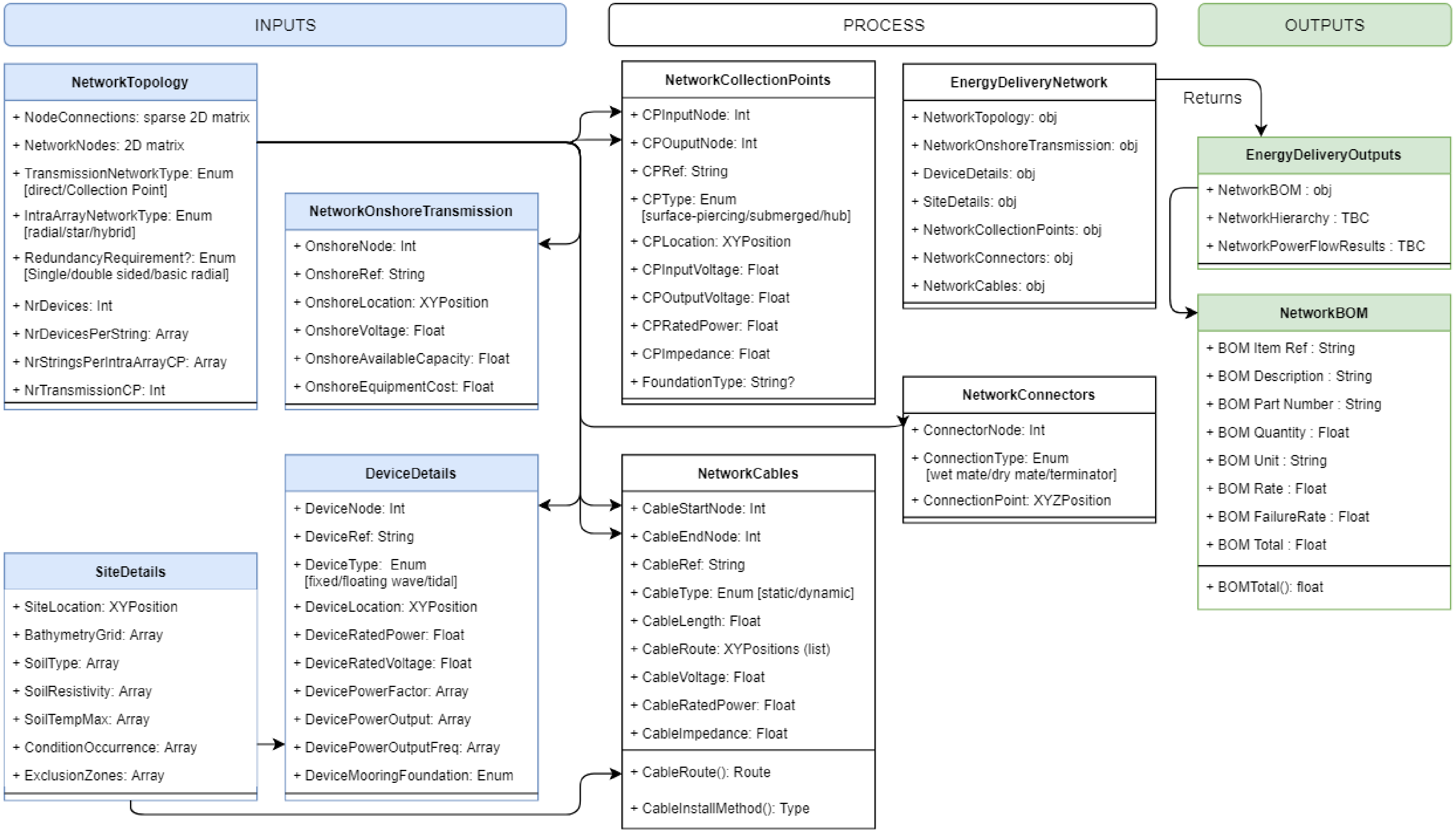


FIGURE 2-22: CLASS DIAGRAM FOR THE ENERGY DELIVERY MODULE.

2.5 STATION KEEPING

The Station Keeping (SK) design module will support the design of the mooring and foundation subsystems. The module will deal with the full design of gravity foundations, piles, anchors, mooring lines, mechanical design of the dynamic umbilical cable and its interaction with the other elements of the mooring system, defining a local optimal design solution based on the cost of components, not taking into account the installation costs at this stage.

2.5.1 FROM FUNCTIONAL TO TECHNICAL REQUIREMENTS

The technical requirements allowing to deliver to the user the functionalities defined in Deliverable D2.2 [9] are shown in the below table.

TABLE 2-10: FUNCTIONAL AND TECHNICAL REQUIREMENTS OF THE STATION KEEPING MODULE

Functional Requirements	
FR-SK-1.	Modelling of the Station Keeping system: Represent the Station Keeping system based on appropriate models, respecting the desired level(s) of accuracy. Considered models are: Load models, umbilical models, mooring line models, motion solving models (frequency-domain) and foundation models.
FR-SK-2.	Definition and optimisation of the Station Keeping system: Propose design alternatives based on the proposed site/technology and following techno-economic criteria.
FR-SK-3.	Support the decision-making process: Provide the users with the design options and let them select the best solution or run additional computation to test other alternatives.
Technical Requirements	
TR-SK-1.	Get from the user or core module of the tool the needed global input data to run the module: -1.a. Type of analysis (design or assessment) and associated options and constraints -1.b. Complexity level for the design [if not done by the stage gate tool] -1.c. Get Water Depth from the Site Characterisation module or Core module -1.d. Get the Station Keeping module options and constraints (e.g. lease area description) -1.e. Extreme environmental conditions [if not done by the stage gate tool or site characterisation tool]
TR-SK-2.	Drive the Station Keeping module at the array level: -2.a. Select the most vulnerable device from the array for analysis -2.b. Design the selected device -2.c. Analyse if the design is applicable to the full array -2.d. Produce complementary design(s) if applicable
TR-SK-3.	Get and process inputs from various sources and format these for use in Station Keeping solvers sub-modules: -3.a. Get the devices positions within the array from the Energy Capture module -3.b. Get hydrodynamics loads (forces) from the Energy Capture module -3.c. Get soil mechanical properties from the Site Characterisation module -3.d. Get umbilical cable electrical characteristics from the Energy Delivery module -3.e. Get data from the catalogue or other modules about the proposed components physical characteristics -3.f. Get data from the catalogue or other modules about the proposed components economic

characteristics (procurements, possibly installation)

TR-SK-4. Compute internally the additional information needed, such as the hydrodynamic loads based on empirical/analytical formulas.

TR-SK-5. Design (optimise) or evaluate (TR-SK5.b only) the mooring system:

- -5.a. Initiate the system by producing a(n) initial design(s)
- -5.b. Perform evaluation: analyse the design(s) with the quasi-static mooring solver and evaluation against KPIs
- -5.c. Produce new design(s) based on last iteration (if applicable)
- -5.d. Perform the above actions in an iterative process if needed

TR-SK-6. Design the mechanical characteristics of the umbilical (dynamic power cable)

TR-SK-7. Design the foundations based of different types of anchors / foundations.

TR-SK-8. Provide relevant metrics (extreme loads / motions, costs, bill of materials...) and graphical representations of the proposed design solutions and the hypothesis considered to achieve it to the user

TR-SK-9. Provide outputs and/or public methods to other DTOceanPlus tools and modules:

- -9.a. Logistics and Marine Operations Planning
- -9.b. System RAMS
- -9.c. System Life Time Costs
- -9.d. Environmental and social impacts
- -9.e. Stage gate

TR-SK-10. Interaction with the GUI, taking information from the user as for:

- -10.a. Specifying input data
- -10.b. Specifying parameters
- -10.c. Making decisions (e.g. "load example file", "launch computation", close warning messages...)

TR-SK-11. Display information through the GUI:

- -11.a. Display general options offered to the user (move to another module, go to input tab...)
- -11.b. Display the input data and parameters specific to the SK module (e.g. environmental loads, design options...)
- -11.c. Display the input data from other modules, providing a link to those GUIs (e.g. bathymetry, soil type, ...)
- -11.d. Display the current mooring and foundation configuration (tables or graphically)
- -11.e. Display results and assumptions (tables or graphically)
- -11.f. Display prompt messages such as warning or error messages

TR-SK-12. Export the Station Keeping design description in a generic format easily readable

TABLE 2-11: FUNCTIONAL REQUIREMENTS / TECHNICAL REQUIREMENTS RELATION MATRIX FOR THE STATION KEEPING MODULE

		Functional Requirements		
		FR-SK-1	FR-SK-2	FR-SK-3
Technical Requirements	TR-SK-1	X	X	X
	TR-SK-2		X	X
	TR-SK-3	X		
	TR-SK-4	X		
	TR-SK-5		X	
	TR-SK-6		X	
	TR-SK-7		X	
	TR-SK-8			X
	TR-SK-9	X	X	
	TR-SK-10	X	X	
	TR-SK-11	X	X	
	TR-SK-10	X	X	X

2.5.2 ARCHITECTURE OF THE TOOL

Software architecture

The global architecture of the station keeping module is described in the following figure. The station keeping module will comprise interfacing modules (GUI, API), to converse with the user or with other modules, and a core where the module functionalities will be implemented.

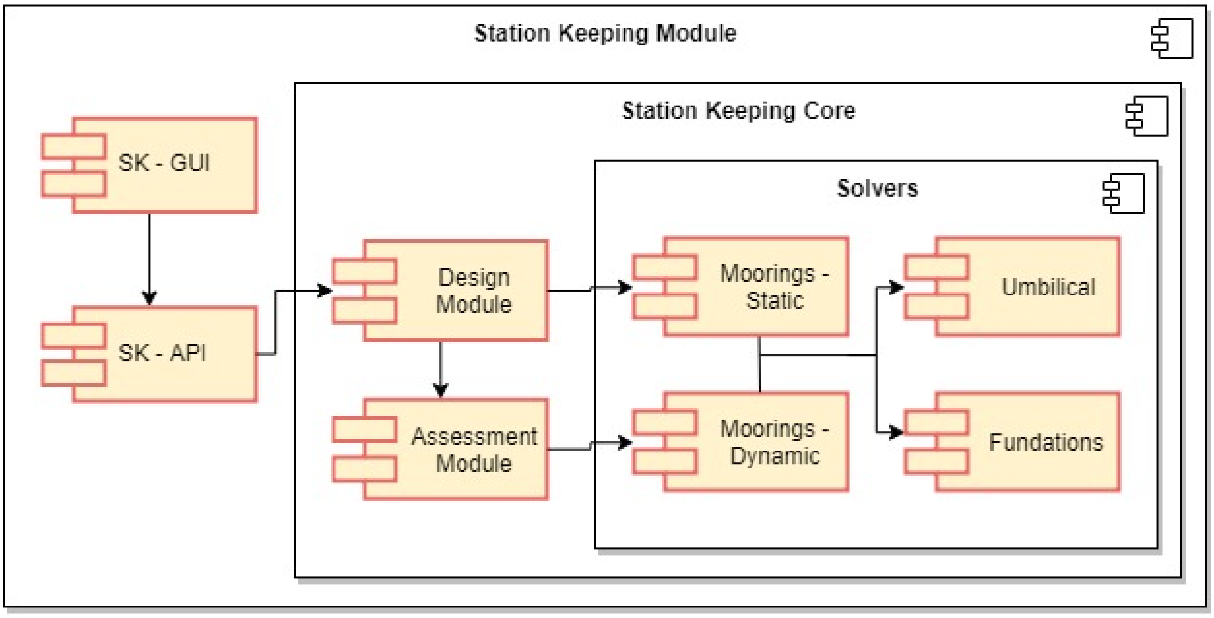


FIGURE 2-23. SCHEMATIC OF THE STATION KEEPING ARCHITECTURE

The core will consist of a module for the design generation, of a module for the design performance evaluation and of different solvers (each dedicated to a sub-component and possibly to a specific kind of analysis).

The design module will be calling to the global evaluation module, which will in turn call successively the different solver modules.

Figure 2-24. displays the main principles of the station keeping workflow (on the left) and the way data will be circulated between the station keeping sub-modules (right). Local storage needs are displayed as vertical cylinders. The figure also highlights from which other deployment tools will originate part of the required input data.

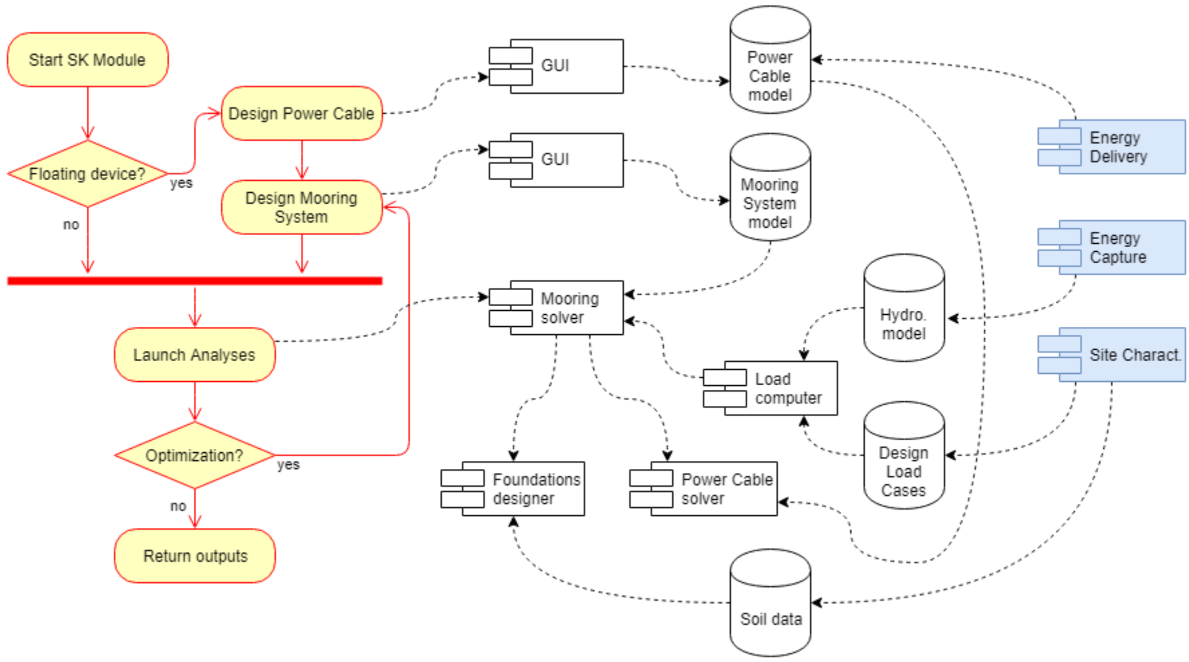


FIGURE 2-24. ARCHITECTURE OF THE STATION KEEPING MODULE

In Figure 2-24.,the architecture of the station keeping module is also represented. For floating devices, the *mooring designer* function will be used to:

- Design the mooring system using the hydrodynamic loads from the EC module (if applicable), extreme values of environmental conditions from the Site Characterisation module and data from the database;
- Perform the umbilical mechanical design considering the cable characteristics from the Energy Delivery module, material properties from the Database.

The *foundation designer function* will design the foundations considering:

- For floating devices: the line tension calculated during the mooring design and,

- For fixed devices: calculating the hydrodynamic loads using data from the EC module.

2.5.3 MAIN FUNCTIONS AND MODELS/USE CASES

USE CASES

There are 2 main functions that are foreseen for the station keeping module synthetized from the functional requirements from deliverable D2.2:

1. To provide help in generating a basic design;
2. To evaluate the performances (tensions, displacements, etc...) of an existing design.

Figure 2-25 below shows the main use cases that are described in this section.

The design generation function will first initiate the design process by creating a design to serve as a starting point from the user specifications. Then, iteratively, it will evaluate the design and modify to optimise a few selected design parameters.

Concerning the station keeping system's performances evaluation, the highly dynamic nature of a WEC's motions requires that the dynamic effects of the active mass should be accounted for, using a frequency-domain approach.

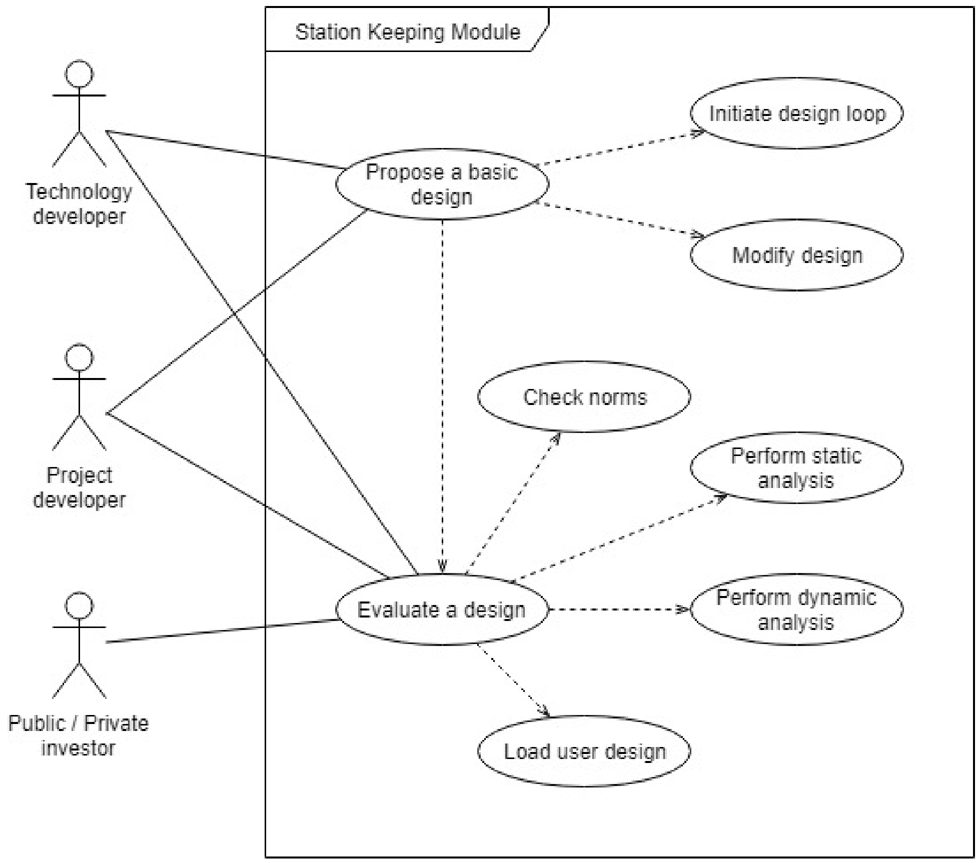


FIGURE 2-25: STATION KEEPING MODULE MAIN USE CASES.

However, while the design functionality also requires the proposed designs performance assessments, the iterative nature of the design process makes it necessary to have a fast resolution method. For the optimisation design process, a static analysis approach will thus be preferred despite its much lower fidelity level. For evaluation, the user will have the choice between static and dynamic frequency-domain solutions.

FUNCTIONAL DETAILS

The Station Keeping module main functions are to provide help in generating basic designs (Figure 2-26) and to assess the existing designs performance (Figure 2-27).

Function 1: Provide help in generating basic designs

The first function of the station keeping module will be to provide help in the earliest stages of design. The user will typically be asked to describe some system parameters (parts that are not optimised by the design process) and some optimisation parameter specifications. Default values may be proposed, based on the water depth, for instance.

The design module will then perform the optimisation through successive calls to the assessment module, by calling the different solver modules. The design module will then return the successful design and the associated performance metrics to the user. The user will have the possibility to test and try different options, and to compare their performances.

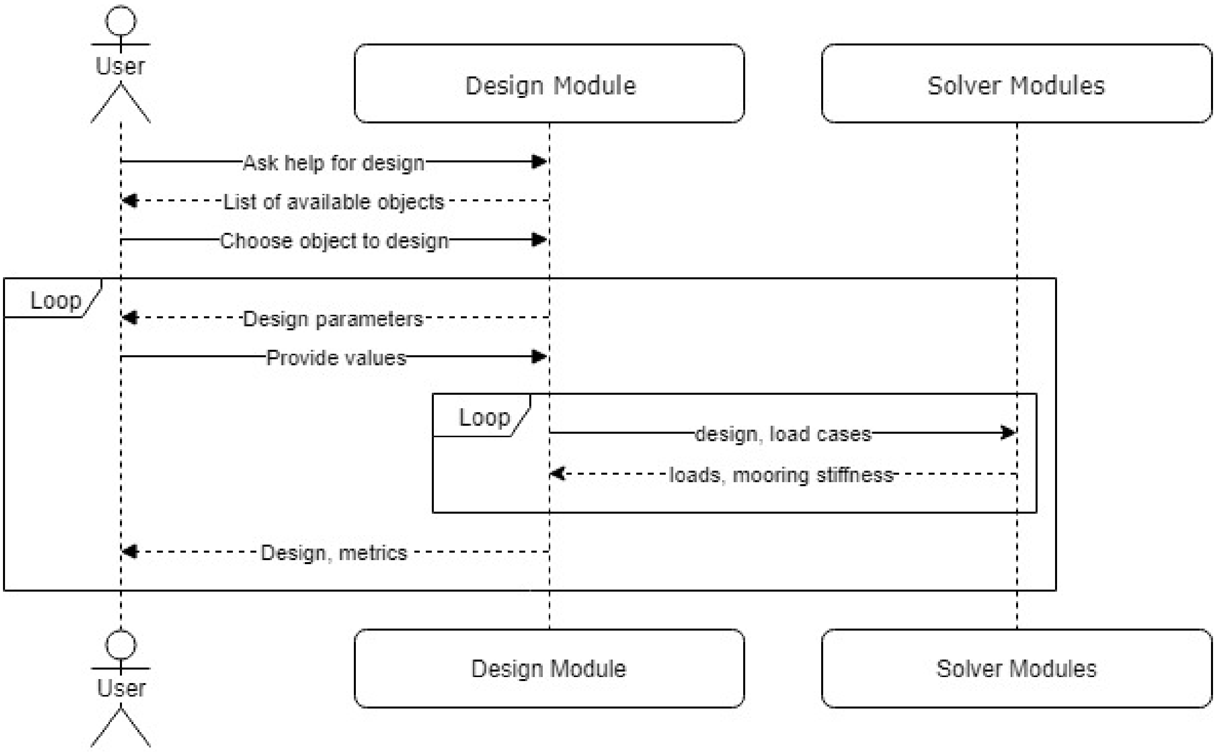


FIGURE 2-26. STATION KEEPING FUNCTION 1 SCHEMATIC

Function 2: Evaluate the existing design performances

The station keeping module should also provide a means for the user to describe its design and for the module to convert it to the right format.

The user will typically be offered 2 options, either to describe his design solution using the Station Keeping module itself, or directly provide the input file containing the description of the mooring system from a standardised format.

The second solution will allow for more flexibility; however, the user will have to provide the correct file format that could be compatible with standard description of Station Keeping systems from commercial software or Open Source solutions such as MAP++.

The station keeping module, through its solver modules, will then evaluate the design performance and return the relevant metrics to the user (i.e. for use in DTOceanPlus assessment modules).

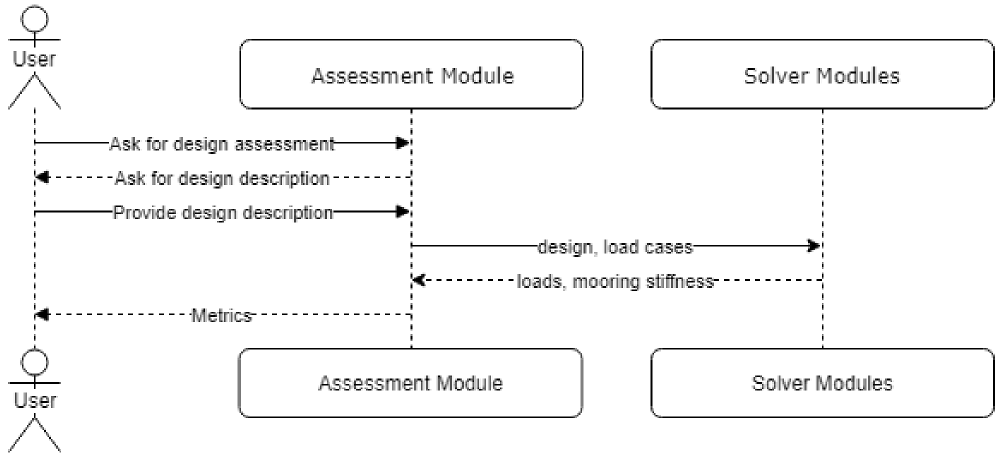


FIGURE 2-27: STATION KEEPING FUNCTION 2 SHEMATIC.

MODEL DETAILS

Mooring system: Both static and dynamic solver solutions will be implemented.

For the static approach, the library MAP++ (Mooring Analysis Program) will be used to compute the equilibrium of multi-segmented (mooring) lines based on catenary equations. The mooring system static equilibrium is then computed with multiple lines and external forces applied to the floating body. This library has been developed by Marco D. Masciola and is made available by NREL [12]. This is a well-suited solution for the static approach for optimising a mooring design due to its computational efficiency.

The dynamic approach implementation will only consider the dynamic effect of the active mass's inertia (plus added mass and damping), neglecting the dynamic characteristics of the mooring lines.

Most system hydrodynamic loads will be computed within the EC module to ensure consistency within DTOceanPlus computations. These would comprise:

- Current thrust forces on tidal devices;
- Wave excitation forces (first and second order wave loads);
- Added mass coefficients;
- Radiation damping coefficients.

Current drag on wave/tidal devices (excluding the thrust force on tidal turbines) will be computed internally to the SK module. It is however expected that the required coefficients will be provided in the database along with the other device-related data, or by the user.

Approximated values from analytical formulations of loads will also be available internally to the SK module in case the Energy Capture module does not provide the above-mentioned data (if a lower fidelity-level is used for instance) or if it is not deemed necessary to use hydrodynamic loads from the EC module (a solution to assess whether those forces need to be computed should be implemented).

Dynamic power cable: Extreme motions of the floater will be imposed to the power cable, neglecting any effect the power cable might have on the floater motions. The response of the power cable will then be computed in a similar manner as what is done in DTOcean.

Foundation: For floating devices, loads on the anchors will be provided by the mooring system solver.

For fixed devices, the hydrodynamic loads on the devices will be transferred to the foundations assuming a rigid body.

2.5.4 DATA REQUIREMENTS

Some inputs should come from other modules, some other inputs should be stored in the catalogue data base (list of mooring line's components references and their properties for instance).

User inputs should be limited to the specification of constraints for the module to propose a design solution, or to the specification of an existing specific mooring / foundation design solution.

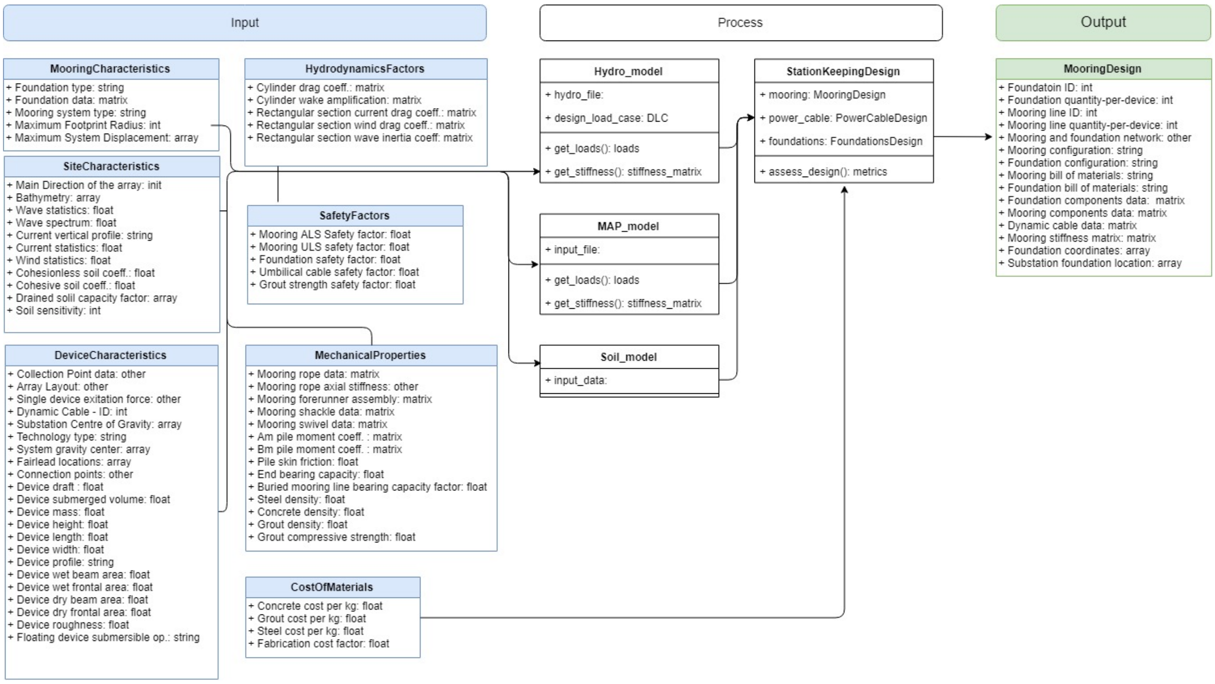


FIGURE 2-28. CLASS DIAGRAM FOR THE STATION KEEPING MODULE.

Inputs required from other modules include (or directly provided by the user:

1. Extreme environmental conditions from the Site Characterisation module;
2. Bathymetry and soil properties from the Site Characterisation module;

3. Array layout from the Energy Capture and the Energy Delivery modules;
4. Exclusion areas from the same 3 sources as the above points;
5. Devices detailed description (mass distribution, draught, geometry above and below the surface, …) from the EC module;
6. Initial mooring stiffness value used by the EC module;
7. Hydrodynamic data base (frequency-dependent) on the devices / substations from the EC module (when applicable);
8. Umbilical electrical description from the Energy Delivery module
9. Components detailed description from the data base;
10. Cost functions (through public methods calls) from the System Lifetime Costs Assessment and Logistic modules (although this is not exactly input data) where applicable.
11. Design load cases

Module outputs:

- Design description;
- Bill of materials (including hierarchy and links between items);
- Costs;
- Extreme loads;
- Extreme position offsets;
- Frequency-domain description (motions, accelerations…) of the system if deemed relevant.

2.6 LOGISTICS AND MARINE OPERATIONS

The Logistic and Marine Operations (LMO) Planning module designs solutions locally optimised in terms of logistical infrastructure and of marine operation scheduling for Ocean Energy projects. The design objective is to minimize the logistic costs associated with all lifecycle stages (installation, operation and maintenance, and decommissioning) of a given MRE project, while considering suitable combinations of ports, vessels and support equipment that fulfil the logistical requirements, such as lifting and towing.

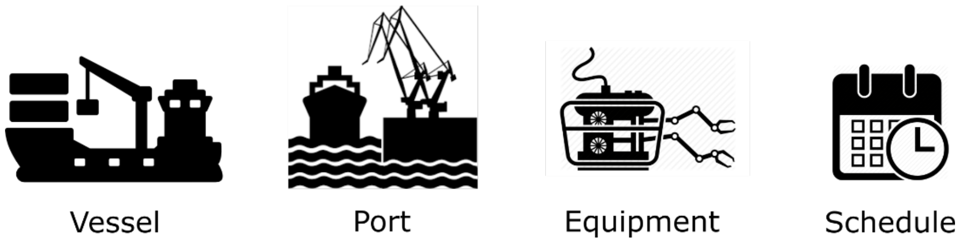


FIGURE 2-29. SCHEMATIC REPRESENTATION OF THE LOGISTICS AND MARINE OPERATIONS MODULE OUTPUTS

2.6.1 FROM FUNCTIONAL TO TECHNICAL REQUIREMENTS

Taking into consideration the functional requirements stated in Deliverable D2.2, the technical requirements of the Logistics and Marine Operations Planning module were compiled in Table 2-12.

These technical requirements represent the actions that the Logistic module will perform to achieve the functional requirements.

TABLE 2-12 FUNCTIONAL AND TECHNICAL REQUIREMENTS OF THE LOGISTICS AND MARINE OPERATIONS PLANNING MODULE.

Functional Requirements
FR-LMO-1. Define the logistic infrastructure requirements for each operation stage of a given project. FR-LMO-2. Identify feasible logistic solutions in respect to infrastructure for each lifecycle stage. FR-LMO-3. Develop long-term maintenance plans at the design stage, based on corrective and/or calendar-based maintenance strategies, which integrate the outputs from the RAMS model public methods developed in task T6.4. FR-LMO-4. Develop short-term planning of maintenance operations when failure occurs. FR-LMO-5. Compute an optimal logistical solution that minimizes total logistical costs FR-LMO-6. Provide logistical assessments results with different levels of complexity depending on the development stage to other DTOceanPlus tools, namely Structured Innovation and Stage Gate.
Technical Requirements
TR-LMO-1. Read attributes from the other Deployment tools that were previously run, including Site Characterisation, Energy Capture, Energy Transformation, Energy Delivery and Station Keeping. TR-LMO-2. Request user to fill inputs for the logistical analysis, namely cargo size, through the GUI. TR-LMO-3. Use of default values and clearly stated assumptions for dealing with missing inputs (e.g. transportation method: assumed on deck) TR-LMO-4. Use of requirement compiling functions to identify logistical requirements and constraints (e.g. lifting requirements, towing requirements, minimum vessel deck area) based on the number, type and physical characteristics of components as well as the specified assembly and load-out strategies. TR-LMO-5. Use of operation flowcharts and design structure matrices (DSM) to identify list of activities (e.g. cable laying) and activity precedence within each operation (e.g. installation of static cables) for each logistic phase (installation, O&M, decommissioning, etc.). TR-LMO-6. Use of default operation sequencing order if not specified by the user TR-LMO-7. Use of lookup tables to search for infrastructure combinations stored in the database that are typically used for each specific operation TR-LMO-8. Use of requirement matching functions to select ports, vessels and equipment that satisfy requirements and constraints TR-LMO-9. Use of feasibility functions to select possible solutions, which correspond to feasible combinations of ports, vessels and equipment that are suitable for each operation, and if applicable, the number of infrastructure units needed to complete it. TR-LMO-10. Use of weather window finding functions to estimate GO and NO-GO weather conditions (workability) for each specific activity TR-LMO-11. Use of scheduling functions to schedule activities according to weather windows and activity sequences, and to output estimated waiting times and total operation duration. TR-LMO-12. Use of System Lifetime Costs public methods to assess logistical infrastructure costs TR-LMO-13. Use of performance functions to determine time and costs associated with each logistic operation TR-LMO-14. Use of scoring functions to select an optimal logistical solution TR-LMO-15. Use of RAMS public methods to obtain time to failures (TTF), and suggested intervals between

repairs/inspections based on TTF data for scheduling maintenance operations

TR-LMO-16. Supply maintenance solution in terms of schedules as inputs to the RAMS module, which will be used to calculate the farm's availability

TR-LMO-17. Use of public methods to provide quick but basic logistical assessments, by comparing cost rankings or cost proxies, to the Structured Innovation and Stage Gate tools

TR-LMO-18. Use of public methods to provide quick but intermediately complex logistical assessments for other design tools, such as the Energy Delivery (and Station Keeping) module, namely for the selection of the electrical infrastructure, including cable routing.

TR-LMO-19. Inform the user with the logistic design results through the GUI.

Some of the listed technical requirements are associated with several functional requirements. These relationships are expressed in Table 2-13. It can be observed that the functional requirement **FR-LMO.05**, which is related to calculating an optimal logistical solution that minimizes total logistical costs, is the one that has the most technical requirements associated with it.

TABLE 2-13 FUNCTIONAL REQUIREMENTS / TECHNICAL REQUIREMENTS RELATION MATRIX FOR THE LOGISTICS AND MARINE OPERATION MODULE.

		Functional Requirements					
		FR-LMO-1	FR-LMO-2	FR-LMO-3	FR-LMO-4	FR-LMO-5	FR-LMO-6
Technical Requirements	TR-LMO-1	X	X	X	X	X	X
	TR-LMO-2	X	X	X	X	X	
	TR-LMO-3	X	X	X	X	X	X
	TR-LMO-4	X	X	X	X	X	X
	TR-LMO-5		X	X	X	X	X
	TR-LMO-6			X	X	X	X
	TR-LMO-7		X	X	X	X	X
	TR-LMO-8		X	X	X	X	X
	TR-LMO-9		X	X	X	X	X
	TR-LMO-10			X	X	X	X
	TR-LMO-11			X	X	X	
	TR-LMO-12			X	X	X	
	TR-LMO-13			X	X	X	X
	TR-LMO-14			X	X	X	X
	TR-LMO-15			X	X	X	
	TR-LMO-16			X	X	X	
	TR-LMO-17					X	X
	TR-LMO-18					X	X
	TR-LMO-19					X	

2.6.2 ARCHITECTURE OF THE TOOL

Although being capable of running standalone is a requirement, the Logistics and Marine Operation module is intrinsically interconnected with all Deployment design modules, being able to collect inputs from the latter. Hence, in case the user decides to run multiple Deployment design tools in a sequence, the Logistics tools are run last, followed by the Assessment tools. The flow of information and main Logistical functions are presented below in Figure 2-30.

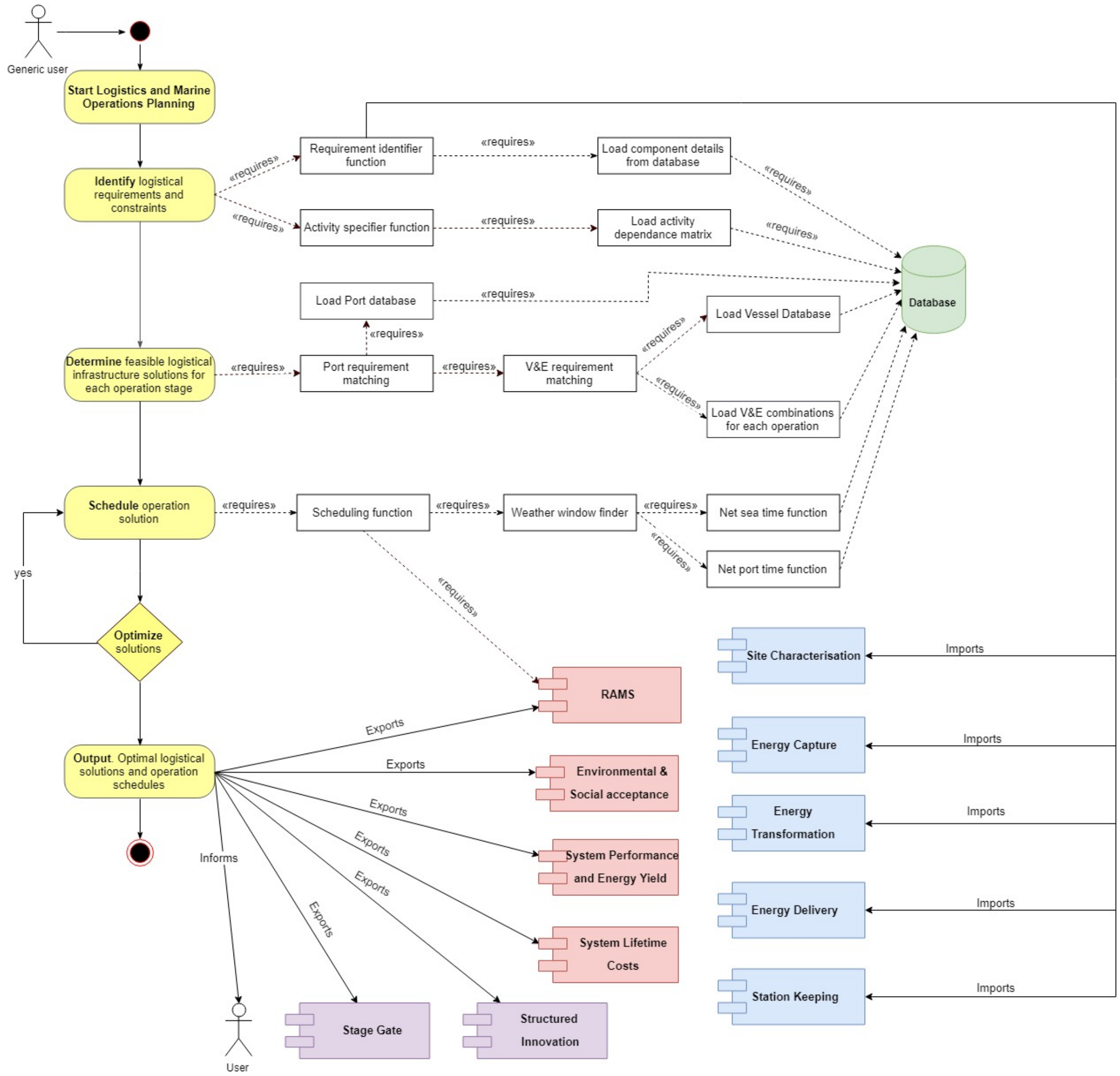


FIGURE 2-30 LOGISTICS AND MARINE OPERATIONS PLANNING TOOLS ARCHITECTURE

In order to achieve the technical requirements proposed for the Logistics and Marine Operation Planning tools, a set of fundamental functions were defined. Some functions were built on the previous DTOcean logistical functions, although most are expected to be different as a novel methodology is considered. At the time of writing, the main functions are still under the development, and are expected to be described in greater detail in subsequent deliverables.

1. **Activity specifier function:** For each logistical operation, a list of logistical activities is specified, as well as suggested operation and activity sequencing. However, the ability to rearrange the activity and operation sequencing as the user seems fit is provided
2. **Requirements compiler:** Different logistical activities (e.g. cable laying, vessel loading, device towing), technology types and device/subsystem characteristics (e.g. weight, dimensions), will result in different logistical requirements (e.g. crane's lifting capability, minimum vessel deck area for transport). This function compiles all the underlying requirements associated with each operation and specific device
3. **Feasibility functions/Requirement matching:** The feasibility functions are functions that produce feasible infrastructure solutions (vessels, equipment and ports), taking into consideration the operation type and logistical requirements previously compiled. They can be decomposed in two matching functions that run sequentially:
    a. **V&E requirement matching:** This function checks V&E combinations – including vessel and equipment type and number of units – that are typically used in similar operations and that meet previously compiled logistical requirements.
    b. **Port requirement matching:** Once the V&E combined solutions are compiled, these are matched against the port database and port requirements, producing a feasible V&E&P solution.
4. **Net time functions**
    a. **Net Port time Function:** Obtains the net port time to carry out each logistic activity.
    b. **Net Sea time Function:** Obtains the net sea time to carry out each logistic activity.
5. **Weather windows finder:** Taking as input Operating Limiting Conditions (OLC) of the vessels, activities and/or user specified limiting conditions, as well as hindcast metocean data, the weather windows finder function checks weather for GO and NO-GO conditions for each logistic activity.
6. **Scheduling function:** For each solution considered, the scheduling function calendarizes all operations and activities according to weather windows, activities net duration (sea or port time) and activity/operation sequencing, in a way that minimizes total project time. When scheduling maintenance operations, this function also calls a RAMS public method, which suggests maintenance deadlines based on component reliability thresholds, or in failure events randomly generated with Monte Carlo simulations, depending on the adopted maintenance strategy (preventive, corrective or both).
7. **Optimal finder function:** Taking into consideration the infrastructure solution and operation schedules, an optimal solution that minimizes costs and project duration is selected. This function interacts with the System Lifetime Cost tools in order to estimate each solution total Logistics cost, while labelling costs as Capex and OpEX. After having selected an optimal solution, which includes infrastructure and operation details and schedules, the solution is supplied to the RAMS and Environmental & Social Impact tools, which calculates the farm's availability and associated environmental impacts respectively.

Finally, the outputs of the optimal finder function may be supplied to the SG & SI tools, possibly unveiling promising cost-reduction opportunities.

2.6.3 MAIN FUNCTIONS AND MODELS

The three identified user targets and expected use cases for the Logistic tools are described in Figure 2-31. As can be observed, most use cases merge into a common use case: to obtain suitable logistical solutions in terms of Vessels, Equipment and Ports. However, each user and specific use case requires information at different levels of detail.

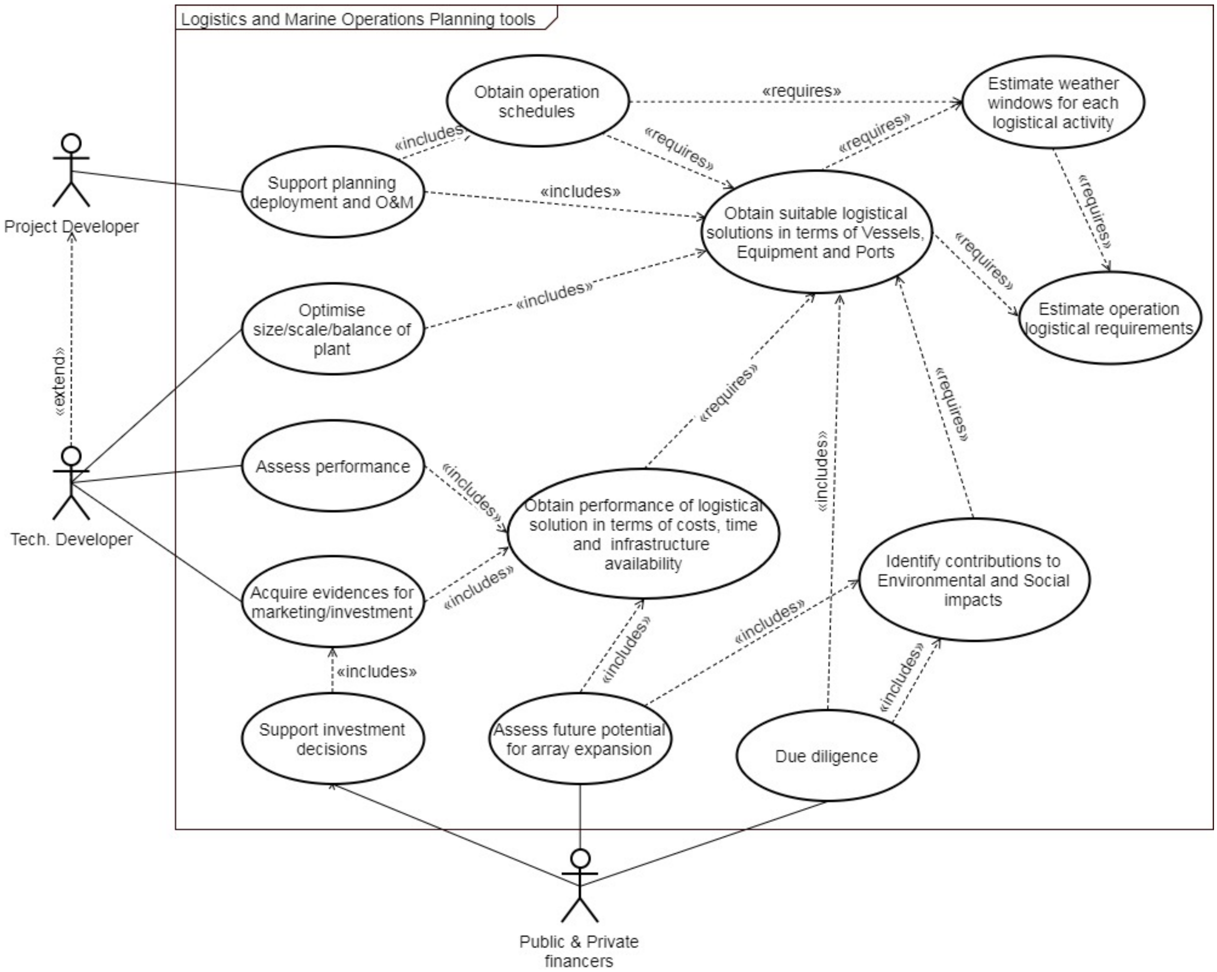


FIGURE 2-31 LOGISTICS TOOLS USE CASE DIAGRAM

Project Developers are mainly interested in obtaining support for the marine operation planning, including installation and O&M. Operation scheduling is a major part of operation planning, which is dependent on the operation type and associated requirements, on the selected support infrastructure in terms of vessels, equipment and ports, and on the typical environmental conditions of the deployment location. Project developers are typically interested in a detailed solution, obtaining an optimal logistical solution, predictions on logistic costs as well as cost-reduction pathways.

Technology Developers are interested in obtaining support for the operation planning, but also in optimizing the scale/size of their device in an array, assessing the performance of their technologies and acquiring evidences for marketing and investment. Technology Developers are typically less interested in obtaining an exact logistical solution, but more in estimating the logistical costs that are associated with their technology, as they play a very significant part in the cost-performance of the MRE project. For these users, using the logistic tools may unveil cost-reduction pathways as well as demonstrate the technology's potential for procuring public and private support and investment.

Public and Private financers are typically interested in obtaining support for evaluating investment decisions, assessing a technology/project potential for upscaling to array scale and performing due diligence. These user needs require a lower level of detail, being more focused on performing high-level assessments on the logistics contribution to the MRE project costs, identifying major contributions to the project's environmental and social impacts.

2.6.4 DATA REQUIREMENTS

Main inputs and outputs of the Logistical and Marine Operation Planning tools were identified in Task 7.1. Each variable was then associated with the digital representation of the Ocean Energy system, which is organized in classes. The architecture of the Logistic tools is presented in Figure 2-30.

According to the class diagram, *Phase, Operation* and *Activity* are class types. Each logistical phase (i.e. Manufacturing, Installation, Operation, Maintenance, Decommissioning) will be of the type *Phase*. Each logistical phase is composed by one or more operations (e.g. cable installation, foundation installation…), which in turn are also classes themselves, of the type *operation*. Each operation is subsequently composed by several activities of the *activity* class (e.g. vessel load-out, cable laying, device lifting, transit from port to site, etc.). The *operation* class will be able access the user selections and catalogues. An example of the class associated with the cable installation operation is shown in Table 2-14.

TABLE 2-14 EXAMPLE OF AN OPERATION CLASS: CABLE INSTALLATION

Cable installation	Value	Type
Operation name	cableinstallation	*string*
Operation_ID	200	*string*
Operation_duration	60 (h)	*float*
Activity_precedenceDSM	[1 0 0] [1 1 0] [0 1 1]	*matrix*
Activity_list	[Mobilization, Vessel loading, load-out, transit, cable laying, transit to port, …]	*list*
Activity_sequence	[201,202,203,205…]	*array*
Typical_Vecombinations	[Multicat+Lifting crane+…]	*list*
OperationStart_timestamp	03/03/xxxx , 14h00	*string*

Following this data architecture, each logistical phase is decomposed in operations, which are subsequently decomposed in activities types.

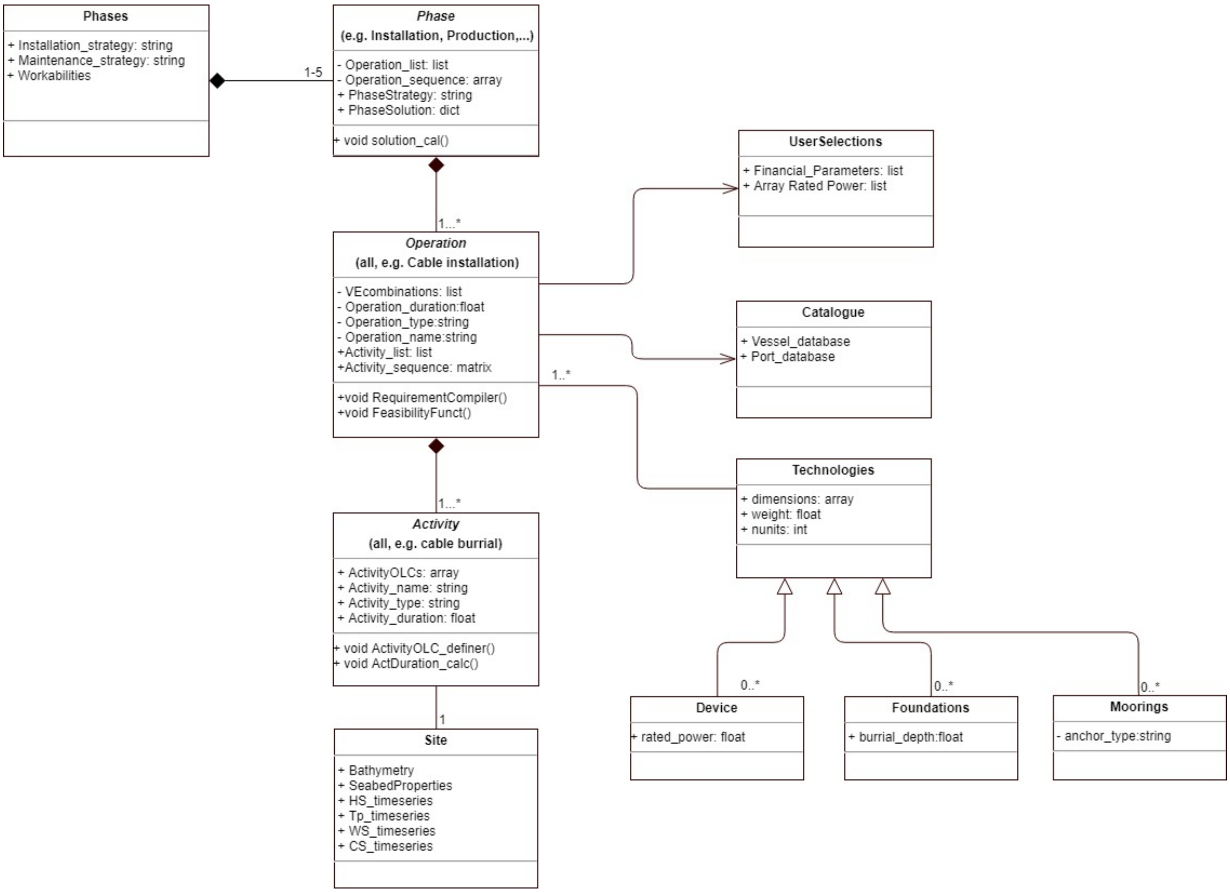


FIGURE 2-32 CLASS DIAGRAM OF THE LOGISTIC TOOLS

2.7 INTERFACES, COMPATIBILITY AND PORTABILITY

The Digital Representation will represent the instrument to interface the Deployment design tools as well as the underlying platform with other external technical tools, and to make them compatible with other software and the inputs/outputs being fully portable (e.g. for the most common station keeping commercial software such as Orcaflex, Ariane or DeepLines).

Moreover, it is envisaged that the input/outputs could be interchanged with the set of tools by means of configuration files and other formats for exporting data. The definition of a generalised and standardised data format for specific data, such as for example the hierarchy of components, is particularly challenging but at the same time it could be necessary to integrate the data/information in a user-friendly manner. Therefore, each module will have several features implemented:

- Project open/save feature: to resume project progress to where it was previously saved and using configuration files.
- Export the module outcomes: to offer the possibility to save the project outcomes.

In general, the interfaces with external software are described in Table 2-15.

TABLE 2-15: INTERFACE OF DTOCEANPLUS MODULES WITH EXTERNAL SOFTWARE

Tool in DTOceanPlus	Interface with other	Notes

	Software	
Site Characterisation	Telemac and WW3	Interface with physical oceanography models
Energy capture	BEM software (Wave Energy Converters): Wamit, NEMOH	A version of NEMOH will be shipped with the DTOceanPlus package. The inputs from the BEM solver are imported or calculated in an external pre-processing module, also included in the DTOceanPlus package.
Station Keeping	MAP++ solver	The Station Keeping module will use an external routine (MAP++ solver). It will be used through a wrapper (binding routines) making it compatible with Python 3 and DTOceanPlus.
Logistics and Marine Operations	Shipbroking service providers databases	It is under exploration the possibility of interfacing with such database to provide updated vessel data and costs.

2.8 MAINTENANCE

This section deals with the management of extension and updates in the future. The tools developed in the DTOceanPlus toolset will be aligned with the most up-to-date state of the art, the Digital Representation will become an acknowledged vehicle in the sector through which it will be possible to connect the platform of DTOceanPlus with other tools, eventually improving or extending the functionalities as long as soon as they become available in the scientific panorama. Further, a number of external Python packages will used (e.g. NumPy, Pandas, SciPy, etc...). In order to maintain the code functionality, the used version of this packages will be packaged within the DTOceanPlus. In a similar fashion, the DTOceanPlus global database will be expandable and easily extended in the future, depending on the availability of the data, in order to update the catalogue of components, as well as a wider range of available PTO types and energy storage systems.

3. TECHNICAL SPECIFICATIONS FOR THE INTEGRATION OF THE DEPLOYMENT DESIGN TOOLS IN THE DTOCEANPLUS TOOLSET

In this section, the issue of integrating the Deployment design tool with the other components of the DTOceanPlus platform is discussed. In particular, the attention has been focused on the following topics:

- The interaction with the underlying platform and the Digital Representation: the general architecture of the platform is briefly discussed and then, for each Deployment design module, a diagram has been produced to show the interconnections with the other components of the toolset;
- A brief description of the database will explain the interaction of the Deployment design tool with the global storage;
- The interaction between the deployment design modules;
- The interaction of each Deployment design module with the Assessment design tool, as well as with the Structured Innovation design tool and the Stage Gate design tool;
- The interaction with the User, through the User Interface (UI).

3.1 INTEGRATION WITH THE UNDERLYING PLATFORM AND THE DIGITAL REPRESENTATION

3.1.1 MAIN ARCHITECTURE

The architecture of the DTOceanPlus application is modular and is based on services. Each module will represent a tool or a set of tools. Each module will provide a list of services (i.e. Python functions), and the main application will publish these services in the main UI.

This architecture allows modules to be developed independently and also to be run, eventually, in a standalone mode, without the main UI, depending on the module characteristics and functionalities.

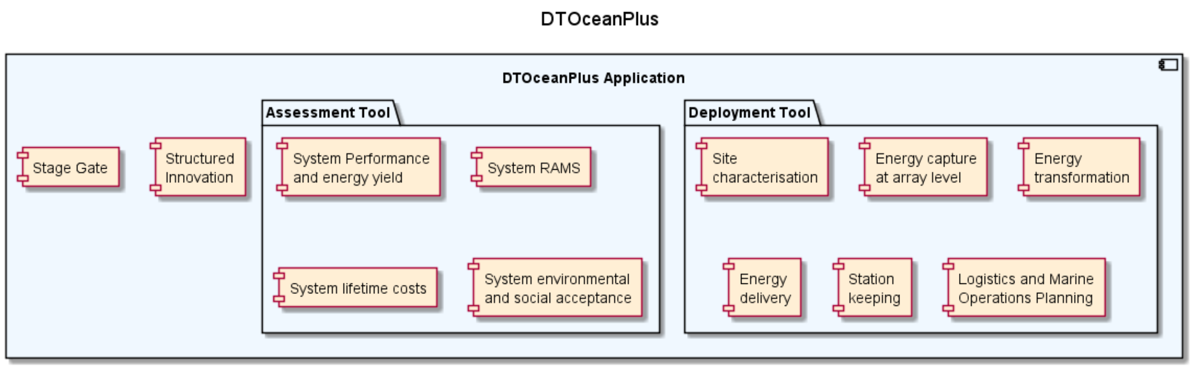


FIGURE 3-1. DTOCEANPLUS ARCHITECTURE

3.1.1.1 Tools

Description

Each tool will be implemented as a module. Modules could eventually work in following scenarios:

- Platform - module as embedded component of the platform
- (eventually) Stand-alone - module as a GUI application

FIGURE 3-2. MODULE SCENARIOS

Modules should provide different interfaces for each scenario:

- GUI
- Embedding API
- Python bindings

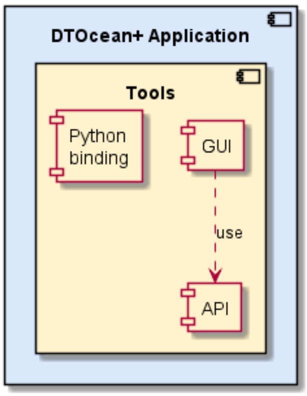


FIGURE 3-3. DTOCEANPLUS MODULE

Embedded mode (External API)

Users want to have APIs (Application Programming Interface) to connect to the different applications and use them in "batch" mode. Each module will need to provide its specific API and generic services, and also the database access will have one too. This API will also be used internally by modules [9].

Modules in this mode:

- Provide an API
- Can be used in batch mode
- Provide specific API (not generic, according domain model)
- This API will also be used internally by modules. Module API will be published for general use. All modules will communicate only via published API.

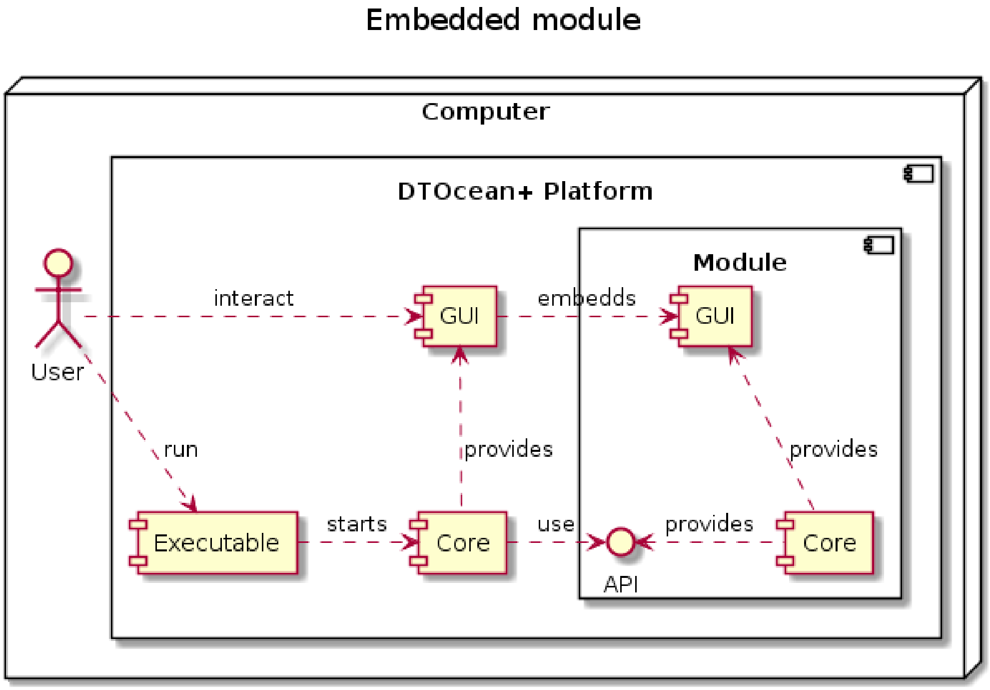


FIGURE 3-4. EMBEDDED MODULE

Standalone mode

The DTOceanPlus modules can be developed in a way that they can "potentially" be run independently in a standalone mode, or with the rest of the modules in the DTOceanPlus application. This can be useful for users who want to use one of the tools, as they won't need to install the full platform but only one tool. A standalone module can work completely independently with local data, but also use data from the database. Note that not all the modules will be developed in a standalone mode, too.

Modules in this mode:

- Run independently (from DTOceanPlus platform);
- Use other modules (implicitly, using data from the database);
- Can be installed separately;
- Are able to work using only local data;

Additionally, modules in this mode:

- Provide their own GUI;
- Are started via executable file;
- Require the user to configure inputs (where to take data, open files, etc.) and outputs (where to save data, save files, etc.);
- Require user to configure the connection to the Global Database.

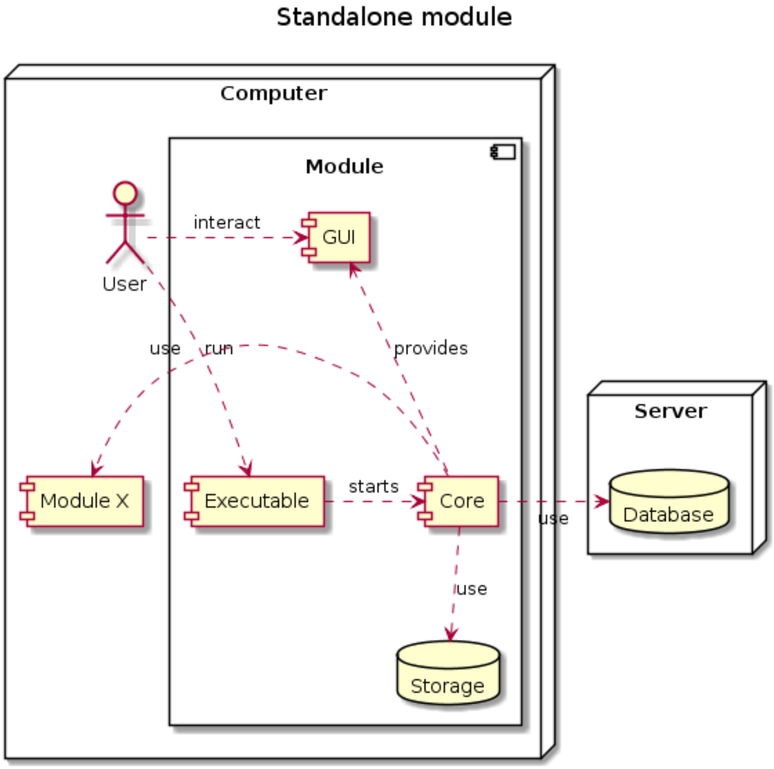


FIGURE 3-5. STANDALONE MODULE

3.1.1.2 Core Tools

All modules will rely on a suite of tools that will provide several features:

- GUI
- Storage
- Access to Database
- Import/Export the Digital Representation
- Other features to be identified.

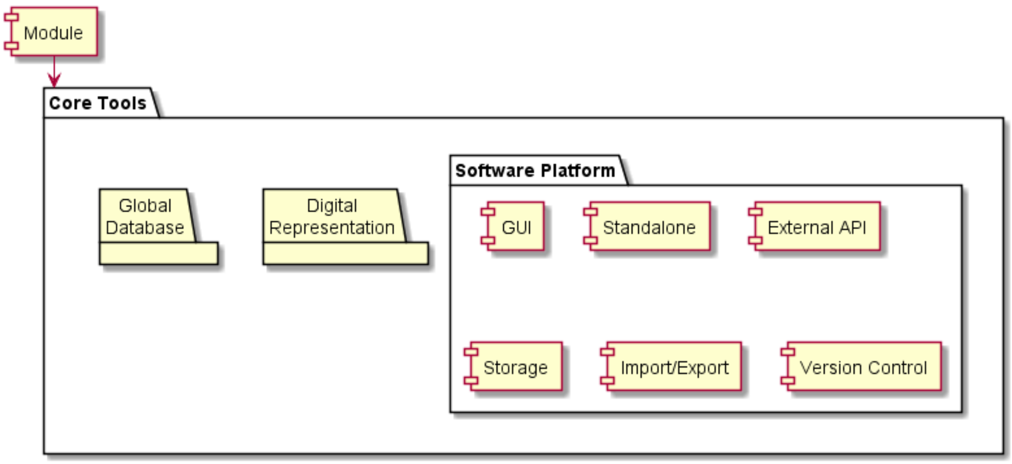


FIGURE 3-6. CORE TOOLS

3.1.1.3 Services

The architecture is based on services. Each module will provide a list of services that can be used by other modules. The services will be created using the Representational State Transfer - REST standard.

The following diagram illustrates how a module will call a service from another module:

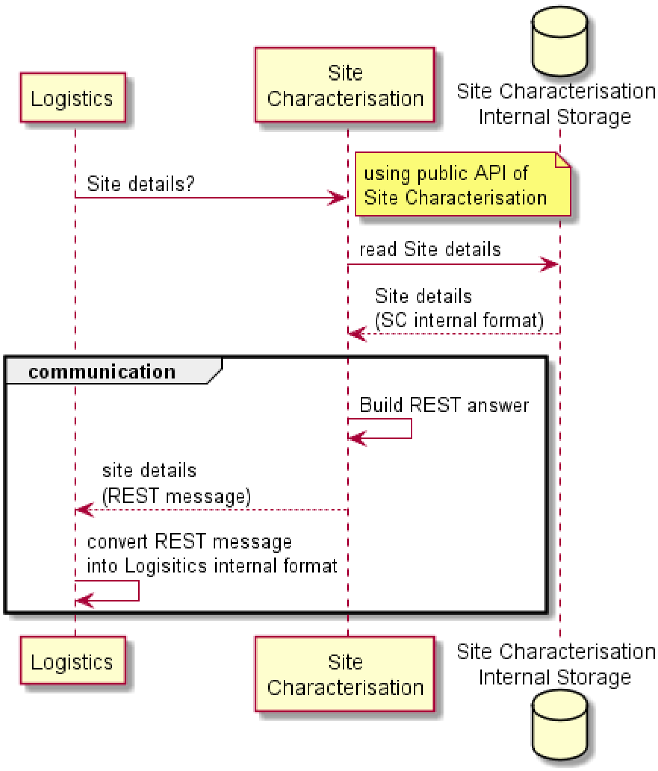


FIGURE 3-7. CALL OF A SERVICE BETWEEN MODULES (EXAMPLE FOR SITE CHARACTERISATION)

3.1.1.4 User Interface

The Core tools (Section 3.1.1.2) will provide tools for developing a GUI. They will simplify GUI unification (across all tools) and speed up tool-specific GUI development. Exact scope and level of detail for this functionality will be defined during actual tool development process, where

- Core tools will come up with some examples that demonstrate GUI basics
- Core tools will collect, mature and promote "best practices"

3.1.1.5 Digital Representation

The Digital Representation is a complete description of the user's project at a given time. It can be seen as a digital version of the real project and therefore it should contain all the needed information to describe the project.

The Digital Representation shall be seen as an export of the current project. This export will be done in a standard format, such as XML or JSON, with a documented structure so that it can be used by other applications, to import a DTOceanPlus project or to generate one that can be imported in the DTOceanPlus application.

The Digital Representation describes the main concepts defined in the DTOceanPlus application (site, technologies …). Each of these concepts is handled by one of the tools of the application, meaning the Digital Representation can be seen as an assembly of extractions of the data of each tool.

However, the Digital Representation is not a complete export of a DTOceanPlus project. Indeed, as this format is presented as a standard to represent an ocean energy system, it is important that it remains independent from the DTOceanPlus application. Therefore, all the concepts that are internal to DTOceanPlus application should not be exported in the Digital Representation.

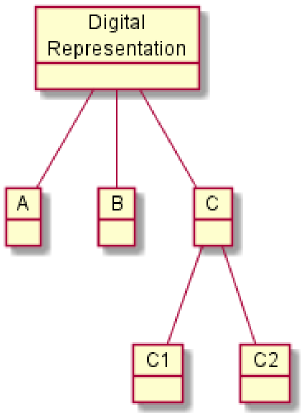


FIGURE 3-8. DIGITAL REPRESENTATION

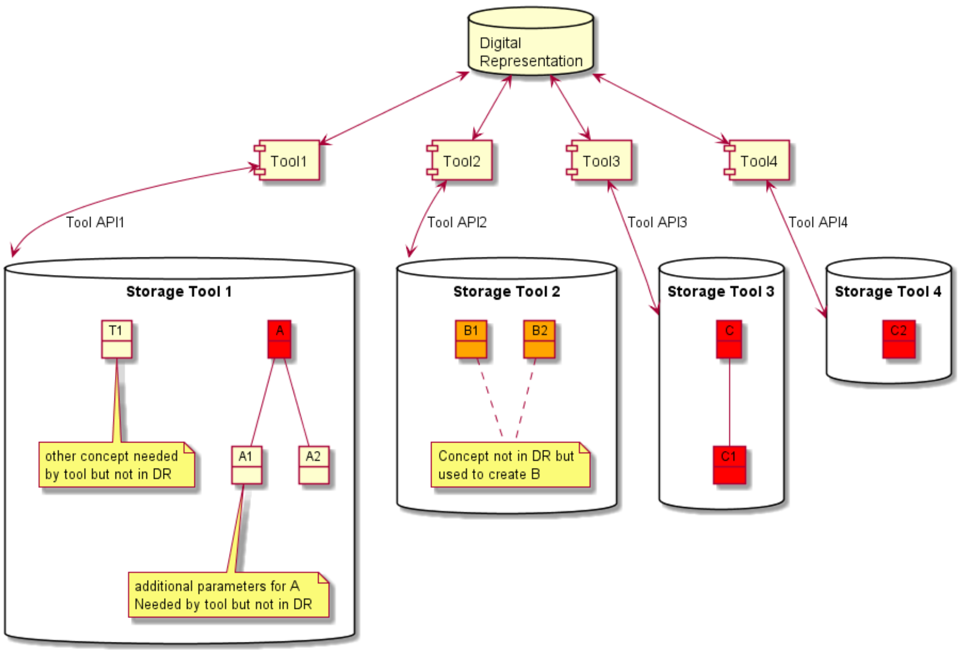


FIGURE 3-9. STORAGE OF THE DIGITAL REPRESENTATION

In the example above, the Digital Representation is represented as a tree of objects (Figure 3-8.). These objects are spread over the storage of different tools (Figure 3-9.), and some tools also use additional objects that are not part of the Digital Representation.

The Digital Representation will be created by a dedicated service of the main application which will ask each tool (and module?) to generate its part of the Digital Representation, in other words convert their internal model into the Digital Representation model and assemble it.

3.1.2 SITE CHARACTERISATION

The interface of the site Characterisation module will be a GIS interface (if possible global to all DTOceanPlus tools and modules) allowing the loading of raster layers (matrix, like the bathymetry, the seabed properties, ...) , and vector layers (shapefile of coastline or extent of the project for example). It will launch the statistics of waves, currents and wind, as well as the visualisation of the results obtained, punctually or in 2D.

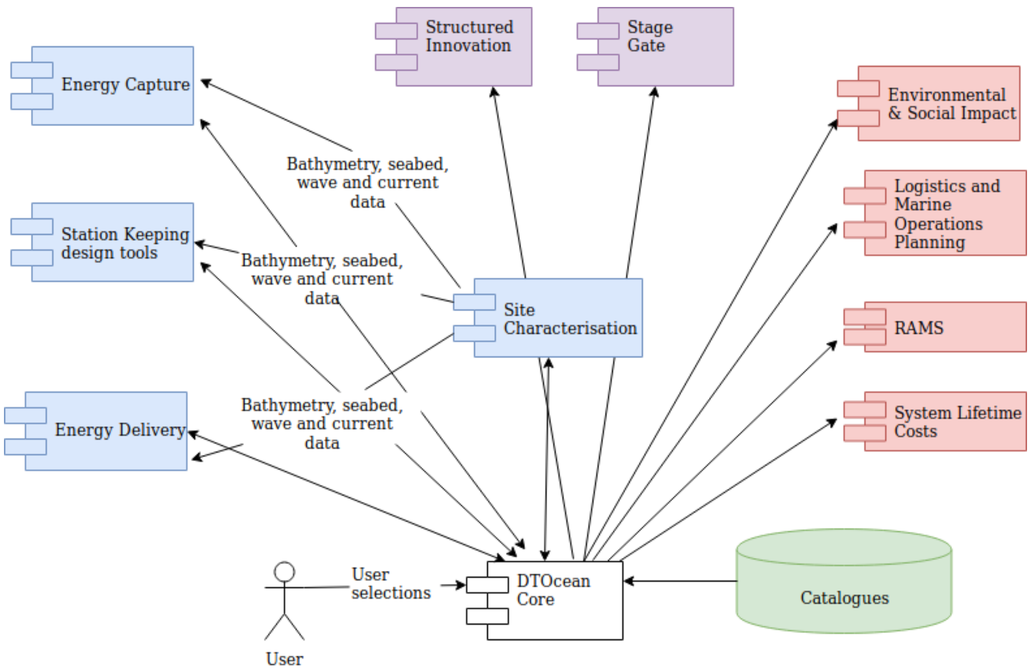


FIGURE 3-10: LINKAGES BETWEEN THE SITE CHARACTERISATION MODULE AND OTHER DESIGN TOOLS AND MODULES, WITH ARROWS SHOWING MAIN FLOWS OF INFORMATION.

3.1.3 ENERGY CAPTURE

The Energy Capture linkage with other tools and the platform is shown in Figure 3-11.. The inputs to the module will be provided either by the Site Characterisation module or by the user through the dedicated UI. The UI will be also used to push results back to the user for data visualisation and further analysis.

The Stage Gate tool and the Structured Innovation tool will interact with the Energy Capture module, too.

The outputs provided from the Energy Capture to the Energy Transformation and the Station Keeping modules are highlighted in blue, to represent the interaction developed in the form of public services.

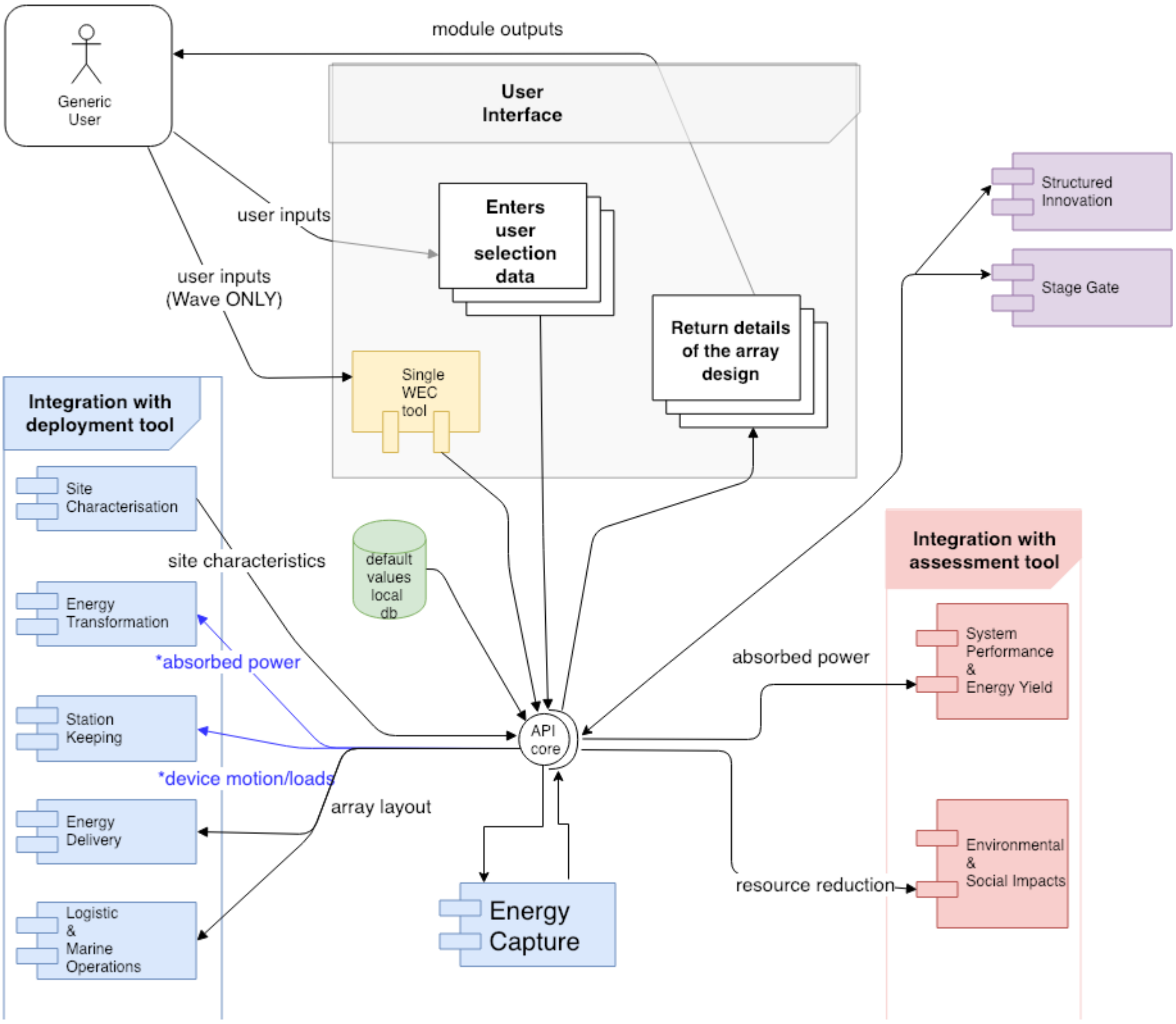


FIGURE 3-11. LINKAGES BETWEEN THE ENERGY CAPTURE MODULE AND OTHER DESIGN TOOLS AND MODULES, WITH ARROWS SHOWING MAIN FLOWS OF INFORMATION.

3.1.4 ENERGY TRANSFORMATION

The integration of the Energy Transformation module with all the other entities of the DTOceanPlus software is shown in Figure 3-12.. At a high level, inputs on the design will be received from the other Deployment modules (Site Characterisation and Energy Capture), from the user through the interface and from the catalogue in the tools, to other Deployment design modules, to the Structured Innovation and the Stage Gate design tools. The user will be able to make selections and input data via the GUI and will be presented with outputs showing both graphical and tabulated data.

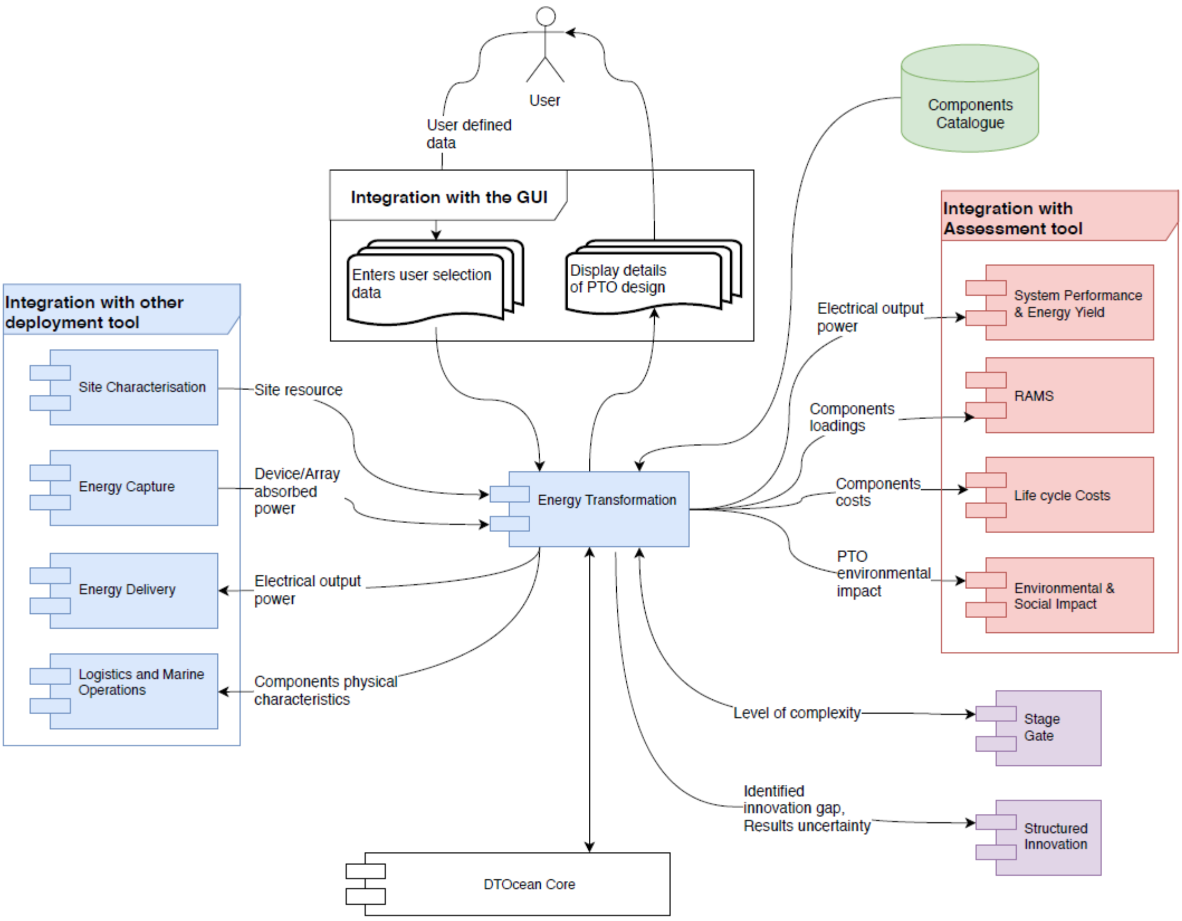


FIGURE 3-12. LINKAGES BETWEEN THE ENERGY TRANSFORMATION MODULE AND OTHER DESIGN TOOLS, WITH ARROWS SHOWING MAIN FLOWS OF INFORMATION.

3.1.5 ENERGY DELIVERY

The integration of the Energy Delivery module with all the other entities of the DTOceanPlus software is shown in Figure 3-13.. At a high level, inputs on the design will be received from the other Deployment modules (Site Characterisation, Energy Capture and Energy Transformation), from the user through the interface and from the catalogue in the global database, with outputs provided to the Assessment tool as well as to other Deployment modules, the Structured Innovation and Stage Gate design tools. The user will be able to make selections and input data via the GUI and will be presented with outputs showing both graphical and tabulated details of the network.

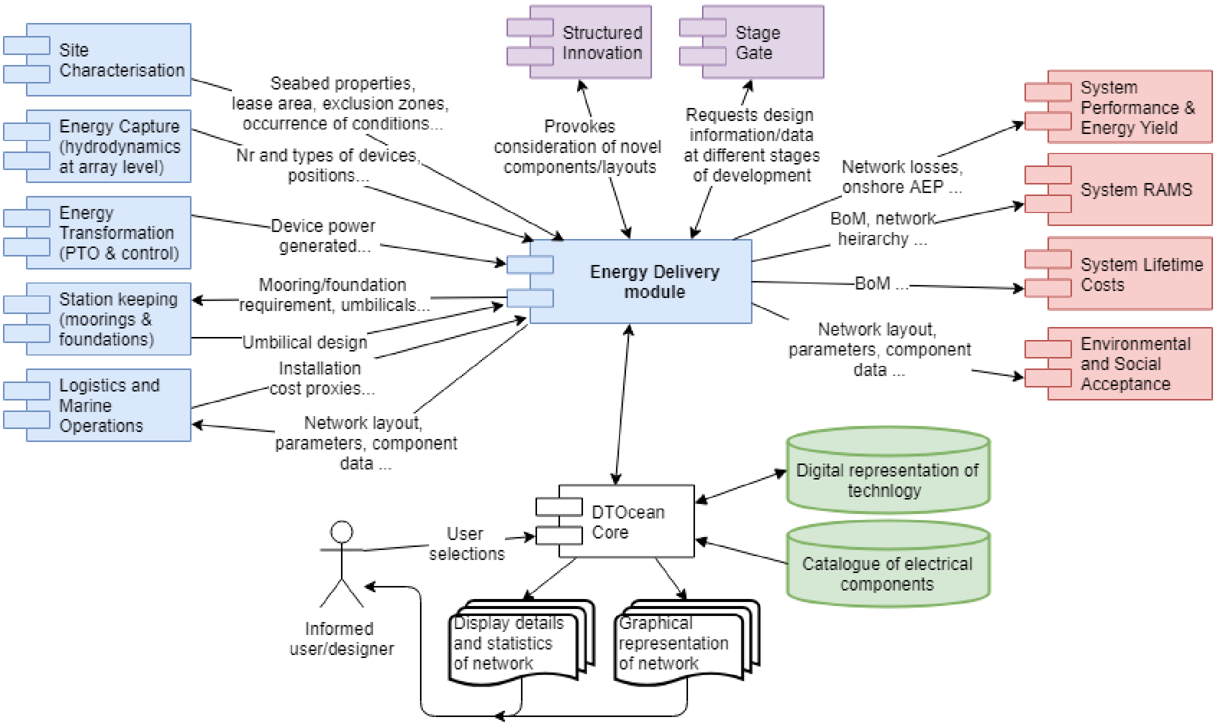


FIGURE 3-13. LINKAGES BETWEEN THE ENERGY DELIVERY MODULE AND OTHER DESIGN TOOLS & MODULES, WITH ARROWS SHOWING MAIN FLOWS OF INFORMATION

3.1.6 STATION KEEPING

The integration of the Station Keeping module with all the other entities of the DTOceanPlus software is shown in Figure 3-14.. At a high level, inputs on the design will be received from the other Deployment modules (Site Characterisation, Energy Capture, Energy Transformation and Energy Delivery), from the user through the interface and form the catalogue in the database, with outputs provided to the Assessment tool, to other Deployment modules, to the Structured Innovation and the Stage Gate design tools. The user will be able to make selections and input data via the GUI and will be presented with output showing both graphical and tabulated details of the station keeping subsystem.

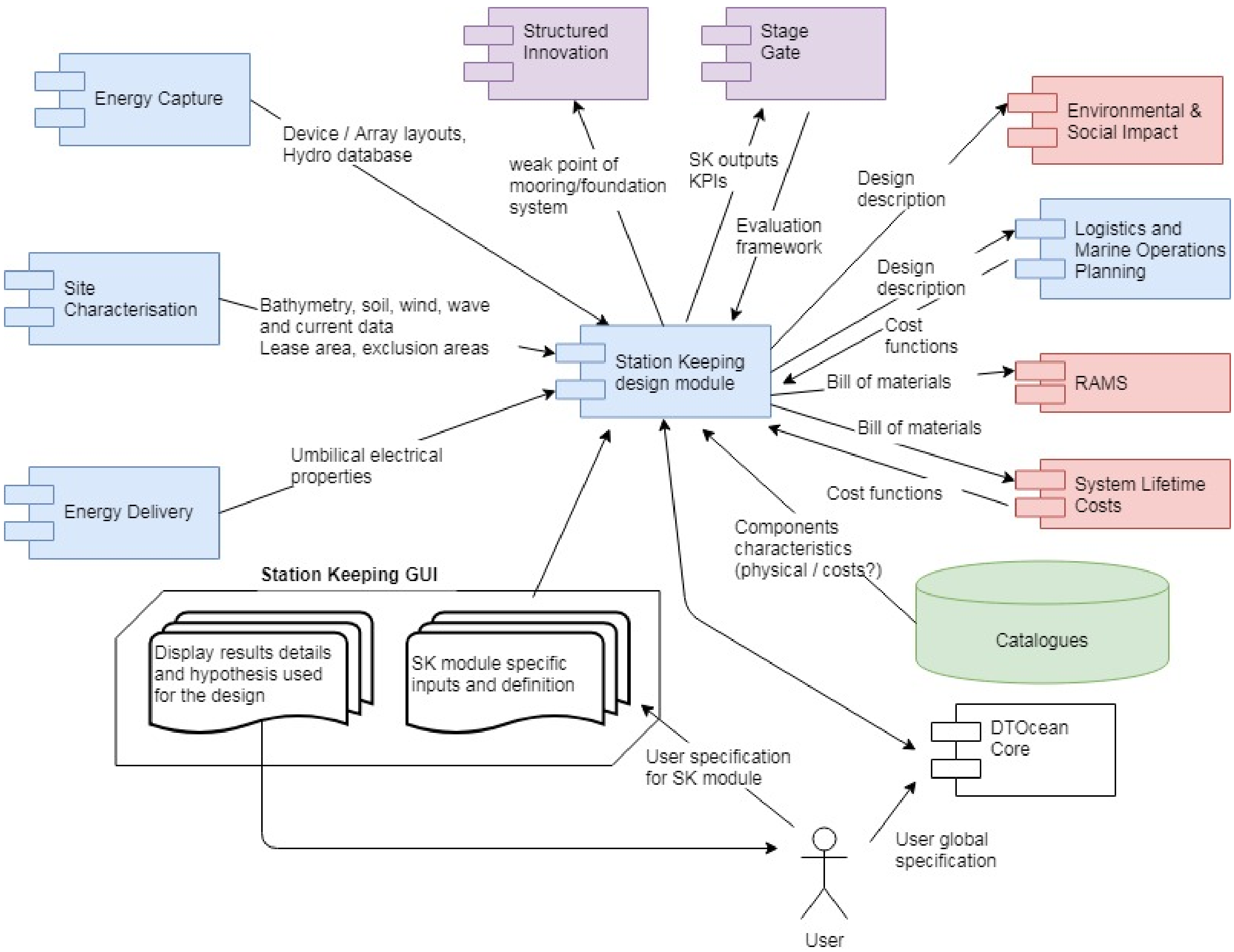


FIGURE 3-14. LINKAGES BETWEEN THE STATION KEEPING MODULE AND OTHER DESIGN TOOLS, WITH ARROWS SHOWING MAIN FLOWS OF INFORMATION

3.1.7 LOGISTICS AND MARINE OPERATIONS

The Logistics and Marine Operation Planning module is expected to communicate with all DTOceanPlus Deployment and Assessment tools, as well as the Structured Innovation and Stage Gate tools. In general, the Logistics tool will take inputs from all deployment design modules and produce outputs to the assessment tool. In some instances, the Logistics module will provide low complexity analysis in the form of public methods to support Station Keeping and Energy Delivery designs, but also to the Structured Innovation and Stage Gate tools. The linkages between the Logistics and remaining tools are depicted in Figure 3-15..

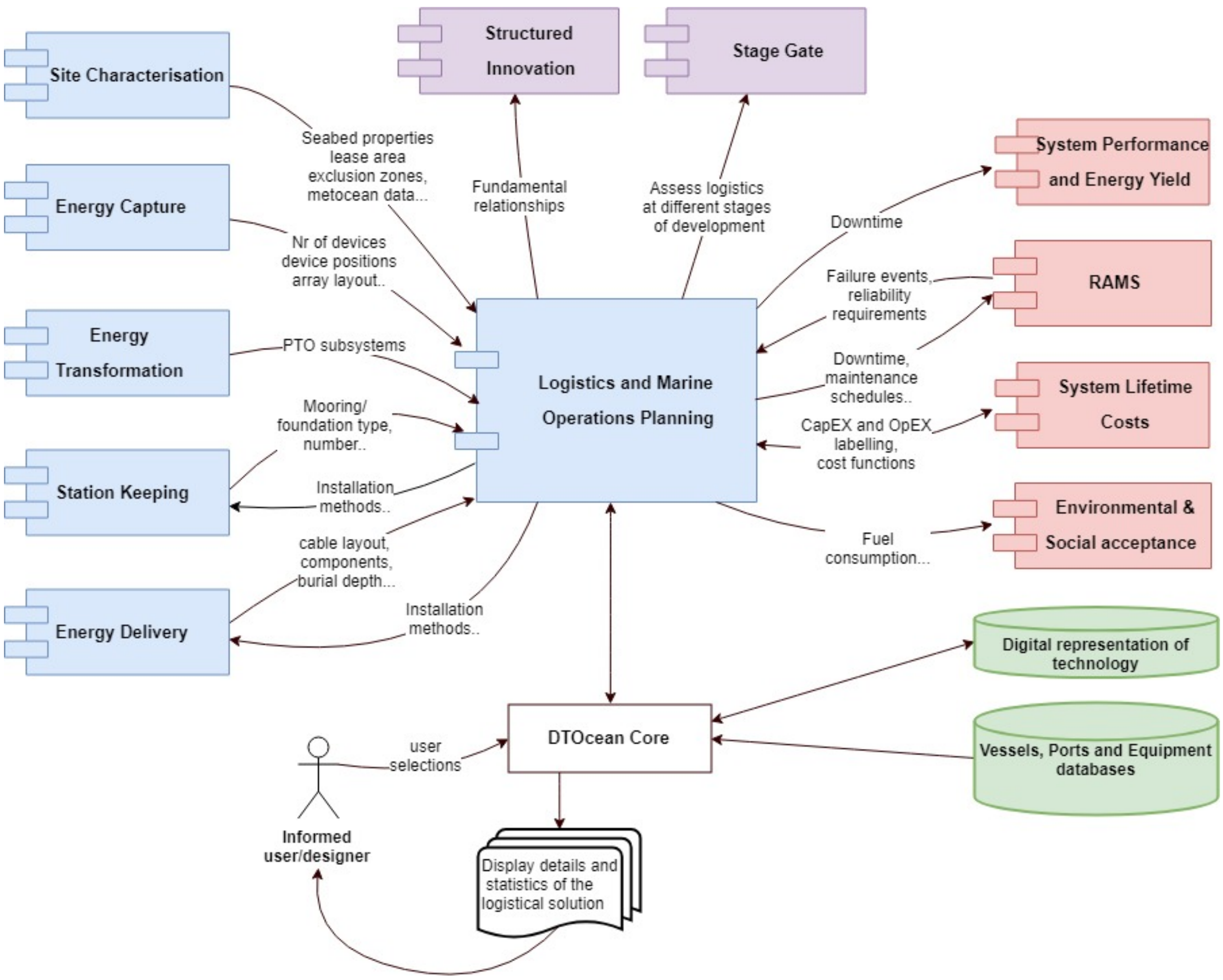


FIGURE 3-15. LINKAGES BETWEEN THE LOGISTICS AND MARINE OPERATION PLANNING MODULE AND OTHER DESIGN MODULES AND TOOLS, WITH ARROWS SHOWING MAIN FLOWS OF INFORMATION

3.2 INTEGRATION WITH THE DATABASE

The Database is a centralised storage for common references of the applications. It will contain a list of catalogues that will be accessible by any module. The purpose of the global database is to store permanent data shared among the different design tools, reducing inefficiencies and ambiguities as well as reducing the burden in uploading data for each project by the user; however, it will not store intermediate solutions generated while calculating the final results or the final results themselves.

The modules will consult the catalogues through one or several services offered by the main application.

The Database can be deployed locally, or on a server (see Figure 3-16.). Even if a full design for the database has not been deployed at this stage of the project, the main requirements from a technical point of view are herein summarised:

- The database will be a relational Structured Query Language (SQL) database, similar to the previous database built for DTOcean [7]. The data will be structured as a set of tables and broken down into normalised form, this avoids data duplication and thus improves performance;
- Parent and child tables will be created, these are normally 1-to-1 or 1-to-many relationships;
- Tables will be linked by the use of primary and foreign key constraints.

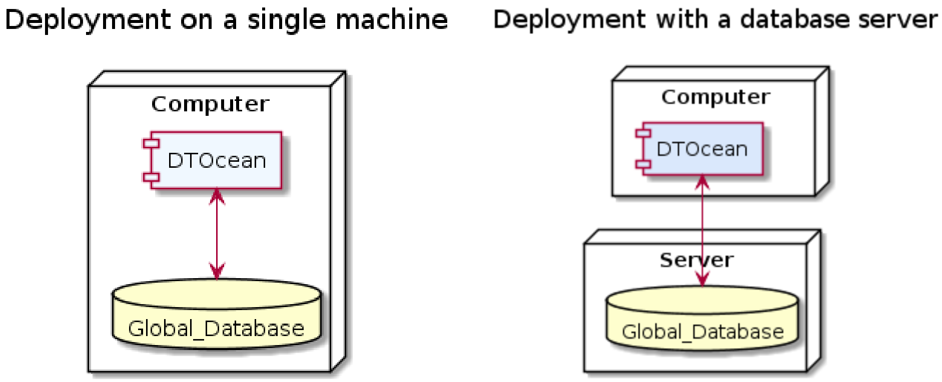


FIGURE 3-16. POSSIBLE DEPLOYMENT FOR DTOCEANPLUS

In order to guarantee high quality levels of the data stored, the database will apply data validation rules on new and updated data records. The levels at which such validation may operate could be (not an exhaustive list):

- Data Type
- Field Size
- Nullability
- Uniqueness

The global database, in order to fulfil with the functional requirements identified in D2.2 [9], should interact with the GUI in order to be easily accessible by the user, allowing also the update of fields and the insertion of new entries.

3.3 INTEGRATION WITH THE OTHER DEPLOYMENT TOOLS

In this section, the interaction of each tool with the other Deployment design modules is described.

3.3.1 SITE CHARACTERISATION

The goal of the Site Characterisation module is to provide outputs acting as input data (such as seabed properties, bathymetry, physical forcing statistics and time series) to other modules.

Table 3-1 presents the data that will be provided to other modules.

TABLE 3-1- OUTPUT DATA TYPE WITHIN THE SITE CHARACTERISATION MODULE AT DIFFERENT LEVEL OF PROJECT COMPLEXITY.

Module	Input for / Output of the SC module	Parameters	Lower Complexity	Intermediate Complexity	Higher Complexity
Energy Capture	O	Bathymetry	Single value	Simplified	Detailed
	O	Exclusion zones	Ignore	Consider	
	O	Seabed properties (soil type, resistivity, temperature…)	Ignore	Averaged	Detailed
	O	Site: Wave and Tidal conditions	Single Value	Simplified	Detailed
	O	Site: Installation Area	Consider		
Energy Transformation	O	Wave scatter diagram	Hs/Tp	Hs/Tp/Direction	Wave scatter diagram
	O	Wave spectrum	Ignore	Name of the spectrum	Wave spectrum
	O	Current statistics	Velocity	Current Velocity profile	Current statistics
	O	Current velocity spreading factor			
Energy Delivery	O	Bathymetry	Assumed (flat/sloping)	Simplified	Detailed
	O	Exclusion zones	Ignore	Consider	
	O	Lease area	Assumed distance from shore	Known coordinates	
	O	Seabed properties (soil type, resistivity, temperature…)	Ignore	Averaged	Detailed
	O	Ocean wave and current statistics	Ignore	Averaged	Detailed
Station Keeping	O	Lease Area geometry and bathymetry, if not provided by the general GUI (for the geometry)	Assumed (flat/sloping)	Simplified	Detailed
	O	Exclusion areas, if not provided by the general GUI	Ignore	Consider	
	O	Soil properties: physical characteristics of each layer	Ignore (homogenous hypothesis)	Simplified	Detailed
	O	Wave statistics (direction and extrema at RP1, RP10 and RP100 years) for	Consider		

		the area			
	O	Current statistics (direction and extrema at RP1, RP10 and RP100 years) for the area	Consider		
	O	Wind statistics (direction and extrema at RP1, RP10 and RP100 years) for the area	Consider		
	O	Water Levels	Consider		
Logistics and Marine Operations	O	Lease Area Bathymetry	Assumed (flat/sloping)	Average	Detailed
	O	Cable Corridor Bathymetry	Assumed	Average	Detailed
	O	Exclusion zones	Ignore	Consider	Consider

3.3.2 ENERGY CAPTURE

Table 3-2. reports the Input/output data required by the Energy Capture module and shared with other Deployment design modules. The data is described at different level of project complexity.

TABLE 3-2. INPUT AND OUTPUT DATA TYPE WITHIN THE ENERGY CAPTURE MODULE AT DIFFERENT LEVEL OF PROJECT COMPLEXITY.

Module	Input/ Output	Parameters	Lower Complexity	Intermediate Complexity	Higher Complexity
Site Characterisation	I	Bathymetry	Single value	Simplified	Detailed
	I	Exclusion zones	Ignore	Consider	
	I	Seabed properties (soil type, resistivity, temperature…)	Ignore	Averaged	Detailed
	I	Site: Wave and Tidal conditions	Single Value	Simplified	Detailed
	I	Site: Installation Area	Consider		
Energy Transformation	O	Device absorbed power	Single value	Detailed	
	O	Target PTO coefficients	Ignore	Consider	
	O	PTO loads	Ignore	Consider	
Energy Delivery	O	Array layout (Device positions)	Calculated value		
	O	Number and type of	Calculated Value		

		devices		
Station Keeping	O	Target mooring coefficients	Ignore	Consider
	O	Loads	Ignore	1st order and 2nd drift loads
Logistics and Marine Operations	O	Array layout (Device positions)	Calculated value	

3.3.3 ENERGY TRANSFORMATION

In principle, the Energy Transformation module will not share any public method with other deployment modules. In that aspect no conflict is expected. The link with them will be assured by producing outputs compatible with the digital representation where the required input data will be loaded, and the outcomes of the ET module will be passed to the digital representation and make them available for the other tools.

The Energy Transformation module will require as input some data which are outputs of other modules and will output some data which will be input for other modules. In Table 3-3., all the Input/output data required by the Energy Transformation module and shared with other Deployment design modules are described for data type at different level of project complexity.

TABLE 3-3. INPUT AND OUTPUT DATA TYPE WITHIN THE ENERGY TRANSFORMATION MODULE AT DIFFERENT LEVEL OF PROJECT COMPLEXITY.

<table>
<tr><th>Deployment Tools</th><th>Input/ Output</th><th>Parameters</th><th>Lower Complexity</th><th>Intermediate Complexity</th><th colspan="2">Higher Complexity</th></tr>
<tr><td rowspan="4">Site Characterisation</td><td>I</td><td>Wave scatter diagram</td><td>Hs/Tp</td><td colspan="3">Hs/Tp/Direction</td></tr>
<tr><td>I</td><td>Wave spectrum</td><td>Ignore</td><td>Name of the spectrum</td><td>Spectrum peakedness and spreading factor</td><td>Directional spectra per sea state</td></tr>
<tr><td>I</td><td>Current statistics</td><td>Velocity</td><td>Current Velocity profile</td><td colspan="2">Directional velocity profile</td></tr>
<tr><td>I</td><td>Current velocity spreading factor</td><td></td><td></td><td colspan="2"></td></tr>
<tr><td rowspan="2">Energy Capture</td><td>I</td><td>Device Captured Power (per SS for WEC, per current vel for TEC)</td><td>In function of the sea state/current</td><td colspan="3">In function of the directional SS/current</td></tr>
<tr><td>I</td><td>RAOs per device and sea state</td><td>Ignore</td><td>Simplified</td><td colspan="2">Detailed</td></tr>
</table>

	I	PTO settings per device (stiffness Kpto/damping Cpto)	Typical ranges of PTO settings	Adjusted values	
	I	Device Torque current vel/dir?	Typical ranges of PTO settings	Adjusted values	
Energy Delivery	O	PTO sizing (device rated power and voltage)	Catalogue/user rated values	Optimised rated capacity (Power/Voltage)	
	O	Electrical power output	Rough estimate with efficiency from catalogue	Detailed	Fine tuned
	O	Power quality (device reactive power absorption/ capability)	Ignore	Qualitative in function of the hardware capability	Detailed
Logistics and Marine Operations	O	PTO sizing	Catalogue / User provided dimensions	Optimised values	

3.3.4 ENERGY DELIVERY

The Energy Delivery module expects to interact with the other Deployment design modules as shown in Figure 3-13.. The Energy Delivery module will require as input some data which outputs of other modules and will output some data which will be input for other modules. In Table 3-4, all the Input/Output data required by the Energy Delivery module and shared with other Deployment design modules are described for data type at different level of project complexity.

TABLE 3-4: INPUT AND OUTPUT DATA TYPE WITHIN THE ENERGY DELIVERY MODULE AT DIFFERENT LEVEL OF PROJECT COMPLEXITY.

Module	Input/ Output	Parameters	Lower Complexity	Intermediate Complexity	Higher Complexity
Site Characterisation	I	Bathymetry	Assumed (flat/sloping)	Simplified	Detailed
	I	Exclusion zones	Ignore		Consider
	I	Lease area	Assumed distance from shore		Known coordinates
	I	Seabed properties (soil type, resistivity, temperature...)	Ignore	Averaged	Detailed
	I	Ocean wave and current statistics	Ignore	Averaged	Detailed
Energy Capture	I	Number and type of devices	Ignore		Consider

	I	Array layout (Device positions)	Ignore (treat as lumped array)		Known coordinates
Energy Transformation	I	Device rated power and rated voltage	Typical value		Known value
	I	Power produced	Use rated power	Histogram for whole array	Histogram per device
	I	Power quality (Reactive power absorption/ capability)	Ignore	Array averaged absorption, ignore reactive power control	Per device, per sea state absorption including reactive power control
Station Keeping	O	Dynamic cables (umbilical)	Ignore	Generic design (cable length = depth × factor)	Detailed design
Logistics and Marine Operations	I	Electrical system installation/protection method cost proxies	Simplified cost proxies for generic components		Cost proxies based on site location for specific components
	O	Network layout	Typical/estimated cable lengths		Optimised cable layout(s)
	O	Cable installation/protection method used	Generic	Single method for all cables	Most appropriate value for each section of cable
	O	Cable burial depth	Ignore	Typical value	Calculated value
	O	Electrical components used and equipment data	Generic types and properties		Identified component parts and properties

3.3.5 STATION KEEPING

The Station Keeping module expects to interact with the other Deployment modules as shown in Figure 3-14.. In Table 3-5, all the Input/output data required by the Station Keeping module and shared with other Deployment modules are described for data type at different level of project complexity.

TABLE 3-5: INPUT AND OUTPUT DATA TYPE WITHIN THE STATION KEEPING MODULE AT DIFFERENT LEVEL OF PROJECT COMPLEXITY.

Module	Input for / Output of the SK module	Parameters	Lower Complexity	Intermediate Complexity	Higher Complexity
Site Characterisation	I	Lease Area geometry and bathymetry, if not provided by the general GUI (for the geometry)	Assumed (flat/sloping)	Simplified	Detailed
	I	Exclusion areas, if not provided by the general GUI	Ignore	Consider	
	I	Soil properties: physical characteristics of each	Ignore (homogenous	Simplified	Detailed

		layer	hypothesis)		
	I	Wave statistics (direction and extrema at RP1, RP10 and RP100 years) for the area	Consider		
	I	Current statistics (direction and extrema at RP1, RP10 and RP100 years) for the area	Consider		
	I	Wind statistics (direction and extrema at RP1, RP10 and RP100 years) for the area	Consider		
	I	Water Levels	Consider		
Energy Capture	I	Array layout	Ignore (same SK design for all devices)	Consider (SK definition can vary amongst the various devices)	
	I	Devices detailed description (mass distribution, draught, geometry above and below the surface, …)	Ignore	Consider	
	I	Initial mooring stiffness value used by the EC module	Consider	Consider	
	I	Hydro database (frequency domain)	Ignore	Consider when applicable	
Energy Transformation	-	n/a	n/a	n/a	
Energy Delivery	I	Dynamic cable electrical characteristics	Ignore	Consider	
Logistics and Marine Operations	I	Cost functions for the SK components logistic operations (e.g. anchors…)	Ignore		Consider, if applicable
	O	Foundation description (ID, coordinates, config.)	Ignore	Consider	
	O	Mooring and foundation quantity	Consider		
	O	Mooring line - Device ID	Ignore	Consider	Ignore
	O	Dynamic cable data (config dimensions)	Basic		Detailed

3.3.6 LOGISTICS AND MARINE OPERATIONS

The Logistics and Marine Operation tools are intrinsically interconnected with all Deployment design tools, expecting inputs from the latter as shown in Figure 3-15.. When run together with multiple Deployment design tools in a sequence, the Logistics tools are run last. However, in some instances, public methods are expected to be shared with other deployment tools, which may slightly increase complexity and require special care to avoid conflicts.

The Logistics and Marine Operation Module will require as Input some data which outputs of other modules and will output some data which will be input for other modules. In Table 3-6., all the Input/output data required by the Logistics and Marine Operation Module and shared with other Deployment design modules are described for data type at different level of project complexity.

TABLE 3-6. INPUT AND OUTPUT DATA TYPE WITHIN THE LOGISTICS AND MARINE OPERATION PLANNING AT DIFFERENT LEVEL OF PROJECT COMPLEXITY.

Module	I/O	Parameters	Lower Complexity	Intermediate Complexity	Higher Complexity
Site Characterisation	I	Lease Area Bathymetry	Assumed (flat/sloping)	Average	Detailed
	I	Cable Corridor Bathymetry	Assumed	Average	Detailed
	I	Exclusion zones	Ignore	Consider	Consider
Energy Capture	I	Array layout	Ignore	Consider	Detailed
	I	Number of devices	Consider		
Energy Transformation	I	Device - ID	Ignore	Consider	Consider
	I	PTO components physical characterisation	Simplified	Consider	Detailed
Station Keeping	I	Foundation - ID	Ignore	Consider	Consider
	I	Foundation - coordinates	Ignore	Consider	
	I	Foundation - quantity-per-device	Consider		
	I	Moorings and Foundation config dimensions	Basic	Detailed	
	I	Mooring line - Device ID	Ignore	Consider	Detailed
	I	Mooring line - Line ID	Ignore	Consider	Consider
	I	Mooring line - quantity-per-device	Consider		
	I	Dynamic cable data (config dimensions)	Basic	Detailed	
	O	Station keeping installation cost	Ignore	Cost proxies, when appropriate	
Energy delivery	I	Static cable - type	Basic	Detailed	
	I	Electrical components Bill of materials	Simplified	Consider	Detailed
	I	Electrical Component Supplementary data	Simplified	Consider	Detailed
	I	Cable routes / cable network layout	Typical estimated cable length	Detailed cable layout	
	I	Substation data	Ignore	Consider	Detailed
	I	Dynamic cable data	Basic	Detailed	
	I	External protections - split pipe required	Ignore	Ignore	Consider
	I	External protections - type of element	Ignore	Ignore	Consider
	I	External protections - coordinates	Ignore	Ignore	Consider
	I	External protections -zone	Ignore	Ignore	Consider
	I	Connector - type	Ignore	Ignore	Consider
	I	Cable burial depth	Ignore	Assumed	Detailed
	O	Cable installation / protection costs	Simplified cost proxies	Cost proxies	

3.4 INTEGRATION WITH THE ASSESSMENT TOOLS

In this section, the interaction of each tool with the Assessment design tools is described.

3.4.1 SITE CHARACTERISATION

Public methods in terms of GIS interface (digital representation) are expected to be shared with other pieces of tools.

Output passed to Assessment tools	Lower Complexity	Intermediate Complexity	Higher Complexity
System performance and energy yield	No specific interaction expected		
RAMS	No specific interaction expected		
System lifetime cost	No specific interaction expected		
Environmental and social impacts	The inputs taken from Site Characterisation to assess environmental impacts include most of the environmental properties characterising the deployment site, i.e. the lease area and the export cable corridor, in terms of bathymetry, seabed properties and oceanic conditions		

-

3.4.2 ENERGY CAPTURE

The Energy Capture module will produce assessments in the terms of system performance and energy yield and environmental and social impacts.

- System Performance and Energy Yield: the EC module is responsible for assessing the Annual Energy Production of the array and at device level, forming the base for the estimation of the project revenue.
- System Environmental and Social Acceptance: the EC module provides an estimation of the resource reduction on the farm area.

Table 3-7 shows the linkages between the EC module and the assessment tools at different levels of project complexity.

TABLE 3-7: OUTPUTS FROM THE EC MODULE FOR THE ASSESSMENT TOOLS AT DIFFERENT LEVELS OF COMPLEXITY

Output Parameters for Assessments	Lower Complexity	Intermediate Complexity	Higher Complexity
AEP	AEP estimated for the array or at device level.		
Resource Reduction	Reduction of the energy content in the undisturbed site conditions.		

3.4.3 ENERGY TRANSFORMATION

All data related with the PTO is to be shared with the four assessments at varying levels of complexity. Since the main purpose of the ET module is to compute the energy flow and intermediate losses in the PTO, its strongest relation is with the System Performance and Energy Yield module (SPEY). All energy losses are to be provided to the SPEY as well as the net energy generated by each device.

Energy transformation assessment is carried out based on frequency domain analysis and, after the corresponding assumptions, their statistical distributions can be estimated as well as forces within the PTO, which are to be provided to RAMS.

Available environmental impacts coming out from each component are to be shared with the Environmental Social Impact module (ESI).

- System Performance and Energy Yield: The ET module sends to the SPEY assessment tool in one hand, the outcomes related to performance (i.e. partial and total PTO efficiencies) and in the other hand the details of the electrical power output of the farm. Based on this power information and the availability of the farm, the SPEY tool will compute the transformed energy.
- System RAMS: This assessment tool receives from the ET module component loading data associated to (based on) the PTO sizing under a certain type of control strategy and considering the corresponding resource of the deployment site. The RAMS will be responsible for assessing the reliability criteria based on the level of the loading profiles of these components.
- System Lifetime Costs: One of the outputs of the ET module is to provide a detailed list of the components for the PTO configuration of each device. When available, each component should be associated to a cost or at least an estimation or a range of costs.
- System Environmental and Social Acceptance: The Environmental and Social Impact will be sensitive to the type of PTO components selected for the assessment made in the ET module. With each component characterised by an impact (low, medium, high) on both environmental and social matters, the component list generated by the ET module will include the associated impacts and send them to this assessment tool.

Table 3-8 shows the linkages between the ET module and the Assessment design tools at different levels of project complexity.

TABLE 3-8: OUTPUTS FROM THE ENERGY TRANSFORMATION MODULE TO THE ASSESSMENT TOOLS AT DIFFERENT LEVELS OF COMPLEXITY

Target Tool	Output Parameters for assessments	Lower Complexity	Intermediate Complexity	Higher Complexity
System performance and energy yield	Efficiency and Power production	Component efficiency from default values taken from the catalogue Power production per device, broken down by conversion step	Realistic efficiencies of components read from the database. Stochastic computations applying the corresponding efficiency at each power level. Accurate results within the limitations of the proposed method.	A very detailed component efficiency introduced by the user. The method of calculation remains the same as in mid stage. The accuracy level is increased by means of more accurate PTO components definition.
RAMS	Load distribution on PTO components	Provide an estimate of the distribution of the PTO loads under basic control strategy	As the PTO components are more detailed so are their operation ranges and working loads. Bill of Materials for a specific Power Take-Off design. The optimiser can include a cost function to improve the reliability criteria.	All components have sufficient amount of failure rate data for FMEA and, along with the load distribution along the project, failure rates can be faithfully derived.
System Lifetime cost	Bill of materials and costs	Generic PTO cost based on rated power and catalogue base data.	Bill of Materials for a specific Power Take-Off design. The optimiser can select the best components reducing the global cost of equipment with the appropriate cost function.	PTO configuration that includes specific user parameters with a specific control strategy. Again, the optimiser can be run with the global cost reduction objective.
Environmental and social impacts	PTO environmental impact	Environmental impact rough estimate based on PTO type and rated power.	Impacts are broken down per component of the PTO and its size. Also, working conditions are known and can influence the impact (i.e. failure of certain component producing liquid leakage, noise…)	The environmental impacts are introduced by the 'advanced' user and should be based on real data.

3.4.4 ENERGY DELIVERY

This section contains details about the interaction between the Energy Delivery module and the Assessment design tools.

- System Performance and Energy Yield: The Energy Delivery module will provide information on the efficiency of the network designed, in terms of AEP at the onshore landing point and grid compatibility, including power quality and capability for voltage and reactive power support.
- System RAMS: The Energy Delivery module will provide details of the components used in the network design via the bill of materials, including the failure rates for the components

used in the network, along with the hierarchy of the network. These will in turn be used by the RAMS module to calculate the failure rates and availability of the whole system.

- System Lifetime Costs: The Energy Delivery module will provide details of the components used in the network design via the bill of materials, including the quantity and costs. Details of component manufacture etc. may be included in the catalogue. The system lifetime costs and the LCOE will be calculated by the lifecycle costs module for the energy yield options provided to SPEY.
- System Environmental and Social Acceptance: The Energy Delivery module will provide details of the network design, including the cable layout and the bill of materials for the environmental and social assessments. The manufacturing process used, and the fabrication composition of the components will be included in the catalogue where possible for assessment by this module.

Table 3-9 shows the linkages between the ED module and the Assessment design tools at different levels of project complexity.

TABLE 3-9: OUTPUTS FROM THE ENERGY DELIVERY MODULE FOR THE ASSESSMENT TOOLS AT DIFFERENT LEVELS OF COMPLEXITY

Assessment tools	Output Parameters for Assessments		Lower Complexity	Intermediate Complexity	Higher Complexity
RAMS, ESA	Network design (affects calculation of other parameters)	Network layout	Typical/estimated cable lengths		Optimised cable layout(s)
		Cable installation/ protection method used	Generic	Single method for all cables	Most appropriate value for each section of cable
		Cable burial depth	Ignore	Typical value	Calculated values along cables
		Electrical components used and equipment data	Generic types and properties		Identified component parts and properties
		Network hierarchy	Simplified		Detailed
RAMS, SLC, ESA	Bill of Materials (including cost/failure rates)		Generic components, length/size/capacity estimated, typical cost/failure rates		Components selected from catalogue, with corresponding cost/failure rates.
SPEY	Network efficiency and AEP at onshore landing point		Based on typical losses, excluding some components.		Losses calculated for all components
SPEY	Grid compatibility, power quality and reactive power control capability		Ignore		Consider

3.4.5 STATION KEEPING

This section contains details about the interaction between the Station Keeping module and the Assessment design tools.

- System RAMS: The Station Keeping module will provide details of the components used in the station keeping system design via the bill of materials (this includes connecting elements such as shackle and swivel, when applicable). Failure rates of components may be included in the catalogue, if available. The reliability level of the mechanical components (or any equivalent quantity for the station keeping system) could be taken from the level assumed within the standard used for the validation of the design (constraint of the SK designer / optimiser).

- System Lifetime Costs: The Station Keeping module will provide details of the components used in the station keeping system design via the bill of materials. These will include both quantities and costs. Details about component manufacturing processes (including logistic aspects) may be included in the catalogue (if possible/available). In the case that some optimisation based on components' cost (functions) is undertaken, and the components' costs (functions) are stored or handled by the System Lifetime Cost module, then some public methods or access to costs will be required. Stand-alone operation of the SK tool can be attained either by either by providing some internal-to-the-SK-module costs (functions) or disabling the optimisation based on those costs in the stand-alone version.
- System Environmental and Social Acceptance: The Station Keeping module will provide details of the station keeping system design, including the mooring system layout and estimated footprint, the foundations footprint, the bill of materials and, if available from the catalogue, the manufacturing process and material composition.

Table 3-10 shows the linkages between the Station Keeping module and the Assessment design tools at different levels of project complexity.

TABLE 3-10. OUTPUTS FROM THE STATION KEEPING MODULE FOR THE ASSESSMENT TOOLS AT DIFFERENT LEVELS OF COMPLEXITY

Target tool	Output Parameters for Assessments	Lower Complexity	Intermediate Complexity	Higher Complexity
System Lifetime Costs tools	Bill of materials and costs	Details of typical components (quantities and costs) used for WEC/TEC rating (e.g. based on a lookup table of standardised moorings and foundations designs) *Not including umbilical and not site specific*	Details of typical components (quantities and costs) based on design computation (station keeping model(s) have been used for the specific site) *Not optimised for minimisation of station keeping costs*	Details of typical components (quantities and costs) based on design computation (station keeping model(s) have been used for the specific site) A technically feasible station keeping design which minimises the station keeping costs.
RAMS tools	Bill of materials	Same as above *Not including umbilical and not site specific*	Details of typical components (quantities and costs) based on design computation. A value of failure rate is associated to each component or group of components (*if available*).	Details of typical components (quantities and costs) based on design computation and optimisation. A value of failure rate is associated to each component or group of components (*if available*).
Environmental and Social tools	Bill of Materials and project details	Same as above *Not including umbilical and not site specific* Components from the catalogue have associated information on the manufacturing process to assess environmental impact of components (*if available*)	Details of typical components (quantities and costs) based on design computation. *Project details are now site specific*	Details of typical components (quantities and costs) based on design computation and optimisation. *Project details are now site specific*

3.4.6 LOGISTICS AND MARINE OPERATIONS

The Logistics and Marine operation Module is expected to produce assessment for all the Assessment design tools.

- System Performance and Energy Yield: The Logistic module's output to the system performance and energy yield tools will consist of downtime, which can be obtained from the marine operation scheduling.
- System RAMS: Outputs for RAMS include selected maintenance strategy (e.g. corrective, calendar-based) and operation schedules (start dates, end dates, and durations that include waiting times due to weather unsuitability, net repair time, etc), which will be used by RAMS to calculate reliability, availability, maintainability and survivability. Given that the maintenance operations will be scheduled by the Logistic and Marine Operation Planning module, taking into consideration subsystem/component reliability data, the integration of the RAMS tools is necessary. The interaction with RAMS will be accomplished by calling for RAMS public methods within the Logistic tool's algorithm. These public methods will provide mean-time-to-failure (MTTF) or random failure events using a component failure generator that considerers the component/system probabilities of failure.
- System Lifetime Costs: The Logistic tools will provide outputs to the System Lifetime Costs, consisting of the start of the operations (based on the scheduling of the activities), the logistic solutions (selected ports, vessels and equipment) and the costs (both Capex and OpEX) associated with the Logistics.
- System Environmental and Social Acceptance: Some Logistic outputs, such as the total vessel consumption, the logistic solutions, the scheduling of activities, and port time and sea time for operations and activities, will be used to estimate social and environmental impacts.

Table 3-11. shows the linkages between the Logistics and Marine Operations module and the Assessment design tools at different levels of project complexity.

TABLE 3-11. OUTPUTS FROM THE LOGISTICS AND MARINE OPERATION PLANNING MODULE FOR THE ASSESSMENT TOOLS AT DIFFERENT LEVELS OF COMPLEXITY

Target tool	Output Parameters for Assessments	Lower Complexity	Intermediate Complexity	Higher Complexity
System Lifetime Costs tools	Vessel, port and equipment solution	Typical vessel combination (e.g. installation vessel + support vessel+ ROV), as well as vessel and equipment costs for a simplified/assumed operation plan.	O&M plan will have vessel, equipment and port costs built-in to produce total O&M cost for lifetime of project. Use of default values	Full and detailed O&M plan will give O&M costs broken down per year of project life
System Performance and Energy Yield Tools	Downtime	Simplified downtime calculation based on Basic O&M schedules and reliability data for assumed subsystems estimated by the RAMS public methods	Simplified downtime calculation based on O&M plan, simplified activity OLCs, weather windows, and considering subsystem and component reliability data calculated by the RAMS public methods.	Complete downtime calculation based on detailed O&M schedules, considering each activity and operation limits, weather windows, and subsystem and component reliability data/MTTF calculated by the RAMS public methods
RAMS tools	O&M plan, including maintenance strategy	Basic O&M schedule for RAMS to calculate Availability (%) of project over lifetime	Detailed O&M plan for both planned and unplanned maintenance broken down per year of project life	Full O&M plan for specific site for both planned and unplanned maintenance using FMEA, broken down per year of project life
Environmental and Social tools	Environmental parameters related to the operations	Fuel consumption based on basic Installation and O&M activities (if not available use of default site location to estimate transit fuel consumption?)	Logistical outputs/parameters that may have an impact on the environmental/social acceptance of a project (e.g. distance to port, vessel routes). Total vessel fuel consumption based on distance to port and O&M plans per year.	

3.5 INTEGRATION WITH THE STRUCTURED INNOVATION TOOL

The Structured Innovation design tool will require high level assessments including lifetime costs and reliability to measure the potential of the proposed concepts which are generated, which will be outputs of the Deployment and Assessment design tools. A high-level summary of the requirements for the Deployment and Assessment tools are that they will

1. Inform the engineering, physics and economic fundamental relationships which drive the earliest stages of assessing the attractiveness of concepts
2. Provide simple tools to support evaluation of requirements and solutions in QFD at an early stage – i.e. objective QFD scoring. These may be the full complexity tools with default inputs.
3. Link to complex tools applied through Stage Gate design tool to guide improvement needs in later stage technologies and prompt use of Structured Innovation design tool.

The interactions of the Deployment design tools with the Structured Innovation design tool are briefly summarised in the following subsections. For full details, please refer to D3.1.

3.5.1 SITE CHARACTERISATION

The Structured Innovation design tool expects to use outputs from the Site Characterisation tool to assess the feasibility of potential sites and device locations. At a very early stage where little to no data are available, simplified basic assessments to define fundamental relationships will be used.

3.5.2 ENERGY CAPTURE

The EC tool will produce required hydrodynamic data for the captured energy. This tool will interact with the QFD/TRIZ modules within the Structured Innovation tool at very early stage to assess the average captured energy for the various high, medium or low energy sites. This Information will also feed into the FMEA module to inform the potential risks associated with existing and proposed areas of innovation. This will enable early assessment of potential energy yield and technologies at different sites. The Structured Innovation design tool will then perform a holistic analysis of the system and propose potential areas of innovation for the tool.

3.5.3 ENERGY TRANSFORMATION

There is an interaction between the Structured Innovation tool and the Energy Transformation tool. The aim of the interaction is to:

- Assess potential innovative design concepts by using the tool's reference data for the analysis of suitable PTO and control designs.
- Determine the technological barriers and identify the gaps in terms of technological availability or compatibility of the components. When the outcomes generated cannot satisfy the user requirements, the Structured Innovation tool is alerted and receives details on the current configuration
- Measure the uncertainty level depending on the level of complexity and the accuracy of the assessment provided in the ET module

3.5.4 ENERGY DELIVERY

The Energy Delivery tool will develop optimal design solutions for the electrical infrastructure by defining and selecting the components within the whole transmission system. The Structured Innovation tool will support this tool by assessing the potential innovation within the systems which will include consideration of new topologies (e.g. multiple export cables), intelligent clustering of devices and improved cable routing, etc.

3.5.5 STATION KEEPING

At the very earliest stage of project development, the Station Keeping tool will assess a range of input values and produce basic designs based on standard components for the various foundations and mooring designs using fundamental physics of loads expected, and a look-up table of standardised designs. These outputs will feed into the Structured Innovation tool to enable the assessment of potential innovation of sub-structures. The characteristics of the proposed innovative concepts from the Structured innovation tool will feed back into the Station Keeping tool to design according to the user requirement.

The structured innovation tool could receive from the Station Keeping module the description of the Station Keeping system in order to identify which components are the weakest ones in terms of limit state, and the best suited for directing innovation efforts.

3.5.6 LOGISTICS AND MARINE OPERATIONS

The Structured Innovation design tool will interact with the Logistics and Marine operations tool in identifying the attractive areas of innovation with respect to the logistical aspect of the project. The tool will provide basic costs related to the operation and maintenance schedules, early logistic requirements (e.g. costs against basic class of sites), infrastructure data (lookup tables of existing vessel capacities and costs, ports, equipment, etc).

The Logistics and Marine Operation Planning tools will interact with the Structured Innovation tools, providing insights and identifying cost-reduction opportunities related to the logistical aspect of a given MRE project. The Logistic tools will deliver logistical analysis through public methods, such as infrastructure solutions (including ports, vessels and equipment) and basic logistical costs.

3.6 INTEGRATION WITH THE STAGE GATE TOOL

The Stage Gate design tool brings structure to the technology development process by using the stage gate process as the basis of its functionality. The aim of this tool is to guide the technology development process and aid decision making by facilitating the assessment of ocean energy technologies. It will be used to guide the user in the assessment of a sub-systems, devices and arrays to support technology development from concept to commercial deployment.

The stage gate design tool interacts with all of the tools in the DTOceanPlus suite:

- The Deployment tools are used to provide design information based on the technology, aggregation level and context choices made by the user
- The Assessment tools take all of this information and calculate key metrics which are fed back into the stage gate design tool
- The Structured Innovation tool is triggered when the results of the stage gate assessment show a divergence from the thresholds as set by the user or a gap in one of the Evaluation Areas when all metrics results are presented together

The output of the stage gate design tool is a report summarising the set-up of the assessment, what was evaluated, the thresholds which were set and the assumptions used when running the stage gate assessment. It's expected that the report which is output from the Stage Gate design tool will be in a standardised format, and can be saved in the Digital Representation. Users will be able to run a stage gate assessment multiple times and have easily comparable reports from each run.

The Stage Gate design tool communicates both directly and indirectly with the Deployment design tools: 1) indirectly, in case the Deployment design tools will be requested to run triggered through the Assessment design tools upon request from the Stage Gate Framework to obtain some assessments; or 2) directly if there is some specific design information which is required from the Deployment tools.

It is important to note that the Deployment design tools are able to deal with data at different levels of project complexity (see the corresponding chapters and tables in Section 3.3 and 3.4) and this is particularly useful within the Stage Gate Framework.

Further details can be found in D4.1, including:

- An outline of the technical requirements of the Stage Gate design tool
- A description of the architecture of the tool
- Diagrams displaying the data classes and use cases
- A description of the external interfaces, compatibility and portability and maintenance requirements
- Integration of the tool with the other tools in the DTOceanPlus suite
- A mock-up of the Graphical User Interface of the stage gate design tool

3.7 DESCRIPTION OF THE USER INTERFACES

DTOceanPlus toolset will interact with the user with a set of user interfaces, mostly graphical, helping the user to input/output and visualise data. In the following sections the technical requirements of the User Interface for the main platforms and the tools, as well as some mock-ups and ideas will be shown. The content of this section is mostly approximate, as it represents just the initial approach to the design of the User Interfaces, and it is assumed that the concepts will evolve over the course of the project. In particular, throughout the following subsections different styles and formats for the UI have been proposed by each module developer. Of course, once all the module developers' requirements have been collected, every proposed UI will be aligned in terms of style, tools and management of space.

3.7.1 MAIN PLATFORM

An initial attempt to design the User Interface has been carried out in order to identify the interface requirements of the main platform.

3.7.1.1 Description

The main UI will have the following layout

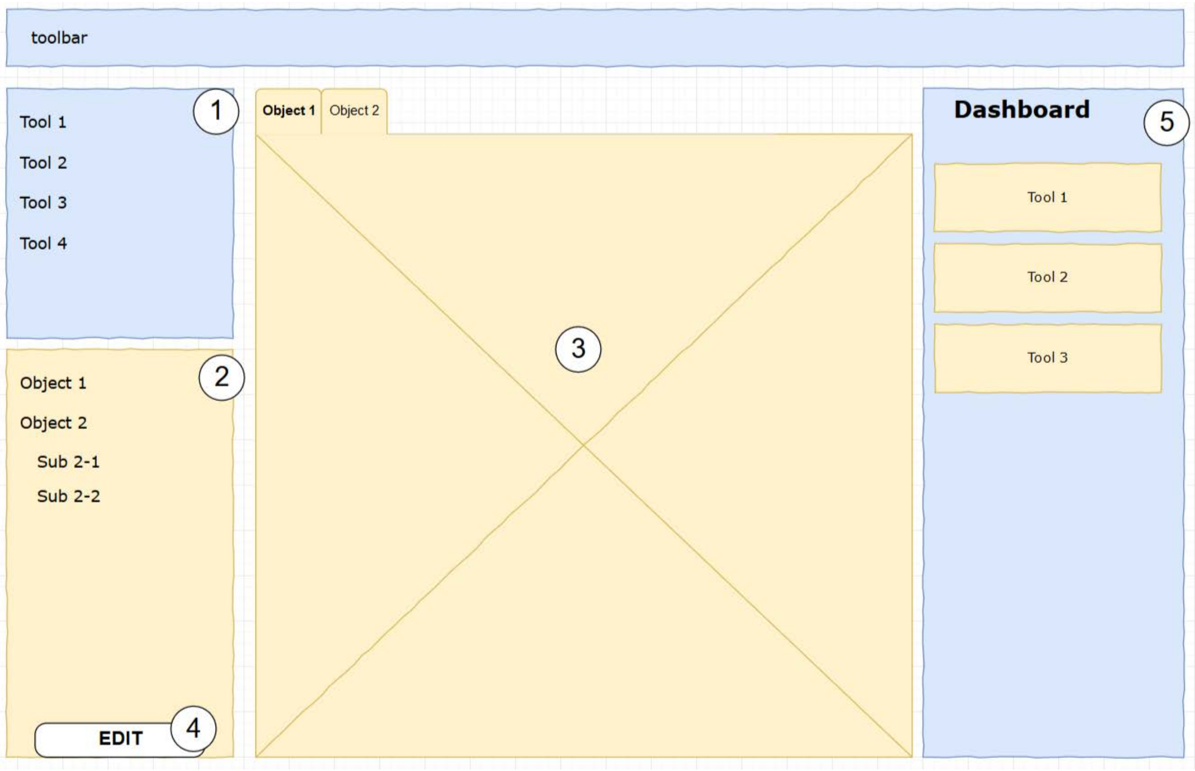


FIGURE 3-17. MAIN UI

(1) On the left, the list of available tools

If needed, this list can be customized to show only certain tools depending on the user profile.

The list can be organized as a tree, to regroup the deployment tools and the assessment tools, or tabs for each category.

(2) When the user selects a tool in (1), the content of this box will show the "main information" for this tool. It can be a tree representing the tool's items (its data structure), or any kind of presentation.

(3) The user can view (read only mode) the detail of an item in the central view. The different views will be opened as tabs.

(4) If the user wants to edit data, they can activate the tool with the "Edit" button (double click or select popup menu item on corresponding module from the (1) "list of available modules"). The module will be then opened in write mode as a modal dialog on top of the main application. When the module is closed, the UI of the main application will be refreshed (data structure and views) to represent the changes made by the user.

(5) A Dashboard can be displayed on the right, with a section for each module. For example, the Energy Cost assessment tool can show the last computed cost.

The elements in blue are part of the main application, and the elements in orange are provided by the modules.

3.7.1.2 Integration of modules

The UI components (2) and (3) described in the previous paragraph are managed by the tools. Also the tool's UI, which is displayed when the user clicks the Edit button, is part of the tool. This UI will be the same in embedded and in standalone mode.

It is possible to base the UI on a description format. The UI will be defined as a configuration file (XML, JSON ...). When the main UI wants to open the tool, it will read this configuration file and build the UI from it.

The advantage of this kind of solution is that it gives consistency to the UIs since they are all built by the same engine, using the same controls.

One drawback is that it should be limited to simple UIs, like "two column UIs" with labels in the first column and simple controls (text box, list box, tree, combo box, date selector, checkbox...) in the second. Otherwise the engine is too complex to maintain. If there is a need for a complex UI, it will be possible for a tool to skip the engine and directly build its UI.

3.7.2 SITE CHARACTERISATION

The graphical user interface for the Site Characterisation module should be able to:

- allow user to import or to define their project area
- import geo-referenced datasets bathymetry, seabed properties, wave and current statistics, ...
- to visualise the imported datasets
- to export data to other DTOceanPlus modules or directly for user needs.

An example mock-up of the module is presented in Figure 3-19. It is divided in three parts:

- Window n°1: On the left upper part of the window, the imported parameters (called "layers") are displayed. These parameters could be organised by groups; for instance: "tidal current velocity" and "tidal current direction" can be grouped in the "tidal current" layer.

In this window, the user selects (by clicking on) the layer he wants to display on the main window (window n°3), and the main information of this layer are displayed in the window n°2.

- Window n°2: On the left lower part of the window are displayed the active layer, the name of the active layer and the main information of the active layer.

Functions to export data from this layer are also available in this window; the format (DTOceanPlus format, png, ...) can be then choose in a pop-up window.

- Window n°3: In the middle of the screen, this main window allows to visualize the active layer parameters. This visualization will be a GIS-type display, with geographical coordinates and a colour bar of the graduated values of the selected parameter.

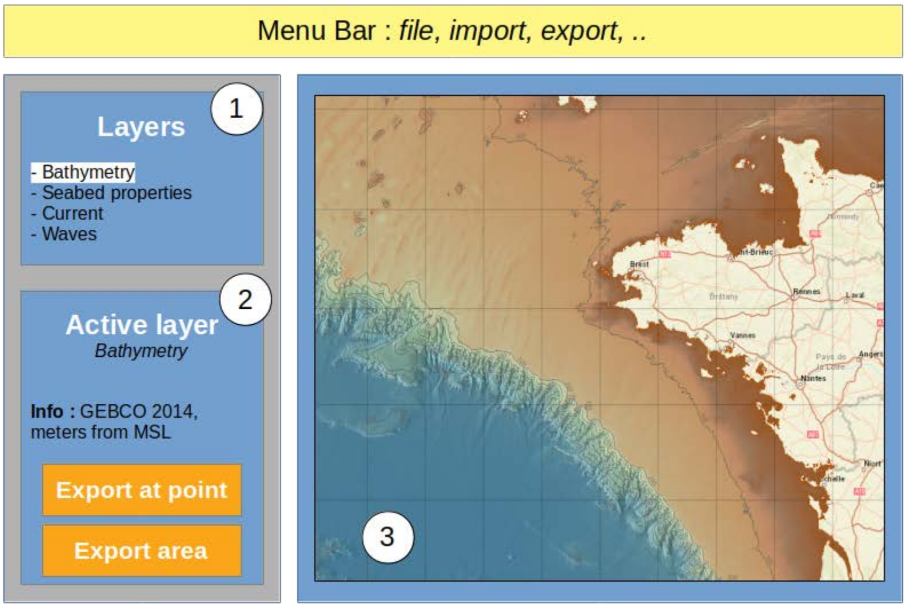


FIGURE 3-18. EXAMPLE MOCK-UP OF THE GUI FOR THE SITE CHARACTERISATION MODULE.

3.7.3 ENERGY CAPTURE

The majority of the input will be in the form of input fields, either direct variables (int, array) or strings that will be used to load more complex files, such as HDF5, JSON, XLS, ASCII, etc.

Additionally, some inputs will have multiple choices, such a dropdown item.

The EC module inputs will come either completely from the user or partially from the user and partially from the Site Characterization module. In this second case, the user will be prevented from modifying the Site Characterization share of the input to avoid any compromise of the project consistency.

The UI will have a visualization area to show simulation outputs, such as power production, array layout, etc.

The menu bar should contain options to allow the user of the module to run, load, reset and perform similar project actions.

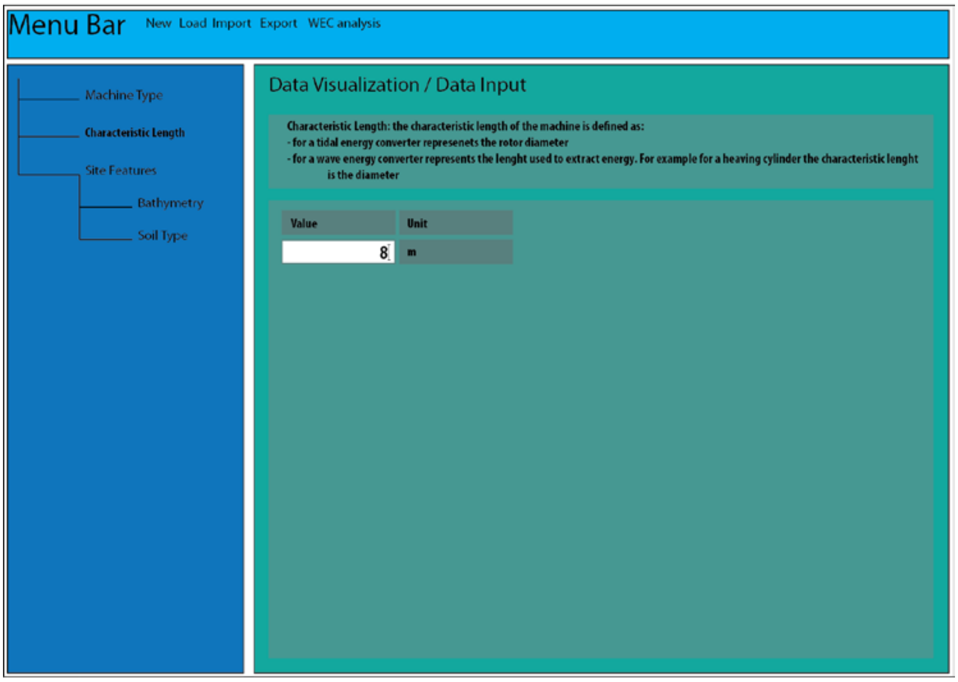


FIGURE 3-19. EXAMPLE MOCK-UP OF THE GUI FOR THE ENERGY CAPTURE MODULE.

3.7.4 ENERGY TRANSFORMATION

When loading the ET module, the user will be asked to fill in the required input through the GUI, such as:

- the selection of the use modes Assessment OR Design;
- the PTO technology depending on whether the software is previously set for tidal or wave projects;
- the type of control strategy;
- other characteristics.

These selections could be done by means of dropdown menus when the alternatives are countable. Similarly, the user might be asked to input specific data/values into blank spaces, etc... The Input GUI for the ET module will be similar to the one reported in Figure 3-20.

Moreover, after the tool is run, the GUI should be able to display results and export outcomes and reports.

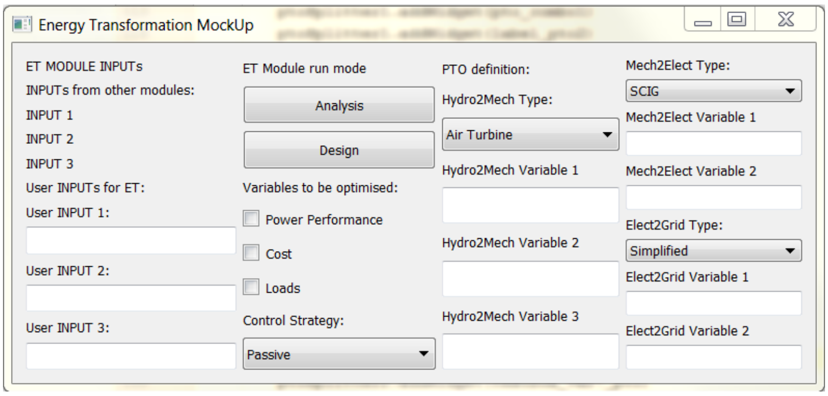


FIGURE 3-20. EXAMPLE MOCK-UP OF THE GUI FOR THE ENERGY TRANSFORMATION MODULE.

3.7.5 ENERGY DELIVERY

The GUI for the Energy Delivery tool will need to:

- Accept user inputs for various parameters, with a range of data types including multiple-choice dropdowns; text strings; numerical values (float & integer) as single values, 1D or 2D arrays.
- Display the network design graphically, both as a schematic network diagram, and as a georeferenced map including cable routes and device/collection point locations.
- Output reports (possibly HTML or PDF format) with a summary of the network design and analysis.

An example mock-up of the Energy Delivery tool is shown in Figure 3-21, with a list of the main steps shown in the left-hand column and a main content area that will change depending on the step. Two examples of this are shown in Figure 3-22, for entering the network topology via a user input form, which will then be represented diagrammatically. Note that the style and content of this diagram are still to be confirmed.

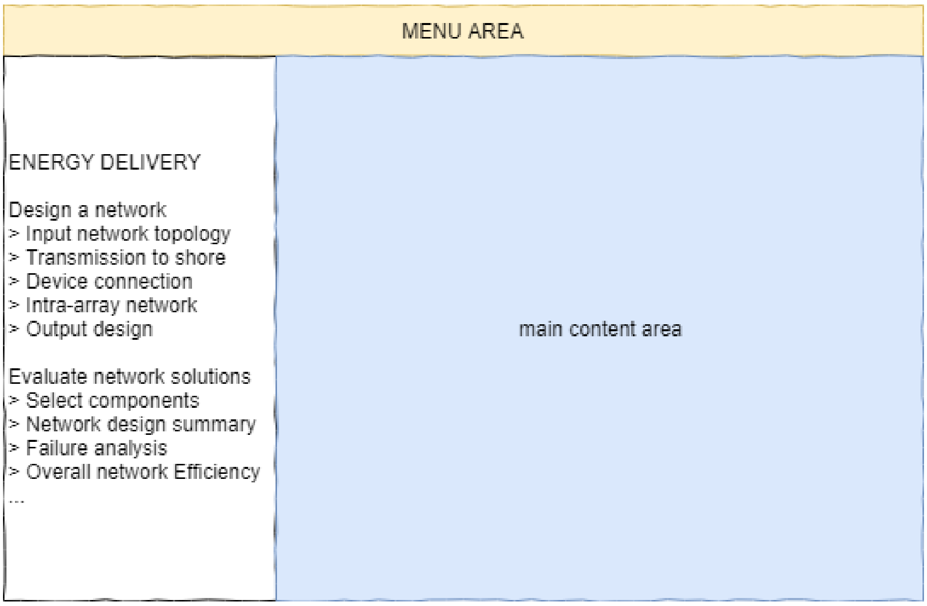


FIGURE 3-21: ENERGY DELIVERY TOOL MAIN SCREEN EXAMPLE MOCK-UP

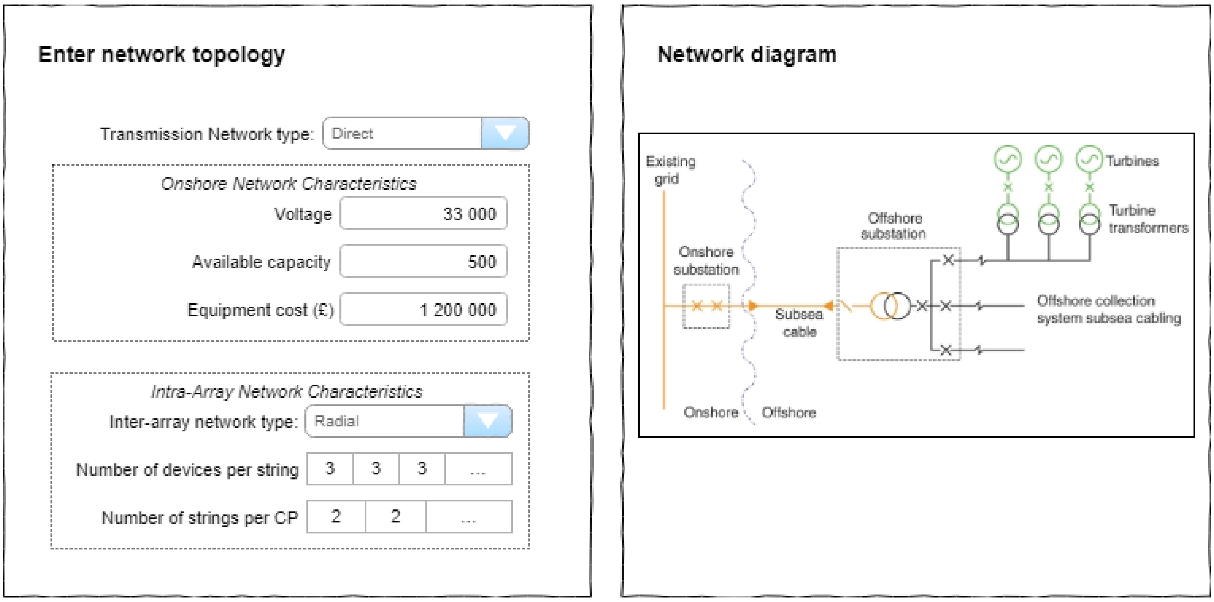


FIGURE 3-22: ENERGY DELIVERY TOOL NETWORK TOPOLOGY INPUT AND NETWORK DIAGRAM DISPLAY EXAMPLE MOCK-UPS

3.7.6 STATION KEEPING

The graphical user interface for the station keeping should be able to:

- Allow user inputs and parameters: numbers, text strings, multiple-choice dropdowns, tables;
- Allow actions from the user, upon request or on their own initiative;
- Display (graphical) information;
- Print output report that will summarize input and output data.

An example mock-up of the module is presented in Figure 3-23 and Figure 3-24. It is divided into four parts:

1) On the left side of the window "Inputs" and "Results" are organized in two tabs. Each tab has categories with groups of inputs and parameters.
   Groups of inputs / parameters are organized in a tree structure in each category. In the example for input data: the site characteristics category has three groups, "Bathymetry", "Environmental data" and "Soil properties". Most certainly, a third tab "Calculation parameters and options" will be inserted before the inputs tab to define whether a design or assessment computation will be performed. Those options might as well be located on the right side of the screen together with the "Run Module" button.
2) In the middle of the screen, a main window where blank spaces, tables and graphical information can be displayed.
   For an input (ex.: "Soil properties"), all the variables related to this group are going to be shown (coefficients, material properties, environmental data, etc.) and user will be able to fill the blank spaces and tables. In the "Soil properties" example, the user should be able to

inform the number of soil layers and fill the table with its properties or load them from the Site Characterization module.
For the results section (ex.: "Equilibrium Solution"), tables and graphical information will be displayed.
At the bottom of the window important information should be displayed about hypothesis, standards and methods that the user should know about. A permanent log window might also be located at the bottom to inform the user what the tool is doing, where part of the above-mentioned information could be displayed too (e.g. hypothesis, low-impact warning messages…)

3) On the right side buttons are located that allow: a) to choose the level of complexity of the analysis (might be imposed by the SG tool at a higher level) b) to run the analysis and c) to print an output report.
4) On the top, a menu area is left for the global tool common functionalities such as to open/save/create project file.

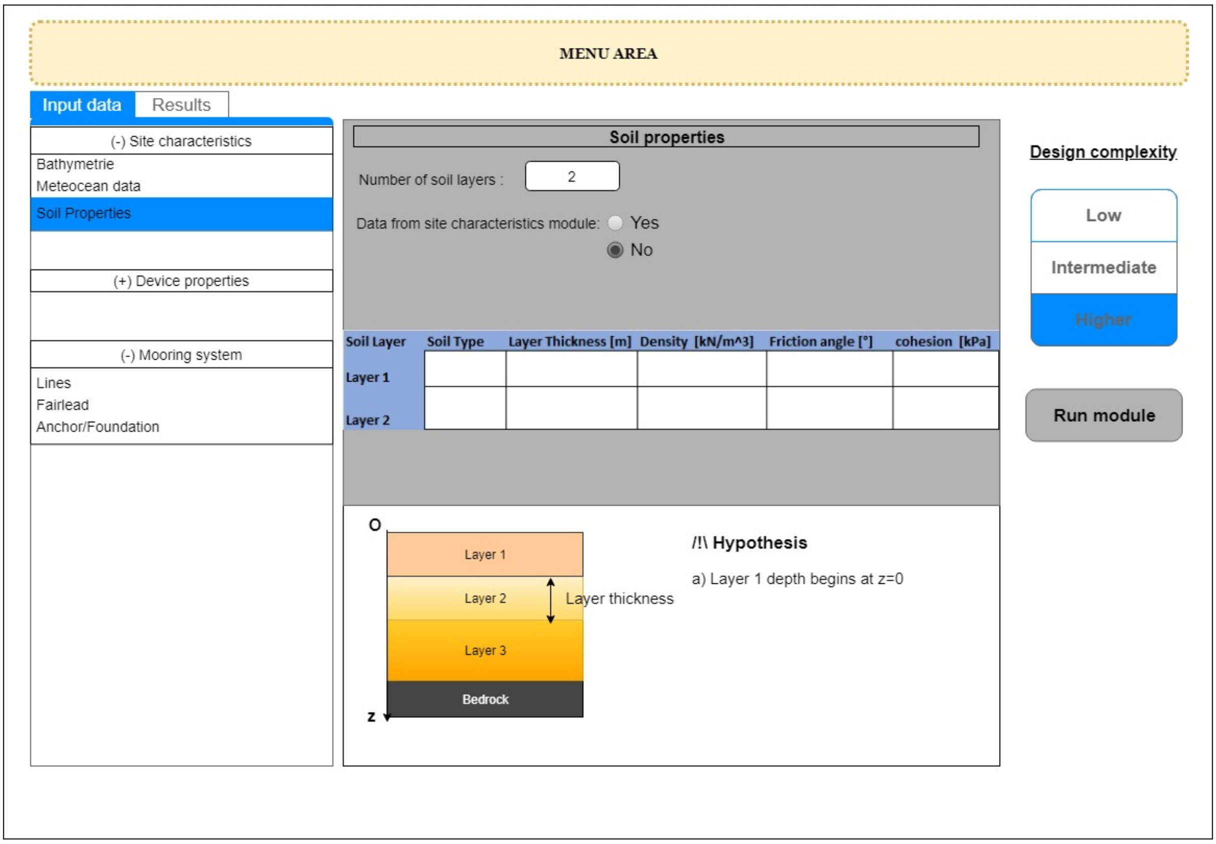


FIGURE 3-23. MOCK-UP FOR STATION KEEPING MODULE, EXAMPLE FOR INPUT DATA

The input data can be summarized as follow:

a. Site Characterisation
   i. Bathymetry

ii. Soil
iii. Environmental loads description
iv. Environmental combinations

b. Device Properties
Individual description of the (various) device(s) composing the farm
i. Geometry and dimensions (including reference systems)
ii. Dynamic properties (mass and inertia properties, hydrostatics, damping and added mass properties… when applicable)
iii. Wind and current properties (if applicable)

c. Line properties
Individual description of the various lines (based on catalogue of components from the database or from user direct input) that can be found in the farm amongst the various devices

d. Mooring system – Individual description of the various mooring systems composing the farm
Assembly of device with lines

e. Farm composition
Attribution to each device of the farm of a mooring system and some device properties

A draft list of computation parameters and options is:

a. Type of analysis: design (optimisation) or evaluation
b. Models to be used (if applicable)
c. Initial conditions
d. Constraints (if applicable / available)
e. Safety factors (default values proposed based on standard)
f. Sequence of analysis (e.g. sensitivity analysis)
g. ..

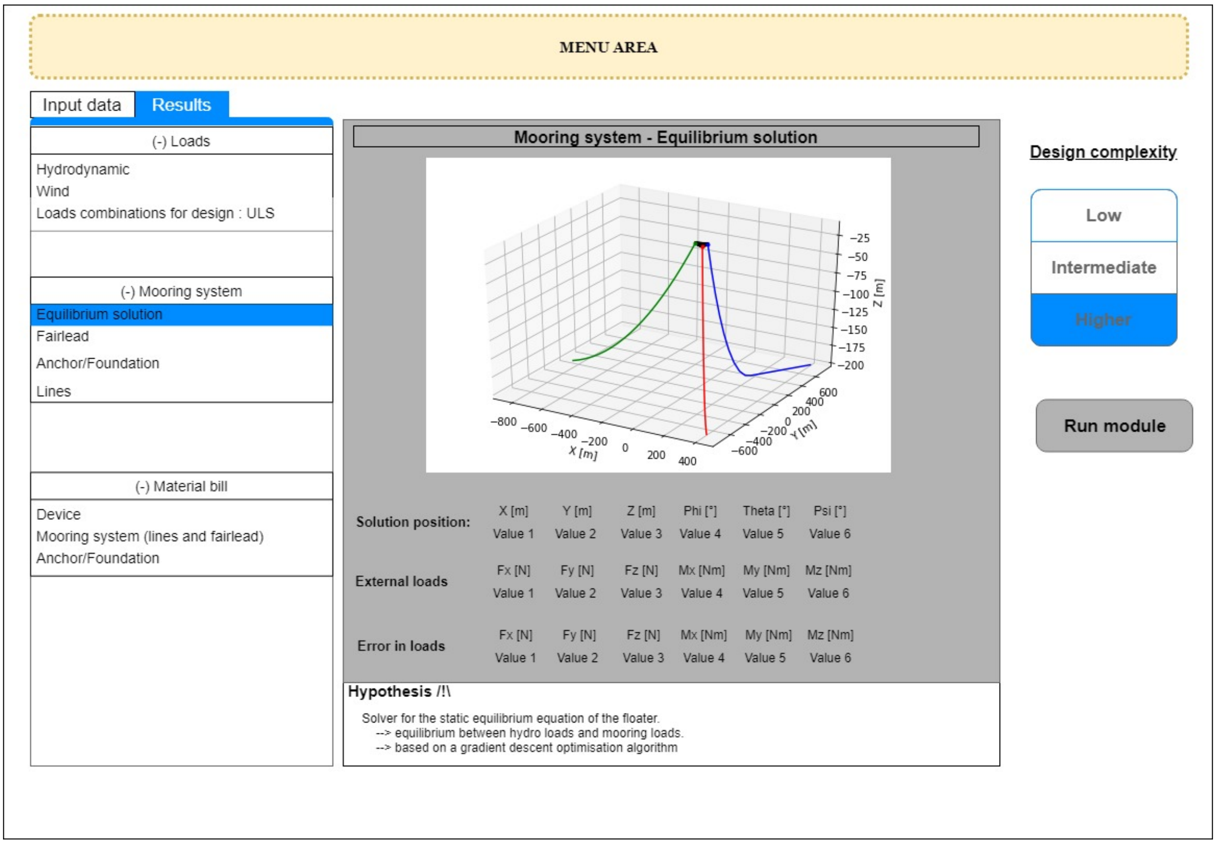


FIGURE 3-24. MOCK-UP FOR STATION KEEPING MODULE, EXAMPLE FOR INPUT DATA

3.7.7 LOGISTICS AND MARINE OPERATIONS

The GUI will be required to facilitate the interaction between the user and the Logistic and Marine Operation Planning tools.

- The GUI will be required to accept user inputs of various data types, such as multiple-choice dropdowns; text strings and numerical values (float & integer) as single values.
- The GUI will be required to present tables and accept and validate user inputs on the table cells.
- The GUI will be required to present reports and figures (possibly HTML, PDF, or JPEG/PNG) with a summary of the logistical solution and relevant illustrations.
- The GUI will require buttons and text forms to allow the user to upload csv files from a file directory specified by the user.
- The ability to plot array cables or array layout according to an introduced csv file may be implemented. This should be coordinated with other tools that may provide similar capabilities, such as the Site Characterisation, Energy Capture and Energy Delivery.

Example mock-ups of the Logistic tools are shown in Figure 3-25 and Figure 3-26. The GUI window is divided into three major sections: a GUI horizontal navigation bar at the top, a left-hand vertical menu on the left for navigating the Logistics tools, and the main content area on the right/centre that will change depending on the context. The left-hand menu groups the tool inputs into different groups and pages such as "device characteristics" and "cable array".

When multiple tools are run in a sequence, some of the required user inputs presented in the Logistic module may be *greyed out*, not allowing changes since they have been derived from other deployment tools.

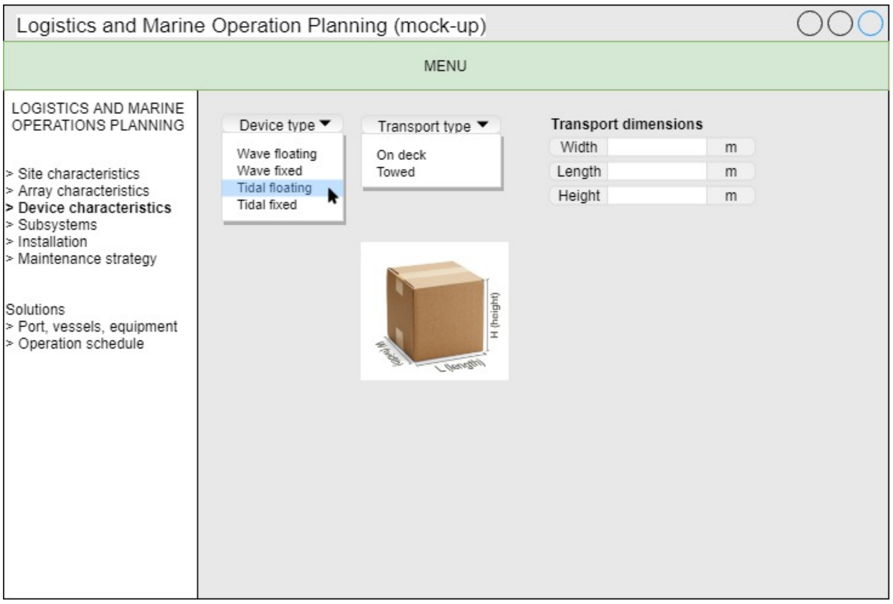


FIGURE 3-25 LOGISTICS AND MARINE OPERATION PLANNING TOOL MOCK-UP 1 IN DEVICE CHARACTERISTICS PAGE

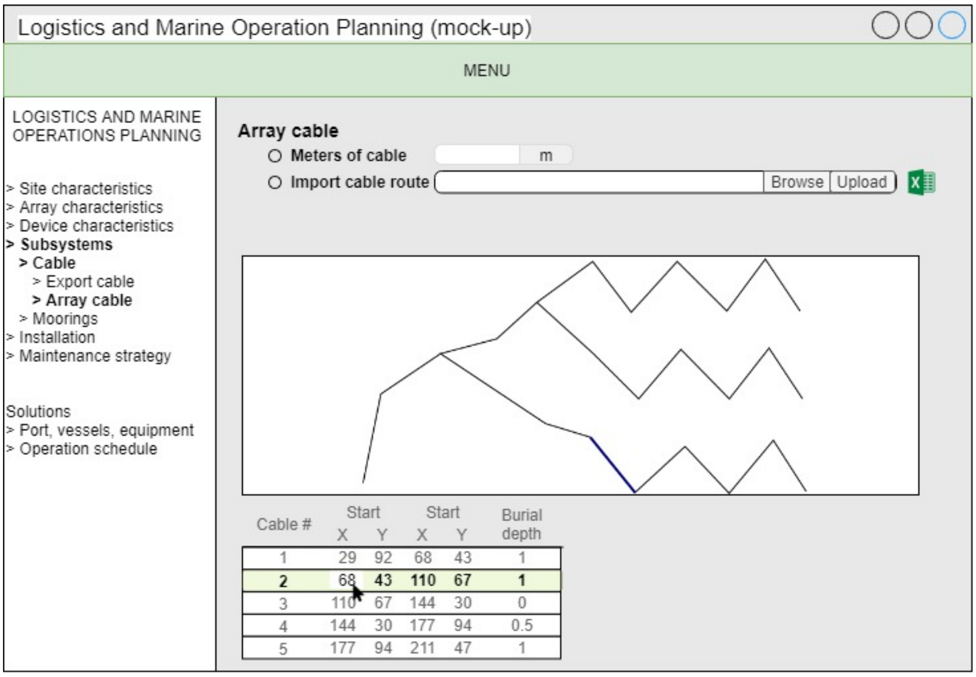


FIGURE 3-26 LOGISTICS AND MARINE OPERATION PLANNING TOOL MOCK-UP IN ARRAY CABLE PAGE

4. CONCLUSIONS

4.1 KEY FINDINGS

The present report D5.1 has collected the main technical requirements of the Deployment design tools in DTOceanPlus. In order to fulfil the functional requirements of the toolset previously identified and reported in D2.2 [9], the identified technical requirements for the Deployment design tools consist of a set of requirements for each tool in terms of architecture, functions, data, interfaces and maintenance able to perform the expected functionalities satisfying time constraints and quality standards. Thanks to the overall modular structure of the software, each module (Site Characterisation, Energy Capture, Energy Transformation, Energy Delivery, Station Keeping and Logistics and Marine Operation Planning) could satisfy the functional requirement addressing a purpose-tailored set of technical requirements, described in Section 2 of this deliverable. Even if each module has identified a set of its own technical requirements, some common guidelines could be identified

- The modules require to interact with the user in a friendly manner through the usage of a User Interface that in most cases could use intuitive graphical objects;
- The computational speed of the modules should be adjustable with the level of complexity of the project; for this reason, most modules have scalable complexity, corresponding to different input data requirements and outputs.
- The Deployment design tools require access to catalogues to provide adequate design at different levels of complexity.

To cover such requirements, each module showed that a strong interaction with the other Deployment design tools, the Assessment design tools, as well as the Structured Innovation tool and Stage tools is required to make the experience of the expected users of DTOceanPlus fully satisfactory. This could be achieved thanks to interaction with the underlying platform, the global database and the interaction of the user through the use of GUI; all the technical requirements for these interactions are described in terms of requirements in Section 3 of this deliverable.

4.2 NEXT STAGES

The following activities will correspond to the implementation of the modules following this set of technical requirements, in order to satisfy the functional requirements. T5.3-5.8, indeed, are aimed at producing the alpha version of the code for the Deployment design tools. The alpha version of the software will cover all the functionalities that are supposed to be implemented. The work done in T5.2 will ensure that the implemented code follows the technical requirements in D5.1. Moreover, it guarantees that all the modules within the Deployment design tools will be developed in a consistent manner; parallel tasks in WP3 (T3.2), WP4 (T4.2), WP6 (T6.2) and WP7 (T7.3) guarantee that all the software produced could be integrated in a unique platform. Approaches based on the Agile programming concepts, such as for example Continuous Integration/Development, will be adopted to reduce the risk of inconsistencies

The final task T5.9 aims at distributing the final beta version of the modules, in which the codes will be functional and fully validated , i.e. they can.1) respond correctly to a varied set of inputs, 2) be installed in the intended platform; 3) perform their function in acceptable time 4) be adequate in terms of usability; 5) be verified against control data.

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