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

Deliverable D6.1

Technical Requirements for the Assessment Design Tools

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EXECUTIVE SUMMARY

This document, D6.1 Technical Requirements for the Assessment 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 subsystems, 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 particular 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 Assessment design tool that will be developed as part of this project.

This document, D6.1, includes a detailed description of the technical requirements of each of the Assessment design tools to be developed within the DTOceanPlus project, i.e. tools for evaluating the System Performance and Energy Yield, the System Reliability, Availability, Maintainability and Survivability, as well as the System Lifetime Costs, and the System Environmental and Social Acceptance. Moreover, a full section is dedicated to the technical requirements for the integration of the Assessment design tools with the other sets of tools (Deployment design tools, Structured Innovation design tool and Stage Gate design tool), as well as for the integration with the underlying platform, 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
BIM	Building Information Modelling
BoM	Bill of Materials
CAPEX	Capital Expenditure
CFD	Computational Fluid Dynamics software
cFMEA	Concept-design Failure Modes and Effects Analysis
CFP	Carbon Footprint
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
EC	Energy Capture module
ED	Energy Delivery module
EDG	Electrical Distribution Grid
ET	Energy Transformation module
EIA	Environmental Impact Assessment
EIS	Environmental Impact Score
ESA	Environmental and Social Acceptance module
ESC	Energy Systems Catapult
FiT	Feed in Tariff
FMEA	Failure Modes and Effects Analysis
GIS	Geographical Information Systems
GUI	Graphical User Interface
HoQ	House of Quality Matrix
IP	Intellectual Property
IRR	Internal Rate of Return
KPI	Key Performance Indicator
LCOE	Levelised Cost of Energy
LMO	Logistics and Marine Operation Planning module
MRE/ORE	Marine/Ocean Renewable Energy
MTTF	Mean Time to Failure
MTTR	Mean Time to Repair
NPV	Net Present Value
O&M	Operations and Maintenance
OEC	Ocean Energy Converter (aggregate term for WEC & TEC)
OEM	Original Equipment Manufacturer
OES	Ocean Energy System
OPEX	Operational Expenditure
PoF	Probability of failure
PTO	Power Take-Off
PS	Pressure Score
PSA	Pressure Score Adjusted, or Adjusted Pressure Score
QFD	Quality Function Deployment

R&D	Research and development
RAMS	Reliability, Availability, Maintainability, Survivability assessment tool
RS	Receptor Sensitivity coefficient
RSS	Receptor Sensitivity Score
SC	Site Characterisation module
SEA	Socio Economical Acceptance
SG	Stage-gate tool
SI	Structured Innovation tool
SK	Station Keeping module
SLC	System Lifetime Cost assessment tool
SPEY	System Performance and Energy Yield assessment tool
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 Mark-up Language
WACC	Weighted Average Cost of Capital
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).

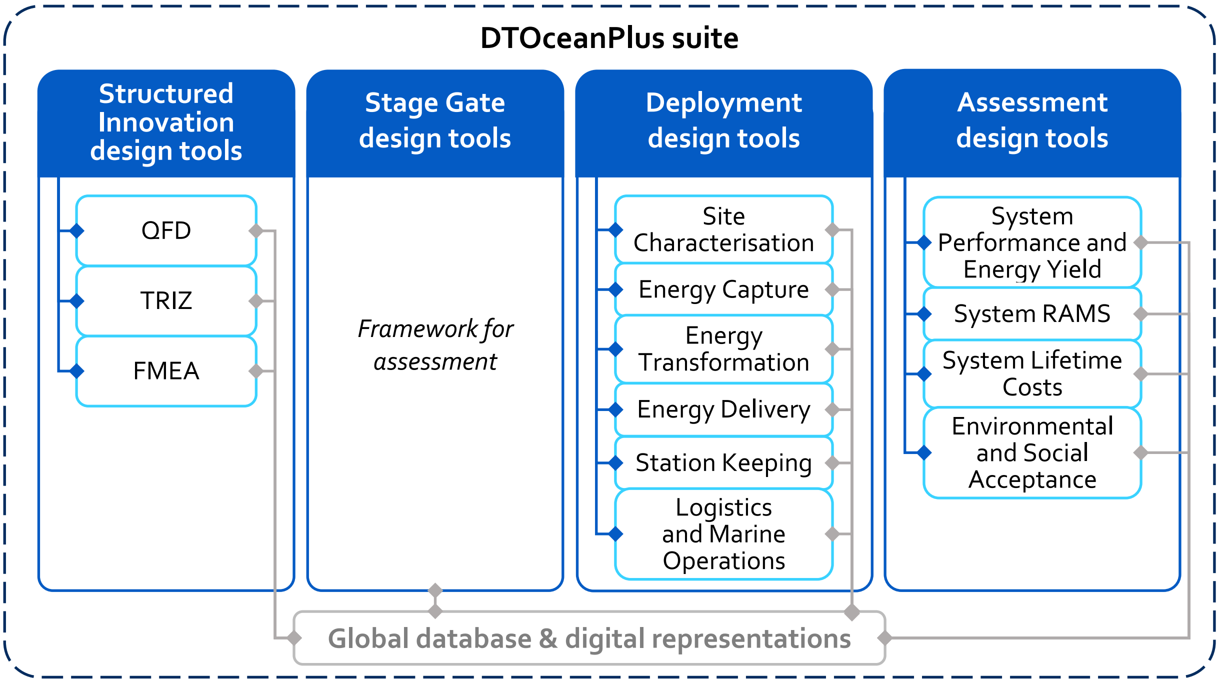


FIGURE 0.1 REPRESENTATION OF THE DTOCEANPLUS TOOLS HIERARCHY

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) which is a matrix used to describe the most important product or service attributes or qualities [1].

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

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.

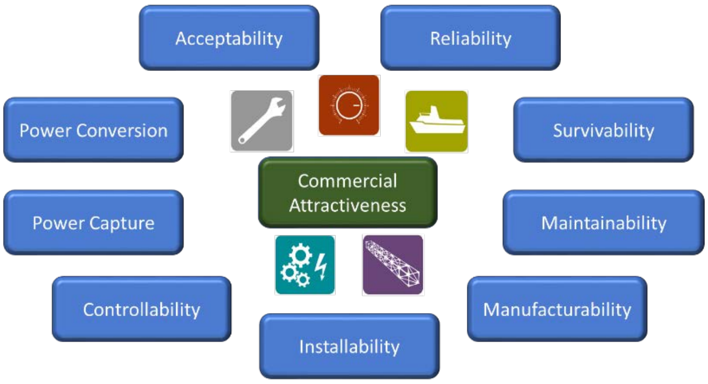


FIGURE 0.2 EXAMPLE OF EVALUATION AREAS IN THE ASSESSMENT OF THE COMMERCIAL ATTRACTIVENESS OF OCEAN ENERGY TECHNOLOGY

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.

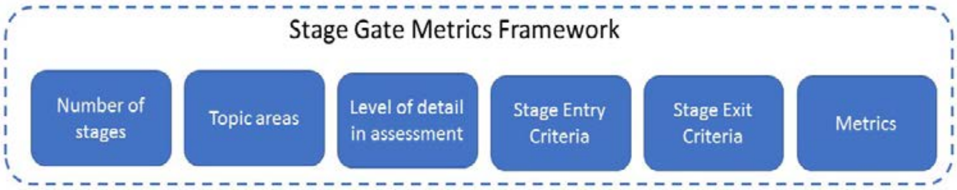


FIGURE 0.3: REPRESENTATION OF A STAGE GATE METRICS FRAMEWORK

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 Methodology	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 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:

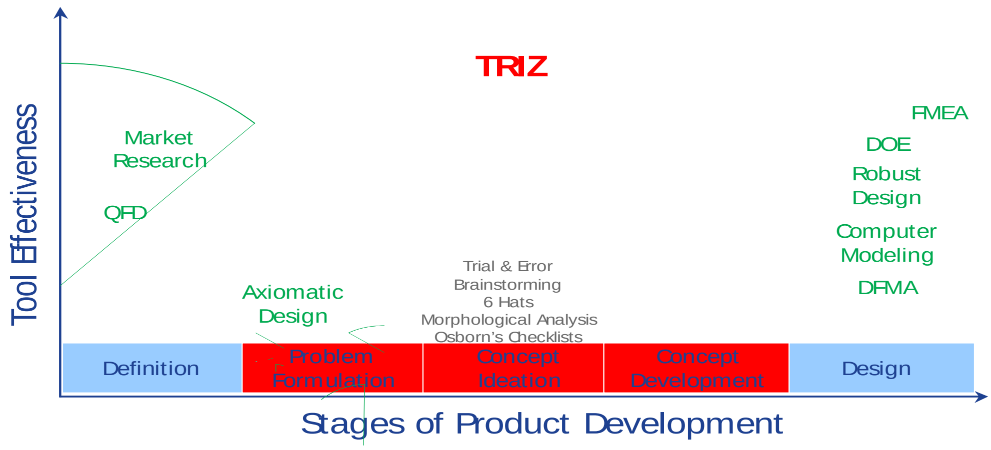


FIGURE 0.4: TOOL EFFECT VS PRODUCT DEVELOPMENT STAGE [4]

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: subsystem, 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 tools**, supporting optimal device and array deployment.
- **Assessment tools**, used by the other tools to quantify key parameters.

1.1 SCOPE OF REPORT

This report is the outcome of Task 6.1 'Technical requirements of the Ocean Energy assessment tools'. 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, T5.1, 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.

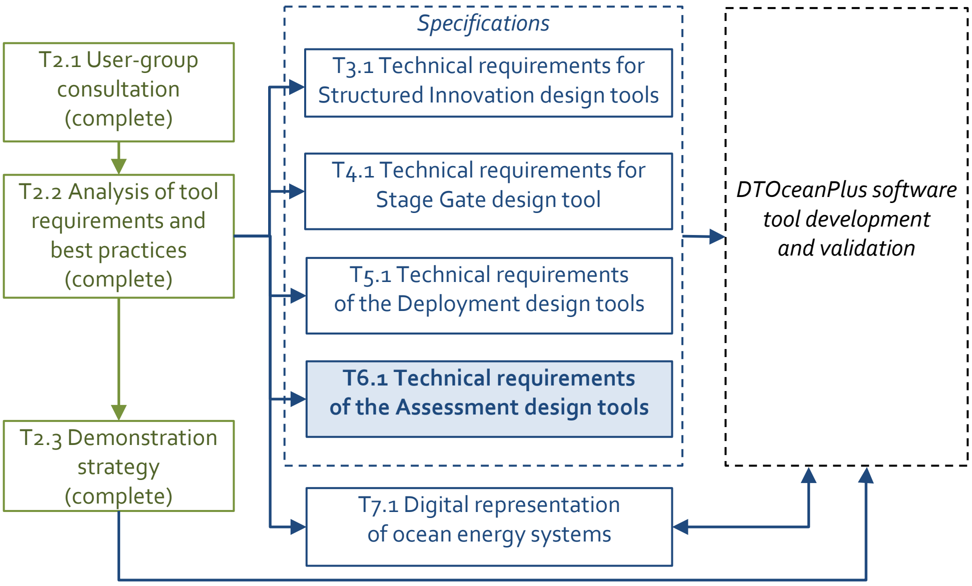


FIGURE 1.1: GRAPHICAL SUMMARY OF SOFTWARE SPECIFICATION TASKS (EXTRACTED FROM GRAPHICAL PRESENTATION OF THE PROJECT [6])

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 1.3 summarises the specifications for the original DTOcean software.
- Section 1.4 provides and outline of the proposed DTOceanPlus suite of tools.
- Section 2 sets out the technical requirements of the Assessment design tools.
- Section 3 sets out the technical specifications for the integration of the Assessment design tools 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 subsystems**: 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 subsystem 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.

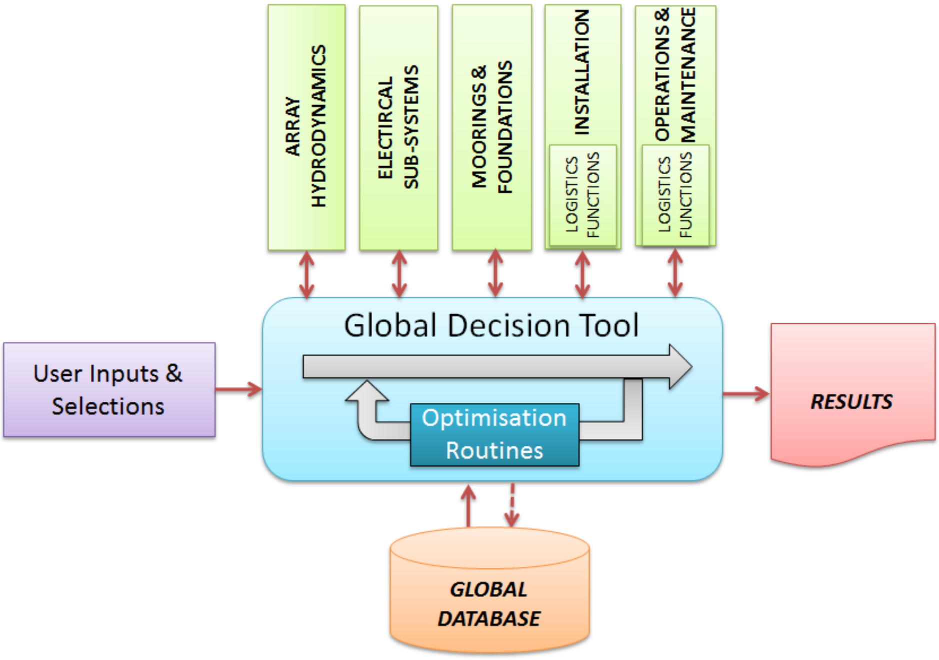


FIGURE 1.2: FUNCTIONAL STRUCTURE OF ORIGINAL DTOCEAN SOFTWARE [7]

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.

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

  - Metrics.
  - 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.

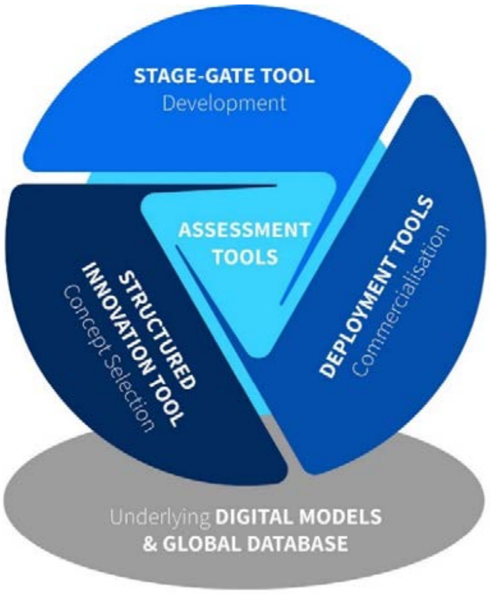


FIGURE 1-3: REPRESENTATION OF DTOCEANPLUS TOOLS.

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 TOOLS

In this section, the technical requirements for all the modules of the Assessment design tools 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 subsections:

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 SYSTEM PERFORMANCE AND ENERGY YIELD

System Performance and Energy Yield (SPEY) is an assessment tool for the evaluation of main key performance indicators (KPIs), or evaluation metrics, so that a technology can be compared with other technologies or the same technology in other sites. The SPEY tool will provide/generate performance data performance at subsystem, device and array level as well as the downtime due to planned and unplanned operations.

Interaction with the Stage Gate design tool enables a benchmarking of the assessed technology with reference technologies and/or case studies.

2.1.1 FROM FUNCTIONAL TO TECHNICAL REQUIREMENTS

Taking into consideration the functional requirements stated in Deliverable D2.2, the technical requirements of the System Performance and Energy Yield (SPEY) were compiled in Table 2.1.

TABLE 2.1 FUNCTIONAL AND TECHNICAL REQUIREMENTS OF THE SPEY MODULE

Functional Requirements
FR-SPEY-1. Estimate the energy production per subsystem, device and array FR-SPEY-2. Estimate the losses of different elements FR-SPEY-3. Compute evaluation metrics to compare different technologies FR-SPEY-4. Inform the user about the main outcomes through the Graphic User Interface (GUI)
Technical Requirements
TR-SPEY-1. Collect power production outputs at different conversion phases from Energy Capture (EC), Energy Transformation (ET) and Energy Delivery (ED). TR-SPEY-2. Collect non-productive periods corresponding to out-of-production power levels as well as planned and unplanned operations downtime from ET module, Logistics and Maintenance Operations (LMO) module and Reliability, Availability, Maintainability, Survivability (RAMS) respectively. TR-SPEY-3. Assess the net energy production aggregating collected data at subsystem, device and array level TR-SPEY-4. Compute the efficiency of the system, at subsystem, device and array level TR-SPEY-5. Compute the evaluation metrics based on performance, efficiency and availability at subsystem, device and array level TR-SPEY-6. Perform a technology benchmark consistently with referenced technology from within Stage Gate tools. TR-SPEY-7. Collect and provide inputs/outputs through the GUI

In addition, a relation matrix is proposed as shown in in Table 2.2, which associates the technical requirements to the functional ones.

TABLE 2.2 FUNCTIONAL AND TECHNICAL REQUIREMENTS RELATIONSHIP MATRIX

FR /TR relation matrix		Functional Requirements			
		FR-SPEY-1	FR-SPEY-2	FR-SPEY-3	FR-SPEY-4
Technical Requirements	TR-SPEY-1	X	X	X	
	TR-SPEY-2		X	X	
	TR-SPEY-3	X	X		
	TR-SPEY-4			X	
	TR-SPEY-5			X	
	TR-SPEY-6			X	
	TR-SPEY-7				X

2.1.2 ARCHITECTURE OF THE TOOL

Figure 2.1 shows the architecture of System Performance and Energy Yield module.

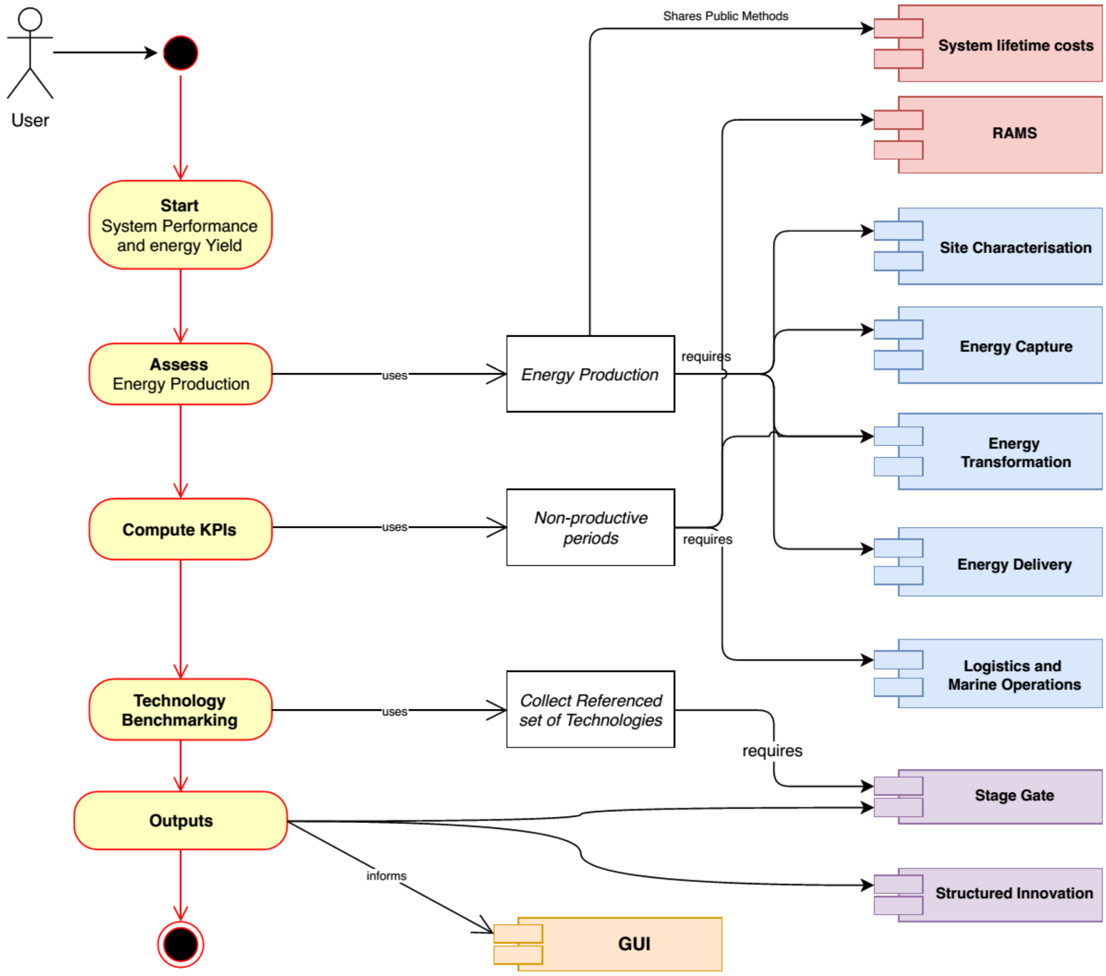


FIGURE 2.1: GLOBAL ARCHITECTURE OF THE SPEY MODULE

The main functions of the System Performance and Energy Yield tools can be described as follows:

1. **Energy production:** The power production function takes the annual power per device and per sea state/current velocity from Energy Capture, Energy Transformation and Energy Delivery modules. The efficiency at subsystem and device level are also gathered from the modules whilst at array level is computed in the energy production object.
2. **Non-productive periods:** Non-productive periods are collected to account for cut-in/cut-off environmental cases as well as planned and unplanned maintenance operations. The former is computed by the ET module since it is a function of PTO sizing. Planned maintenance is defined in LMO module together with the required operations and time. Combination of failure rates of subsystems from different modules along with the required operations and

times from LMO results in the unplanned maintenance operations to be computed by RAMS. These times are the basis for the downtime computation of each device and the whole array. Downtime, energy production, device dimensions and installed capacity enable the definition of the metrics which are the basis for the benchmarking with other technologies/sites.

3. **Collect Referenced set of Technologies:** This function will compare the outcome of the designed/analysed energy array with a set of referenced technologies gathered from the Stage Gate tool.

The main goal of the assessment is to provide the user with relevant metrics of the represented/ designed system. All evaluation metrics (KPIs), along with the absolute performance and installed capacity as well as efficiencies and defined downtimes provide a performance screenshot about the modelled/designed ocean energy system (OES).

2.1.3 MAIN FUNCTIONS AND MODELS

Use cases depend on the type of users. The main targeted users have been identified in deliverable D2.1 to be:

- Funders & Investors
- Innovators & Developers
- Project Developers
- Policy & Regulators

The SPEY assessment is executed to combine outcomes from all modules, each one with its level of complexity. Therefore, use cases will be associated with an overall level of complexity depending on the user type and what they may be looking for.

The SPEY tools are integral to assessment throughout DTOceanPlus, but typical use cases for each end user are shown in Table 2.3:

TABLE 2.3. SPEY USE CASES DESCRIPTION

Use Case ID	User Type	Objective	Stage
1	Funders & Investors	Assess specific technology	Mid-Late
2	Innovators & Developers	Assess specific innovations of subsystems	Early-Mid
3	Project Developers	Look for O&M strategy	Late
4	Policy & Regulators	Assess power performance/environmental impact of OES arrays	Early

There is one run mode in the SPEY in which all performance information from the design modules is gathered and metrics are subsequently computed and compared with the reference cases. It is represented in Figure 2.2.

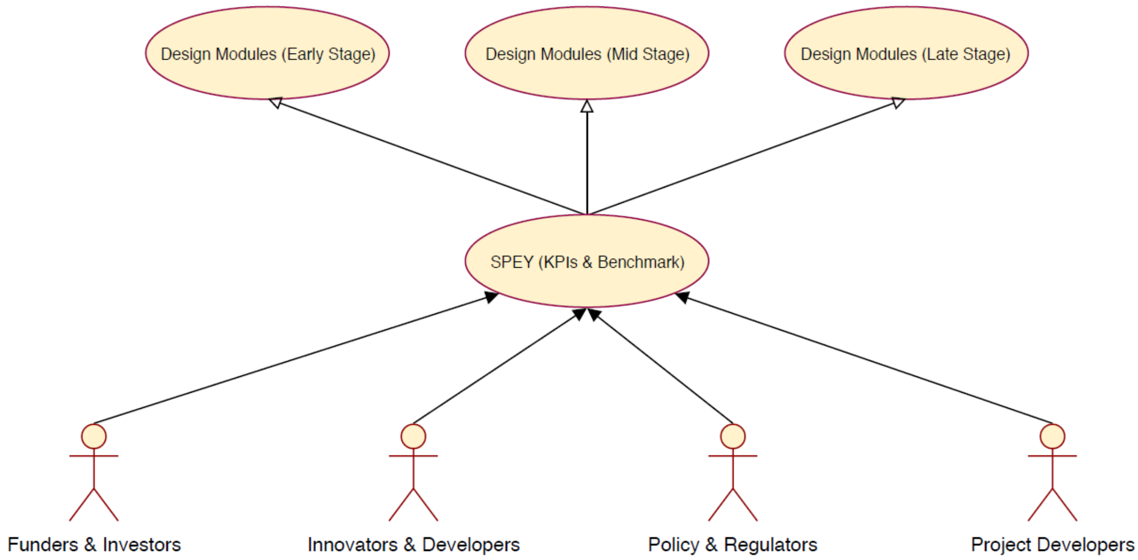


FIGURE 2.2: GENERIC USE CASE ESTIMATION OF METRICS AND TECHNOLOGY BENCHMARK

The most representative use cases, as described in Table 2.3 above, are represented below:

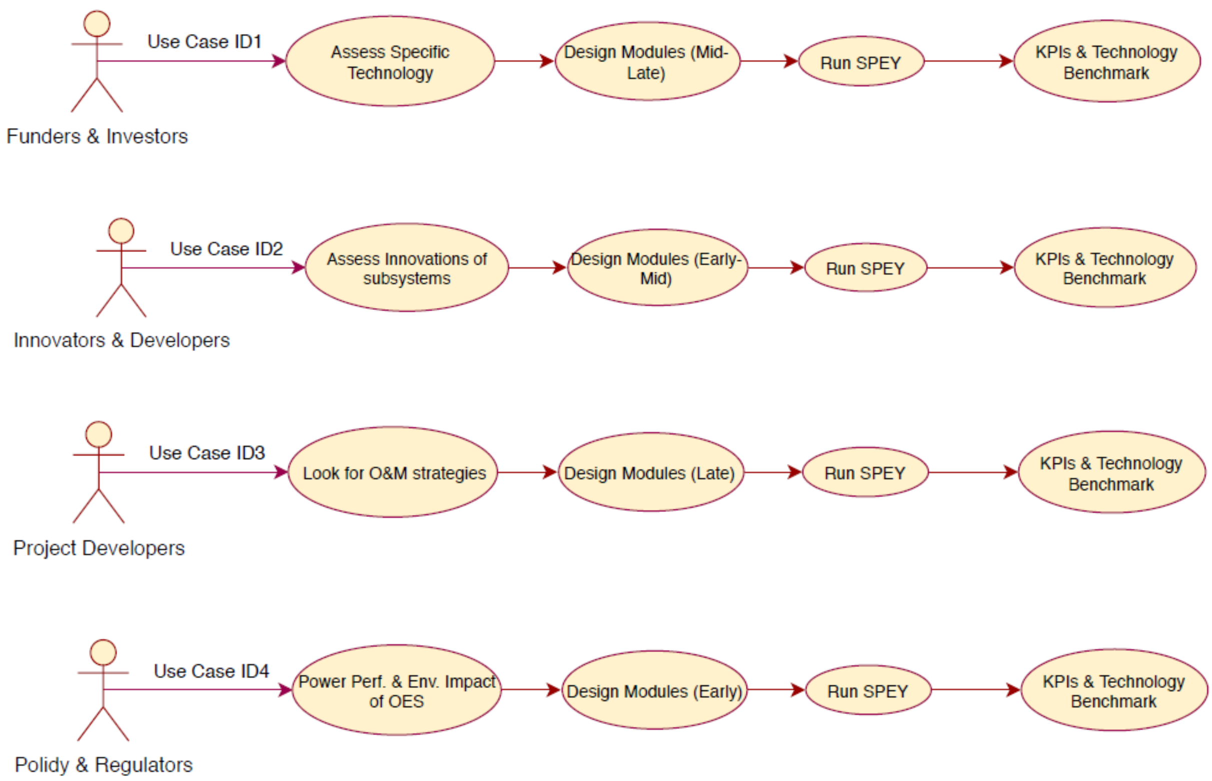


FIGURE 2.3 SPEY USE CASES DESCRIPTION

2.1.4 DATA REQUIREMENTS

Data requirements are detailed in this section. The main variables and procedures of each object within the SPEY assessment are represented in Figure 2.4 and Figure 2.5 in order to check main data flows among modules and assessments. As specified in the assessment architecture, the main functions make use of internal objects (represented in white boxes) to gather and precompute the most critical information.

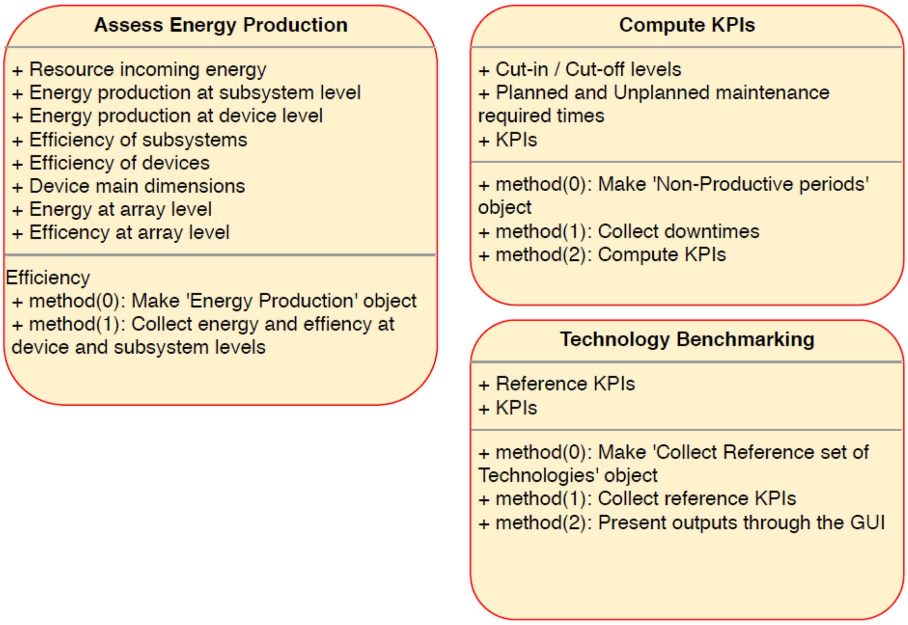


FIGURE 2.4 DATA STRUCTURE OF MAIN FUNCTIONS OF SPEY

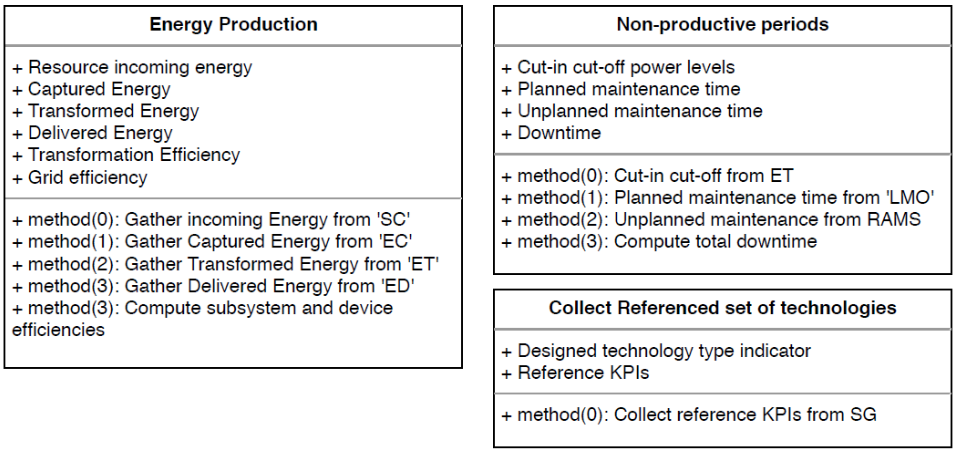


FIGURE 2.5 DATA STRUCTURE OF INTERNAL OBJECTS OF SPEY

2.2 SYSTEM RELIABILITY, AVAILABILITY, MAINTAINABILITY AND SURVIVABILITY (RAMS)

The Reliability, Availability, Maintainability and Survivability (RAMS) module delivers to the end users a solution for assessing/evaluating the RAMS of the ocean energy system (OES) at three stages, namely the concept stage (low complexity), the intermediate stage (medium complexity) and the commercial stage (high complexity). Basically, three essential inputs should be well prepared to ensure the reliability of the outputs from the RAMS module.

- The first essential input is the information on the system structure:
  - the configuration of an array (how individual devices are integrated into an array);
  - the internal configuration of each device (how subsystems are integrated to form a device);
  - the logical interrelationship between subsystems in a device (how individual subassemblies/ components are integrated to form each subsystem).
- The second essential input is the failure database which provides the failure rates of basic units (at a component or subassembly level) for all possible failure modes.
- The third essential input comprises the loads on structural components:
  - time series of simulated load effects for structural components identified as critical, fatigue strength and ultimate strength for these components, see section 2.2.4

Besides the aforementioned three essential input data, the times for estimating mean time to repair are required, see section 2.2.4.

The system structure information can be obtained from the outputs of other tools in this project or be inputted by the user(s). The user(s) can look up the design documents (e.g. bill of materials) where the working philosophy of the system at different levels (array, device, subsystem, subassembly and component) should be detailed. Based upon the working philosophy, a qualitative system analysis can be done to obtain the hierarchy structure which constitutes the basis for developing the reliability models.

For any of three complexity levels, the RAMS module should be able to assess/evaluate the RAMS of the OES, however, different complexity of output will be provided in these cases.

2.2.1 FROM FUNCTIONAL TO TECHNICAL REQUIREMENTS

In this subsection, technical requirements for the RAMS module of DTOceanPlus are proposed, as briefly summarized in Table 2.4.

In principle, a qualitative system analysis can be done to obtain the hierarchy structure which illustrates the logical interrelationship at different levels (e.g. between different subsystems in a device; between different subassemblies/components in a specific subsystem). The number of hierarchy levels is closely associated with the information on the system structure. For the time being, an OES is assumed to be virtually structured in two ways, as summarised below:

- Option 1: A four-level hierarchy structure including the array (the top level), the device, the subsystems and the component;

- Option 2: A five-level hierarchy structure including the array (the top level), the device, the subsystems, the subassembly and the component;

For Option 2, the reason why a subassembly level is added is that some specific subsystems are complicated from the design point of view and the failure path should be carefully defined.

TABLE 2.4. FUNCTIONALAND TCHNICAL REQUIREMENTS OF THE RAMS MODULE.

Functional Requirements
FR-RAMS-1. Assess reliability of mechanical /electrical/control components and systems using classical reliability methods based on component failure rates. FR-RAMS-2. Assess reliability and survivability of structural components (including mooring lines and e.g. load bearing welded steel beams) using structural reliability methods based on formulation of limit state equations and stochastic models for uncertain parameters. FR-RAMS-3. Provide required data to support assessment of availability, maintenance planning and repair costs by other modules (Logistics and Marine Operations Planning & System Lifetime Cost).
Technical Requirements
TR-RAMS-1. Review the output from the other modules, namely the failure mode(s) and the failure rate(s) (these can be user-defined through GUI or automatically loaded from a failure database into the RAMS module), and prepare the data in a readable/identifiable format for the RAMS GUI, including: -1.a.Collect the information on the failure mode(s) for basic units (at a subsystem/subassembly/component level); -1.b.Understand the working philosophy of the OES, namely the logical interrelationship between various basic units (at a subsystem/subassembly/component level); -1.c.Collect the information on the failure rate(s) for basic units, if the failure rate(s) can be exported from other tools. Otherwise, the failure rates(s) should be user-defined or automatically loaded from a failure database into the RAMS module. TR-RAMS-2. Develop the reliability diagrams based upon the output from TR-RAMS-1 TR-RAMS-3. Estimate the failure rate/the probability of failure (PoF)/the mean time to failure (MTTF) based upon the classical reliability theory for the electrical/mechanical/control subsystems TR-RAMS-4. Estimate the failure rate and/or PoF based upon the structural reliability method for the structural subsystem TR-RAMS-5. Export the results as input to the other relevant modules through GUI.

Each technical requirement will be used to achieve the functional requirements. The TRs required to achieve each FR are represented in the Table 2.5:

TABLE 2.5 FUNCTIONAL AND TECHNICAL REQUIREMENTS RELATIONSHIP MATRIX

TR \ FR relation matrix		Functional Requirements		
		FR-RAMS-1	FR-RAMS-2	FR-RAMS-3
Technical Requirements	TR-RAMS-1	X	X	
	TR-RAMS-2	X		
	TR-RAMS-3	X		
	TR-RAMS-4		X	
	TR-RAMS-5			X

2.2.2 ARCHITECTURE OF THE TOOL

A flowchart (UML diagram) is shown in Figure 2.6 to demonstrate the work scope and the interfaces of the RAMS modules with the other relevant modules, and the data flow between the involved tools. The yellow boxes represent the analysis steps of the RAMS module. The RAMS module starts with the working philosophy diagram which is developed based upon key information. The key information comprises the Bill of Material (BoM) (i.e. the system breakdown, the logical interrelationship between various devices in an array/various subsystems in a device) and the failure modes. It is assumed that any of the Energy Transformation tool, the Energy Delivery tool, the Station Keeping tool has a BoM. The data structure of the BoM is readable and self-explanatory. Failure modes (especially critical failure modes) are assumed to be provided by the Structured Innovation tool (FMEA). The RAMS module also requires the failure rates of basic components which are assumed to be obtained from a general failure database or based upon engineering judgement. Besides the aforementioned two types of inputs, the typical load cases (the extreme loads for the low complexity level or the load/stress time series for the medium/high complexity level) are assumed to be provided by Station Keeping. The outputs of the RAMS module are the failure rates/PoFs/mean time to failure (MTTF) of an array/device/subsystem/basic component. These outputs may be used by the Logistics and Marine Operations and System Lifetime Cost modules, or it may be used directly as basis for decision making.

Notes:

1) Given the failure rates of basic components, the failure rates of subsystems, devices and an array can be calculated based upon the classical reliability theory and/or structural reliability analysis methods. The outputs of the RAMS module depend upon the complexity level. For the high complexity level, the failure rate (or Probability of failure, PoF) as a function of time can be the output.

2) If any of MTTF (or mean time to repair, MTTR), PoF and failure rate is known, the other metrics can be calculated based upon the classical reliability theory. In the following part of this document, the failure rate is the only terminology used to avoid misunderstanding. The availability is also closely associated with the failure rate, and can be considered the availability of an array or the availability of a device.

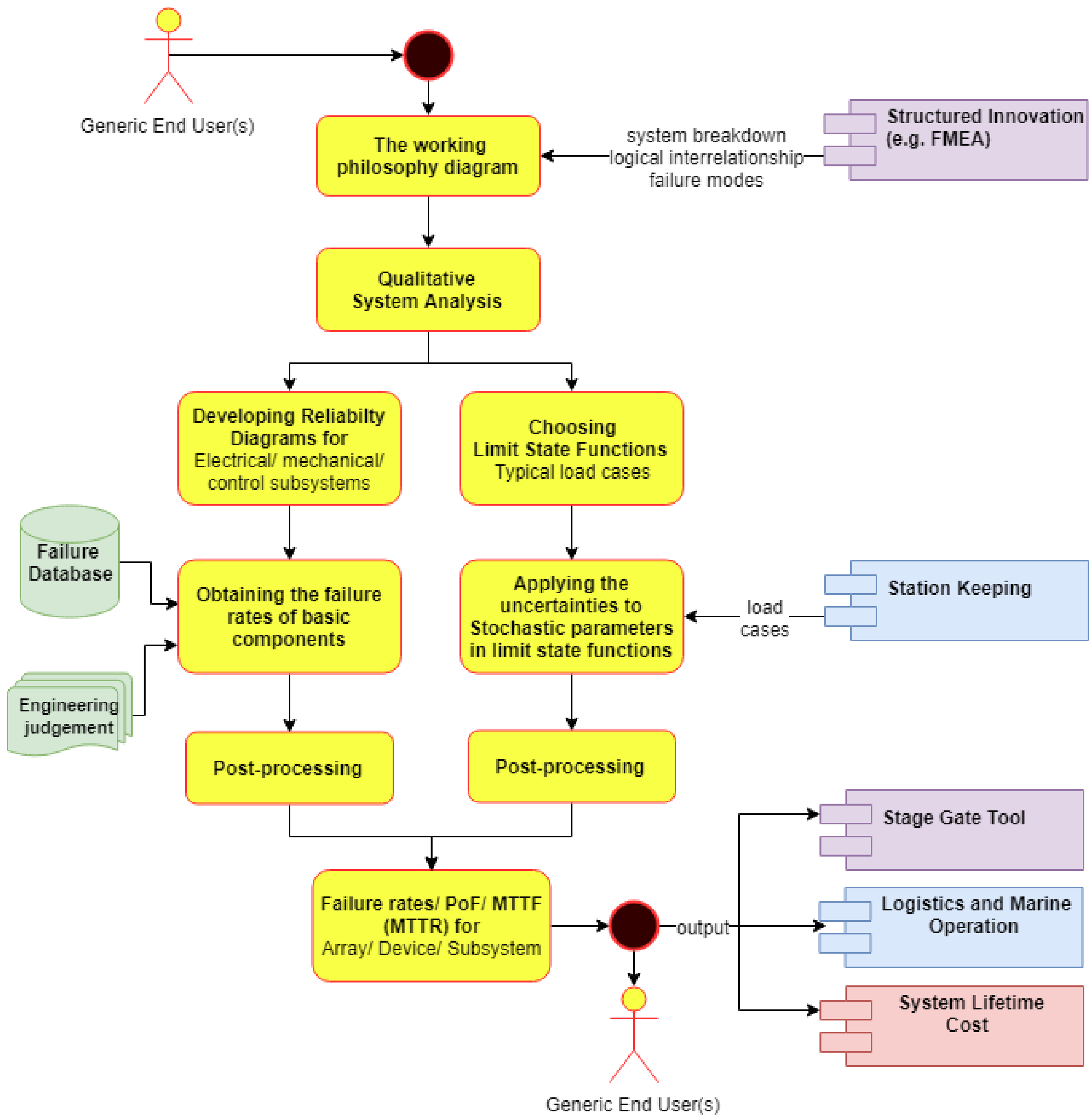


FIGURE 2.6 FLOWCHART OF WORK SCOPE OF RAMS

2.2.3 MAIN FUNCTIONS AND MODELS

The main functions can be briefly explained/described by two types of use cases. Each type is used to demonstrate the way the RAMS module is run to obtain the expected output that satisfy the requirements of different types of end users (Technology developers; Project developers; Public & Private investors) as defined in Section 2.2 of Deliverable D2.2 [9]. The three types of end users have a specific purpose of using the RAMS module, and have access to different data sets. Two major types of use cases are analysed for the Electrical/Mechanical/Control subsystem and the Structural subsystem, respectively. Each of them is composed of three sub-cases, as briefly summarized in Table 2.6.

The analysis steps for the two types of use are illustrated in Figure 2.7 and Figure 2.8. The first two major steps are the same for both types of use cases. From the third step, the two types of use cases follow different tracks. For the Electrical/Mechanical/Control subsystems, reliability diagrams should be developed based upon the collected information regarding the working philosophy and the logical interrelationship between various components and failure modes. With the failure rates found in some specific failure database, the failure rate of a subsystem can be calculated accordingly. For the Structural subsystem, a limit state function can be defined for the chosen failure mode. If the structural subsystem is a complicated system, the failure rate of the overall structural subsystem can be estimated based upon the classical reliability theory by simplifying the structural subsystem as a series, a parallel system or a complicated system. The application of the classical reliability theory is represented by the arrows originating from the two blocks under the second ellipse.

TABLE 2.6 USE CASE DESCRIPTION

Use Case ID	Subsystem Category	User Type	Objective	Analysis Complexity
1-1	Electrical/Mechanical /Control	Public & private investors	Obtain information on the Reliability, Availability, Maintainability and Survivability of a subsystem/device/array	Low complexity
1-2		Project developers	Obtain information on the Reliability, Availability, Maintainability and Survivability of a subsystem/device/array	Medium complexity
1-3		Technology developers	Obtain information on the Reliability, Availability, Maintainability and Survivability of a subsystem/device/array Assess/evaluate the RAMS of a design	High complexity
2-1	Structural	Public & private investors	Obtain the information on the system structure and Reliability, Availability, Maintainability and Survivability of a subsystem/device/array	Low complexity
2-2		Project developers	Obtain the information on the system structure and material specifications and Reliability, Availability, Maintainability and Survivability of a subsystem/device/arr	Medium complexity

			ay	
2-3		Technology developers	Obtain the information on the system structure, material specifications and the loads (for different load cases) Assess/evaluate the RAMS of a design	High complexity

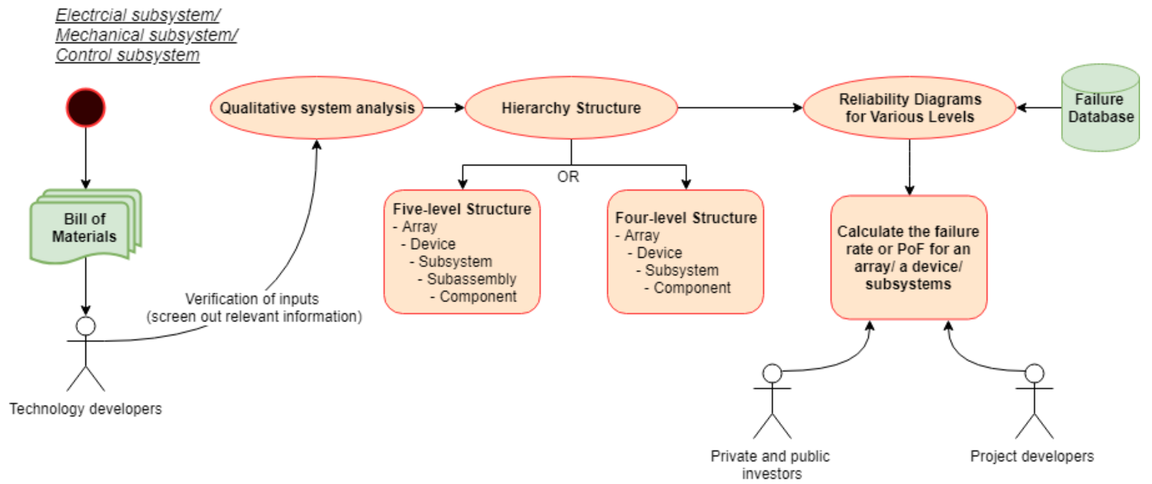


FIGURE 2.7 ILLUSTRATION OF USE CASE 1-1 ~ 1-3

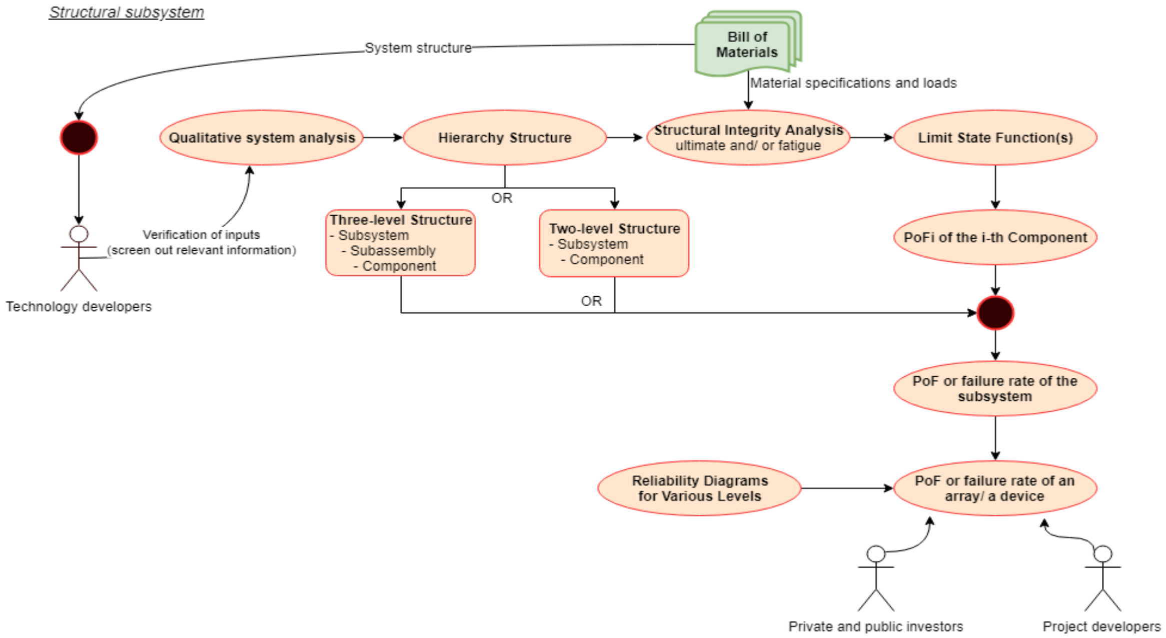


FIGURE 2.8 ILLUSTRATION OF USE CASE 2-1 ~ 2-3

2.2.4 DATA REQUIREMENTS

The RAMS module requires the following input data. The data flow is shown in Figure 2.9.

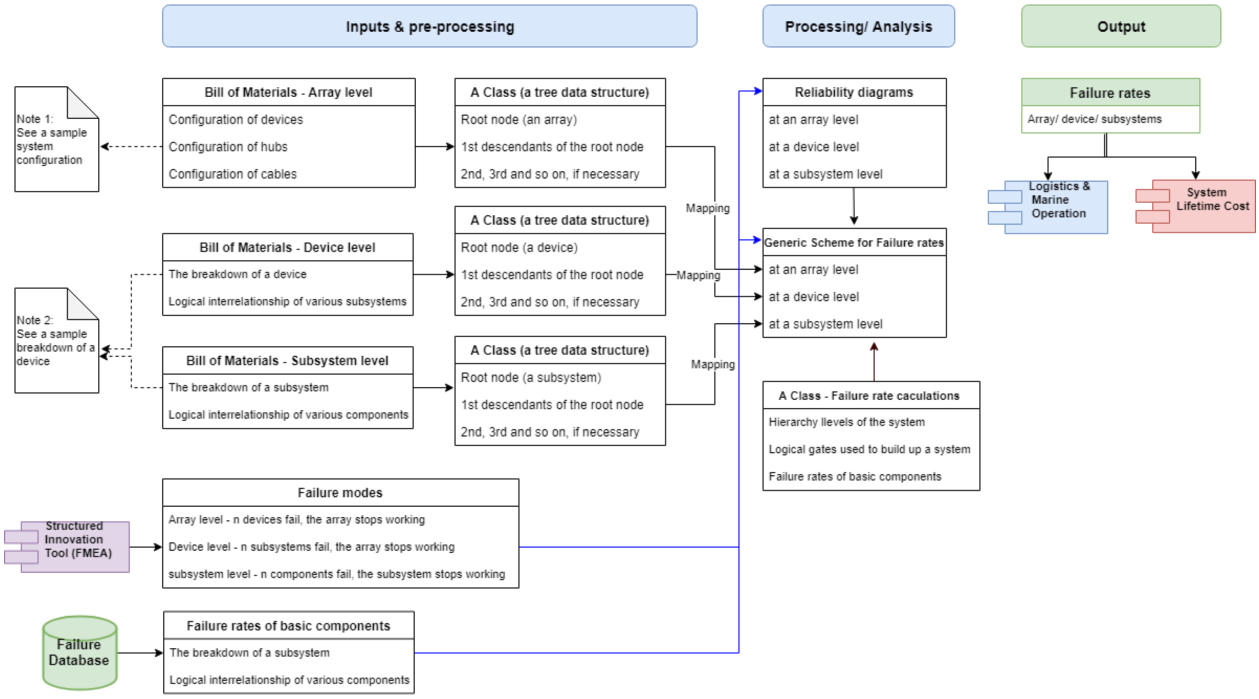
GENERAL DATA REQUIREMENTS

- As mentioned in Section 2.2.2, the bill of materials (BoM) should be provided by the Energy Transformation tool, the Energy Delivery tool and the Station Keeping tool. Each BoM should be well defined and be able to demonstrate the hierarchy structure of an array/device/subsystem, as illustrated in Figure 2.9 (b)&(c). For example, a well-defined hierarchy structure is as follows:
  - An array composed of *N* devices can be split into a couple of assemblies. Each assembly consists a certain number of devices connected to each other by means of cables (low/high voltage). The cables are then plugged to a hub which have access to the main cable.
  - Each device is assumed to be composed of four subsystems, namely structural, mechanical, electrical, and control subsystem. Each of these subsystems consists of some basic components. These basic components could be assembled in a series, parallel or more complicated manner.

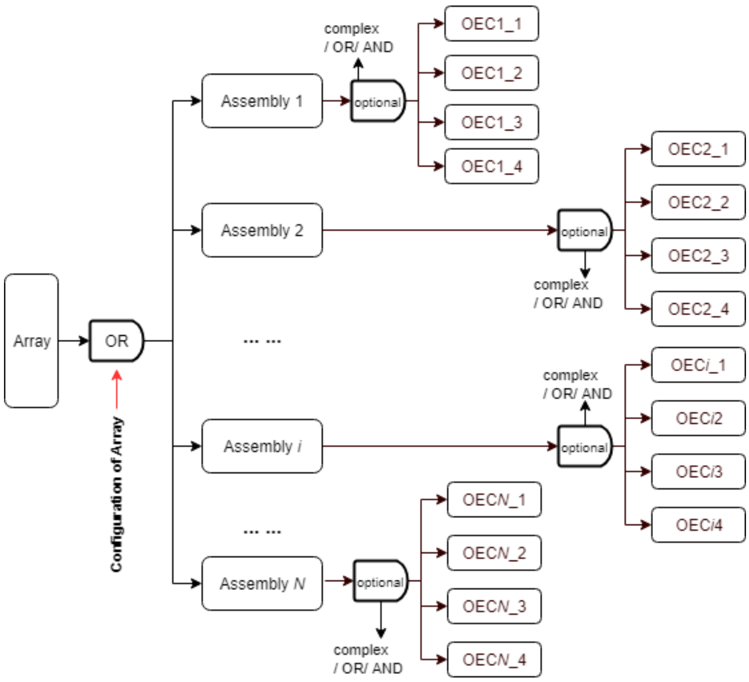
  Note: Reliability diagrams can be developed and used to calculate the failure rates (or Probability of Failure (PoF) or Mean Time to Failure (MTTF)) of an array/device/subsystem, based upon the well-defined hierarchy structure.
- Failure modes of a device or a subsystem from the Structured Innovation design tool
- For estimating Mean Time to Repair (MTTR), the following input is needed:
  - For waiting time and availability estimation:
    Weather windows, e.g. in the form of expected waiting time as a function of required time for the operation (times listed below)
    - Transportation time (depending on the distance from the harbour to the site and the ship selected)
    - The time for getting the personnel (technicians) and spare parts ready
    - The time for chartering a vessel (or waiting for an available vessel)
    - Actual time to do the repair
  - Decision rules:
    Actions taken when a failure (a component/a subsystem/a device) occurs. By default, it is assumed that redundant components are repaired at scheduled maintenance visits and component failure resulting in stop of electricity production are repaired as soon as possible (corrective maintenance strategy).

SPECIFIC DATA REQUIREMENTS FOR STRUCTURAL SUBSYSTEM

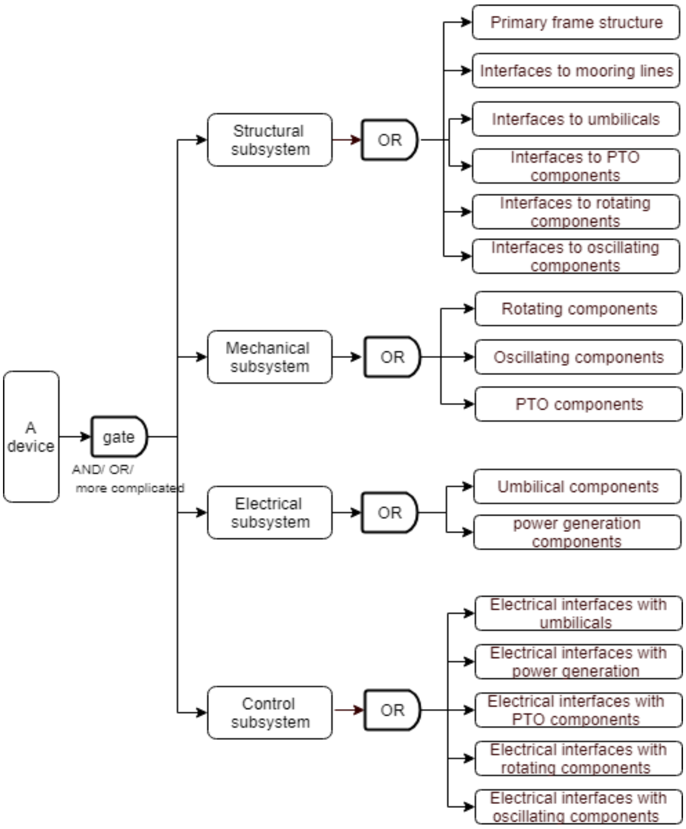
- Extreme and fatigue loads (e.g. those from Station Keeping and Energy Transformation modules)
- Material properties, e.g. S-N curve or a crack propagation model (for the high complexity level)



(a) General layout of data requirements



(b) A sample of system breakdown (at an array level) –Note 1



(c) A sample of system breakdown (at a device level) –Note 2;

FIGURE 2.9 ILLUSTRATION OF DATA REQUIREMENTS

2.3 SYSTEM LIFETIME COSTS

2.3.1 FROM FUNCTIONAL TO TECHNICAL REQUIREMENTS

The System Lifetime Costs tools will provide cost assessments to ocean energy projects. These tools will estimate the costs associated with the subsystems, devices or arrays throughout the project's lifetime, and ultimately the project's economic and financial viability. Taking into consideration the functional requirements stated in Deliverable D2.2, the technical requirements of the System Lifetime Cost tools were compiled in Table 2.7.

TABLE 2.7 FUNCTIONAL AND TECHNICAL REQUIREMENTS OF THE SLC MODULE

Functional Requirements
FR-SLC-1. Estimate lifetime costs based on environmental conditions, such as associated fatigue and operations/maintenance costs FR-SLC-2. Evaluate economic and financial viability FR-SLC-3. Identify cost-reduction pathways FR-SLC-4. Provide investors with the information they need to identify promising technologies and remaining challenges that need to be overcome through further funding and investment FR-SLC-5. Include assessment of financing of pre-commercial projects.

Technical Requirements	
TR-SLC-1.	Use of cost-estimating functions based on physical characteristics of components
TR-SLC-2.	Use of database of typical components
TR-SLC-3.	Interaction with deployment, assessment, structured innovation and stage gate tools, through Bill of Materials, Databases, and Public Methods
TR-SLC-4.	Interaction with the user through the Graphical User Interface
TR-SLC-5.	Use of LCOE function and other economic assessment metrics
TR-SLC-6.	Use of lookup tables with typical project cost to evaluate viability
TR-SLC-7.	Use NPV, IRR and Payback functions based on user inputs on financing breakdown and rates, and on electricity selling price and special tariffs
TR-SLC-8.	Use of lookup table for typical cost-breakdown for similar projects to identify deviations from expected costs
TR-SLC-9.	Estimating revenue support and/or capital grants requirements for profitability, taking into consideration WACC for the project

Some of the listed technical requirements are associated with several functional requirements. These relationships are expressed in Table 2.8.

TABLE 2.8 FUNCTIONAL AND TECHNICAL REQUIREMENTS RELATIONSHIP MATRIX

		Functional requirements				
		FR-SLC.1	FR-SLC.2	FR-SLC.3	FR-SLC.4	FR-SLC.5
Technical Requirements	TR-SLC.1	X				
	TR-SLC.2	X		X	X	
	TR-SLC.3	X	X	X	X	X
	TR-SLC.4	X	X	X	X	X
	TR-SLC.5		X	X	X	
	TR-SLC.6		X	X	X	X
	TR-SLC.7		X	X	X	X
	TR-SLC.8			X	X	X
	TR-SLC.9			X	X	
	TR-SLC.10					X

2.3.2 ARCHITECTURE OF THE TOOL

The architecture of the System Lifetime Costs tool is presented in the figure below. The minimal operation of the tool will maintain the functionality of the original DTOcean tool, i.e. calculating the Levelised Cost of Energy (LCOE). Further assessments that answer the functional requirements detailed above can be run in the sequence of the tool depending on user selection.

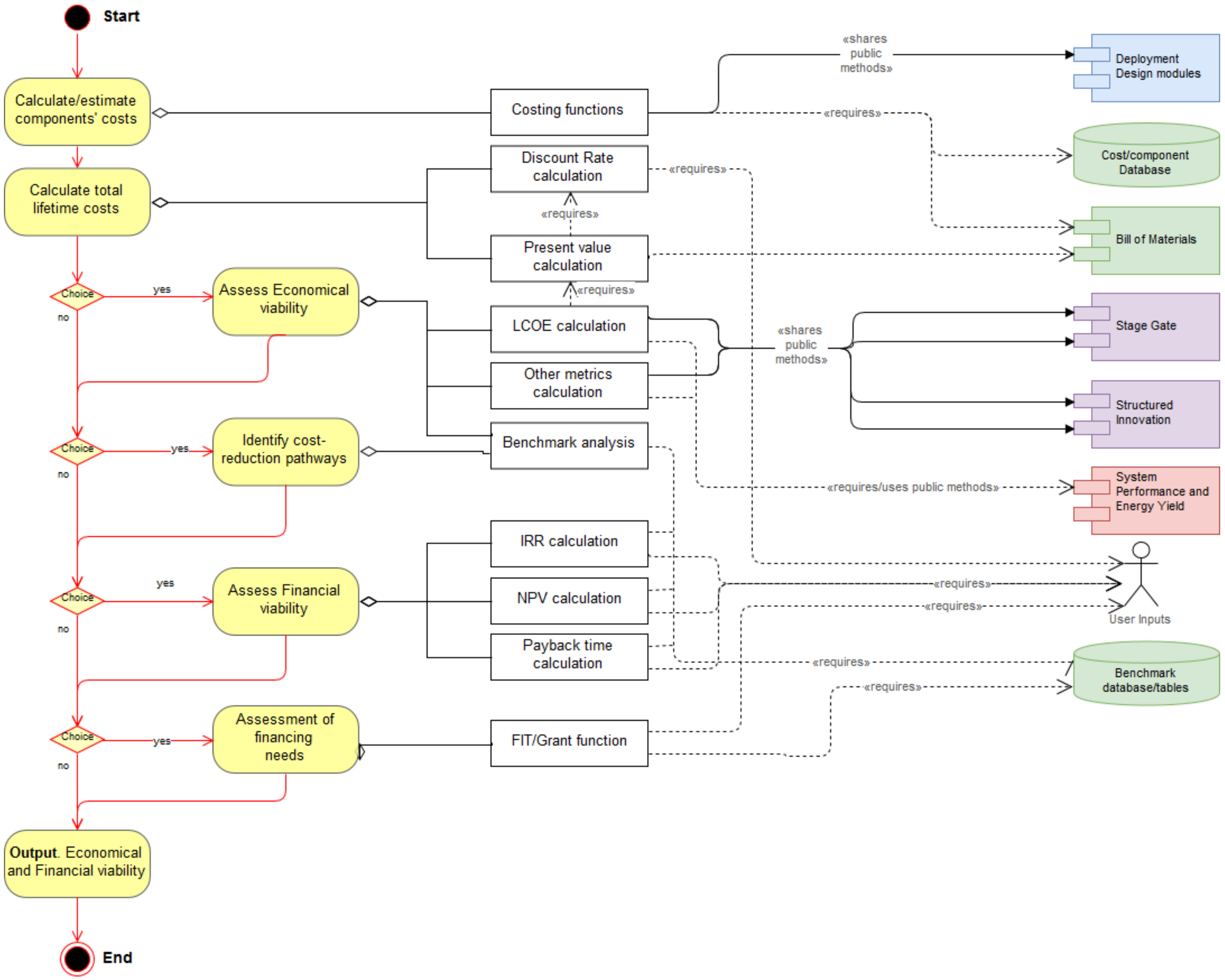


FIGURE 2.10. ARCHITECTURE OF THE SYSTEM LIFETIME COSTS TOOL

2.3.3 MAIN FUNCTIONS AND MODELS

The main functions of the System Lifetime Cost tools can be described as follows:

1. **Costing functions:** The costing functions take as inputs the bills of materials which covers all the components selected by the different Deployment design modules, and calculates the cost of the selected component, either through lookup on a cost database or by using functions to estimate the cost. These functions will be available to other DTOceanPlus modules as public methods.
2. **Discount rate/WACC function:** This function calculates the discount rate to be used in the analysis. The discount rate can be a user input, a reference value stored in a lookup table, or a calculation of the Weighted Average Cost of Capital (WACC) using the financing breakdown as input by the user.
3. **Present Value function:** The present value function returns the present value of future costs and amounts of energy produced. For calculating the total lifetime costs, the function takes as inputs the costs previously calculated by the costing functions, the previously determined discount rate and the year the costs are incurred. Similarly, to calculate the present value of the total energy production, the function considers the expected annual energy production throughout project lifetime.
4. **LCOE function:** Taking as inputs the estimated total energy production throughout the project lifetime, updated to the present day, as well as the present value of the total costs, the LCOE function calculates the Levelised Cost of Energy. This function will be available to other DTOceanPlus modules as public methods.
5. **Other metrics functions:** Using the cost figures for the device, early stage metrics such as indicative CAPEX per MW will be calculated. These functions will be available to other DTOceanPlus modules as public methods.
6. **IRR function:** This function uses as input the non-discounted costs and energy production, and user-inputs or values from a lookup table related with the electricity selling price (Feed in Tariff (FiT) or market value) in order to determine the discount rate that corresponds to a break-even point.
7. **NPV function:** Using the present-day costs and electricity production, and the user-input or values from a lookup table related with the electricity selling price (FiT or market value), the Net Present Value of the project is calculated.
8. **Payback time function:** Calculates the number of years it takes the project to pay back the investment.
9. **Financing requirements:** Using the target FiT/market price of electricity and the LCOE of the project in analysis, calculates different scenarios of Grants and Production revenue schemes which make the project profitable.

Figure 2.11 shows how the different functions can be used to respond to different use cases, and different user types.

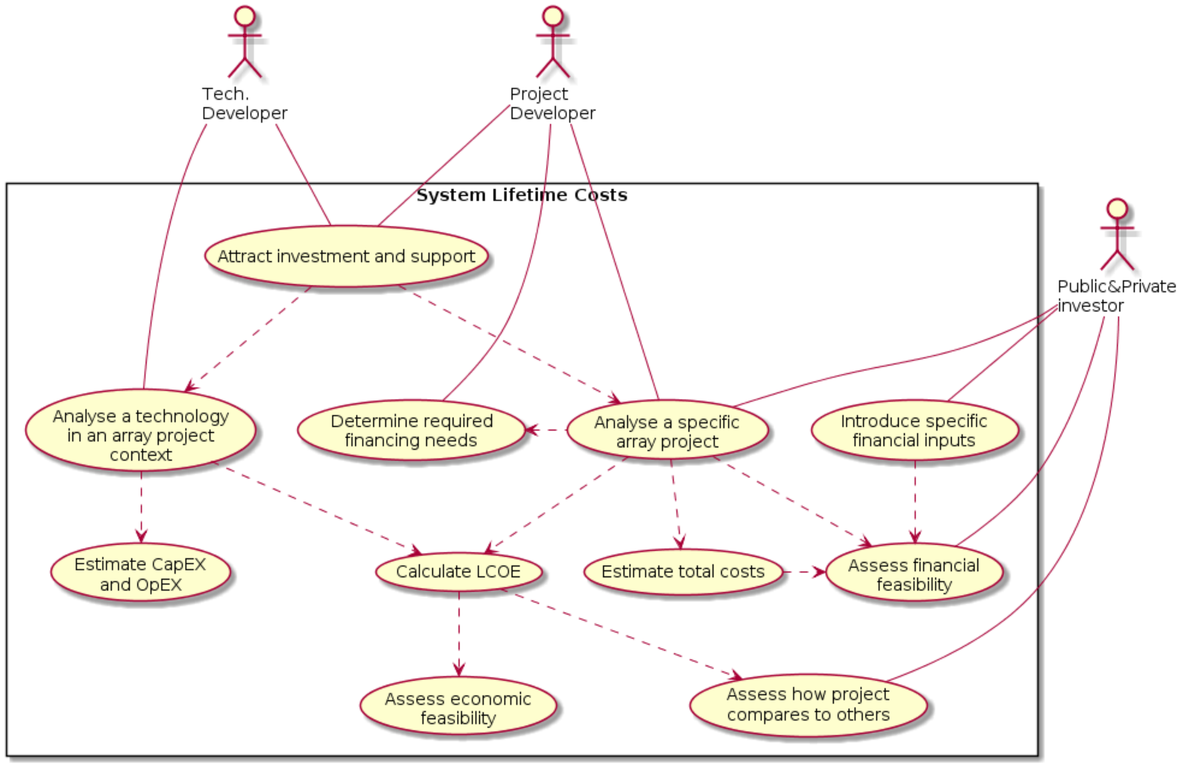


FIGURE 2.11 SLC GENERIC USE CASE DESCRIPTION

2.3.4 DATA REQUIREMENTS

The System Lifetime Cost tools derive their inputs from two different sources: i) user inputs and ii) outputs from other DTOceanPlus modules. The inputs can be categorized as:

- **Bill of materials**: System/device/project description in terms of a bill of materials must be specified to perform the costing analysis. Data will be supplied by several modules, namely the Energy Capture for the number of devices, Energy Transformation for the PTO components, Energy Delivery for the Electrical subsystems, Station Keeping for the moorings/foundations components. Other costs may be supplied by the user.
- **Energy production data**: Data on the energy production is required to estimate the LCOE and assess the economic viability.
- **Project developers' parameters**: Parameters such as the discount rate and project lifetime must be introduced by the user for project appraisal. The project lifetime will have been defined for the operations and maintenance analysis (Logistics and RAMS). For financial viability analysis, these will need to be provided by the user.

As outputs, the System Lifetime Cost tools will yield the Total Lifetime Costs, LCOE, IRR, NPV and Payback Time.

For components, costs should ideally be provided by suppliers and manufacturers, meaning that the cost data would need to be stored according to the following template, which would be connected with a component database with technical descriptions:

- Component ID
- Cost value:
- Cost currency
- Year of quote
- Reference

In the absence of quoted data, the costs of components can be estimated through functions based on experience, which would be related to design specifications, unit price of materials and the geometry of the design.

For the economic analysis, the data needed would include:

- Bill of materials, aggregating all the cost values and when these occur in the lifetime of the project
- Annual Energy Production, either an average number for year, or a specific value for each year and/or device
- Project lifetime
- Discount Rate

For the financial analysis, the following data is needed:

- Project lifetime
- Discount Rate or project financing breakdown
- Bill of materials/Total Lifetime Costs
- Annual Energy Production
- Electricity market price or Production Support Scheme value

For benchmarking analysis and financing needs, the following data would be needed

- Discount rate
- Bill of materials/Total Lifetime Costs
- Annual Energy Production
- Target value(s) to achieve (LCOE, component cost, contribution to CAPEX, etc.)

2.4 SYSTEM ENVIRONMENTAL AND SOCIAL ACCEPTANCE

The Environmental and Social Acceptance (ESA) module aims to assess the environmental and social impacts generated by the various technological choices and array configurations of wave or tidal devices. For each lifecycle operation of a given marine renewable energy project, the Environmental and Social Acceptance module will assess the potential environmental and social impacts of the project in terms of pressure existence (e.g. chemical pollution or collision risk with marine fauna), receptor sensitivity (e.g. functioning of local marine ecosystems) and social acceptance (e.g. carbon footprint of the project or economic benefits). At the end of the simulation, recommendations to reduce the potential environmental impacts and to increase social acceptance during the total lifecycle of a project are proposed to the user.

2.4.1 FROM FUNCTIONAL TO TECHNICAL REQUIREMENTS

Functional and technical requirements are listed in Table 2.9 below. The application of these technical requirements will allow DTOceanPlus tools to acquire an integrated approach of environmental and social impact assessment.

TABLE 2.9 FUNCTIONAL AND TECHNICAL REQUIREMENTS OF THE ESA MODULE

Functional Requirements
FR-ESA-1. Produce multiple Environmental Impact Assessment (EIA) metrics Provide recommendations to reduce the impact score. FR-ESA-2. Estimate global carbon footprint (CFP) and at different key stages of Ocean Energy development and provide recommendations on the design to reduce carbon footprint. FR-ESA-3. Estimate number of jobs and cost of consenting.
Technical Requirements
TR-ESA-1. Load deployment tools outputs (site characteristics, list of components, logistics, energy production). TR-ESA-2. Use default values if not provided by user or deployment tools. TR-ESA-3. Obtain seasonal data and list of red-listed species from database. TR-ESA-4. Calculate score for the identified pressures at different stage of marine renewable energy (MRE) development -4.a. Energy modification -4.b. Footprint -4.c. Collision risk -4.d. Chemical pollution -4.e. Turbidity -4.f. Noise -4.g. Electromagnetic fields -4.h. Temperature modification -4.i. Reserve effect -4.j. Reef effect -4.k. Resting place TR-ESA-5. Calculate the receptor sensitivity score. TR-ESA-6. Calculate adjusted pressure score (PSA). TR-ESA-7. Linear mapping of the PSA. TR-ESA-8. Calculate environmental impact score (EIS) and a level of confidence based on quantity of default data used for every design and at different stages of development. TR-ESA-9. Load tables to translate components (e.g. alloyed steel, aluminium) and logistical solutions (e.g. vessels power) into quantity of Carbon produced (e.g. kg CO_2) from database. TR-ESA-10. Calculate the carbon footprint (CFP) at different stage of MRE development and a level of confidence based on quantity of default data used. TR-ESA-11. Calculate the total CFP averaged by MW (e.g. kg CO_2/MW). TR-ESA-12. Estimate the number of jobs created (Njobs/MW) associated with a given MRE project. TR-ESA-13. Estimate the cost of consenting (€/MW) of the MRE. TR-ESA-14. Output summary table of EIA, CFP, number of jobs and cost of consenting global results, level of confidence and associated recommendations.

TR-ESA-15. Output detailed table of EIA, CFP, Nb of jobs and cost of consenting details results, level of confidence and recommendations for different stage of MRE development and for every design tool.
TR-ESA-16. Output histograms comparing EIA of the different development stages.
TR-ESA-17. Output histograms comparing CFP of the different development stages.
TR-ESA-18. Output histograms comparing global CFP of the project to CFP of other typical energies.
TR-ESA-19. Display results through the GUI.

Some of the technical requirements presented in Table 2.10 are associated with specific functional requirements. The table below presents associations between functional and technical requirements.

TABLE 2.10 FUNCTIONAL AND TECHNICAL REQUIREMENTS RELATIONSHIP MATRIX

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

2.4.2 ARCHITECTURE OF THE TOOL

The following UML diagrams offers an overview of the ESA flow of actions when running the module. Three diagrams are shown below, one for running an environmental impact assessment (Figure 2.12), a second for estimating the carbon footprint (in terms of CO_2 greenhouse gas emission) (Figure 2.13) and a third to evaluate social acceptance through two metrics: number of jobs and LCOE (Figure 2.14).

2.4.2.1 ENVIRONMENTAL IMPACT ASSESSMENT

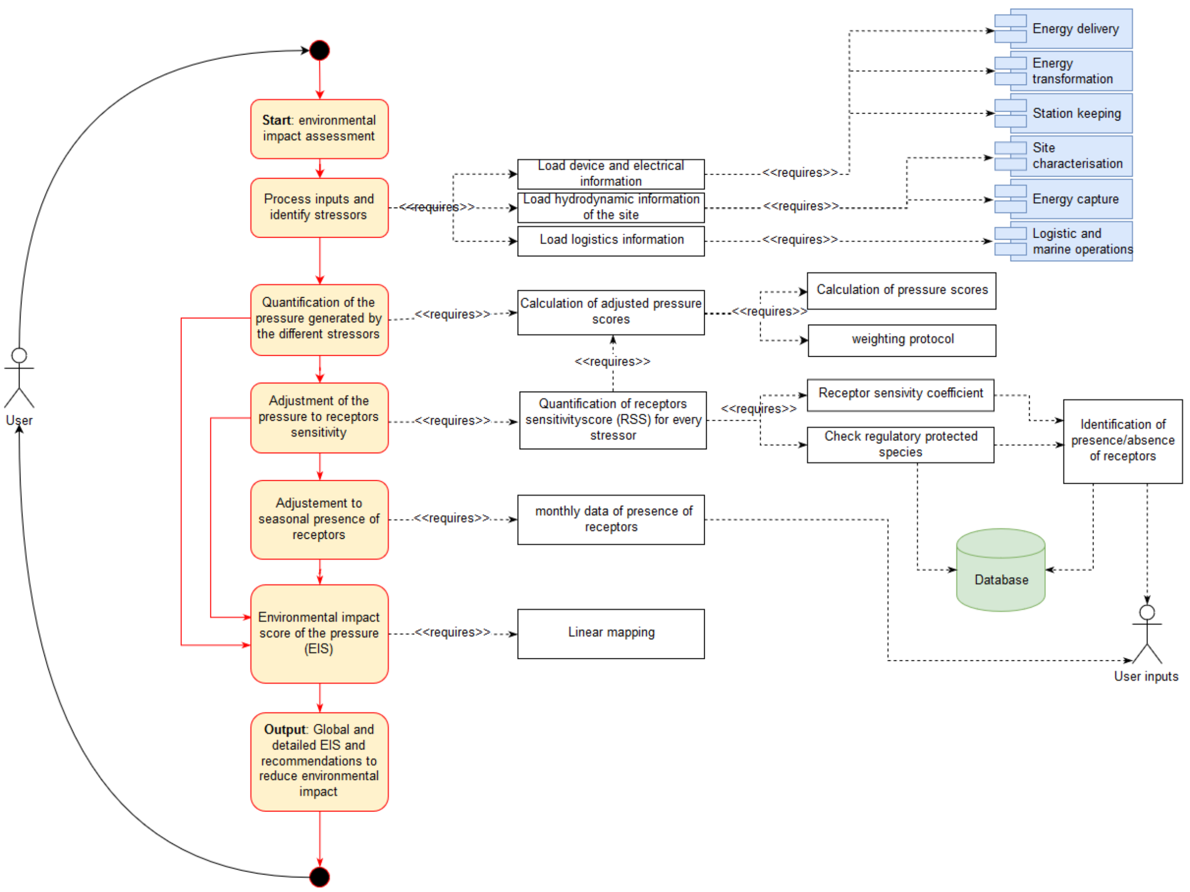


FIGURE 2.12 ARCHITECTURE AND MAIN FUNCTIONS OF ESA MODULE: DIAGRAM OF THE ENVIRONMENTAL IMPACT ASSESSMENT

The environmental impact assessment (EIA) will be performed by a collection of specific functions that evaluate the potential pressures generated by the device array on the maritime environment. These functions are, for instance, dedicated to footprint, noise or risk collision. Each environmental function links two entities:

- The 'stressors', i.e. the entities that generate a pressure or an environmental effect, stressor is any physical, chemical, or biological entity that can induce a response;
- The 'receptors', the entities that are potentially sensitive to stressors;

Stressors may adversely affect specific physical resources of marine ecosystems (the receptors) that interact directly with the biological components of these ecosystems, including plants and animals.

The UML diagram (Figure 2.12) details the main steps used in ESA to produce the global EIA. From information loaded from deployment tools, different stressors are identified. For each stressor, a function is used to quantify the pressure through a 3-step process considering:

(1) The **quantification of the pressure** is obtained from the environmental functions selected and the produced Pressure Score (PS) is then adjusted to a new numerical value

called the Pressure Score adjusted (PSa) through a 'weighting protocol' by multiplying the PS with a coefficient ranging from 0 and 1. This happens if local environmental factors exist, which are independent from the receptors, and are not included in the function's formula. If no weighting is selected, a default value of 1 used.

(2) The second step is triggered if the user is able to indicate the **existence of receptors** onsite. Step 2 uses the score initially generated in step 1 and then adjusts it depending on the receptor's sensitivity by multiplying the PSa with the Receptor Sensitivity coefficient (RS), which ranges from 0 to 5, unless the user has no receptor data, in which case the RS is assumed to be at its maximum value 5. This process leads to the Receptor Sensitivity Score (RSS). The different receptors are gathered within main classes reflecting their sensitivity to pressure. The user will have to choose between these different main classes of receptors that will be characterised by having RS values ranging from 0 to 5 for low to high sensitivity, respectively. When several receptors are identified onsite, the most sensitive receptors will be considered for the EIS calculations. To ultimately obtain the EIS, a linear mapping is applied, and specific calibration tables are used to convert RSS to EIS. In the case where the user declares a receptor that is regulatory protected (list provided by the database), by default this will automatically lead to an EIS of -100. If the user is able to provide details about the existence of receptors, the level of confidence increases to medium, corresponding to the value 2.

(3) The last step is triggered if the user has **monthly data for the existence of receptors** onsite. Step 3 is similar to step 2 for each specific receptor declared onsite and the EIS is equal to 0 for any receptors absent in a particular month. For each month, the EIS is given by the most sensitive species present. If the user has such monthly data, the level of confidence is at its highest value of 3.

When all function scores are estimated, a global (agglomerated) environmental impact score (EIS) is calculated. Negative and positive scores do not compensate each other, the tool provides a mean score of the positive impacts (from 0 to +50) and a mean score for the negative impacts (from –100 to 0) along with confidence level. The EIA score is given with a recommendation text to reduce the environmental impact. Full details at the function level can also be provided and contain the associated level of confidence for each function.

2.4.2.2 CARBON FOOTPRINT (CFP IN KG CO_2/MW) OF THE OCEAN ENERGY PROJECT

CFP is calculated in terms of CO_2 greenhouse gas emission per MW produced (kg CO_2/MW). It is estimated based on the components and materials weight (e.g. weight of alloyed steel) used for the MRE array and also on the logistic information mobilized from production of materials up to their installation and maintenance (typically, the number of vessels, their power and the duration of intervention). Several functions are then used to translate this information into equivalent of CO_2 greenhouse gas emission per MW produced using database information related to conversion. CFP result will be a CFP score along with a recommendation text to limit CO_2 emissions per phase of the project (i.e. production, installation, exploitation, disassembling, and treatment). The CFP of the MRE project will also be compared to other energy types.

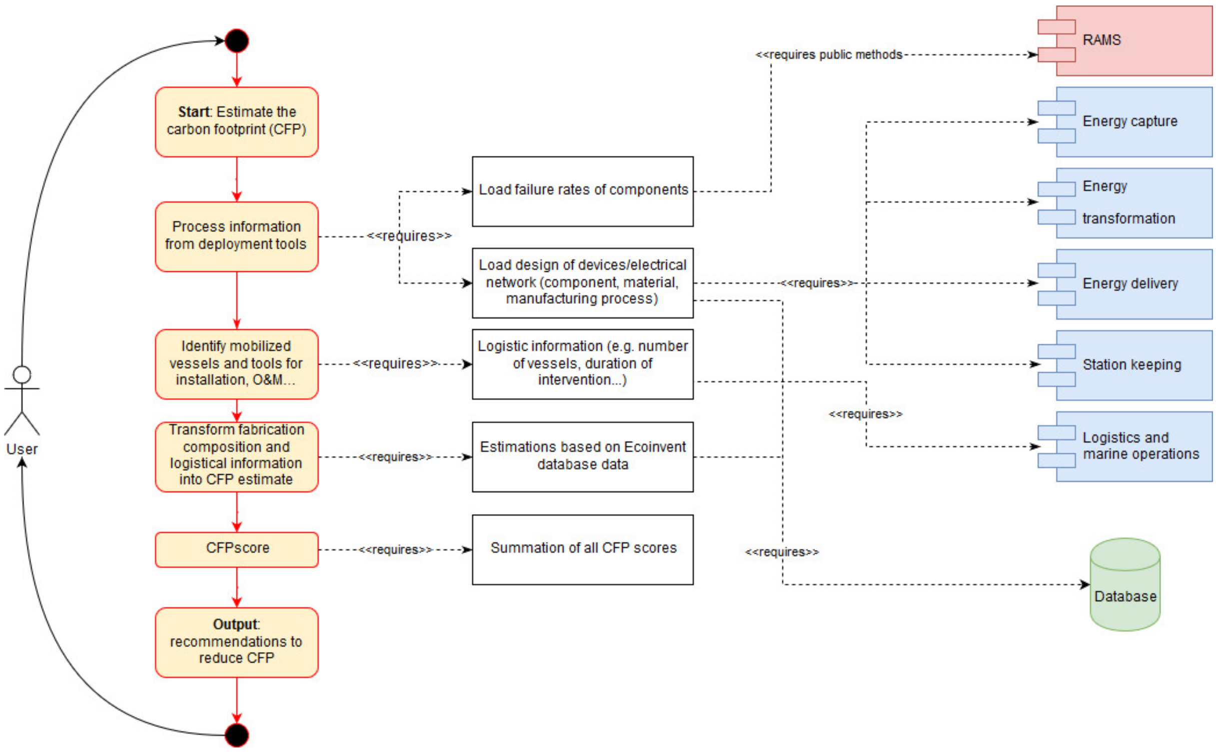


FIGURE 2.13 ARCHITECTURE AND MAIN FUNCTIONS OF ESA: DIAGRAM OF THE CARBON FOOTPRINT

2.4.2.3 SOCIO ECONOMIC ACCEPTANCE (SEA)

The social-economical acceptance part of the ESA module evaluate and propose recommendations to increase social acceptance through the number of created jobs (Njobs/MW) during MRE life cycle and the cost of consenting (euros/MW) of the MRE. Figure 2.14 shows the UML diagrams detailing the main steps used in ESA to produce Socio-Economic Acceptance recommendations (SEA).

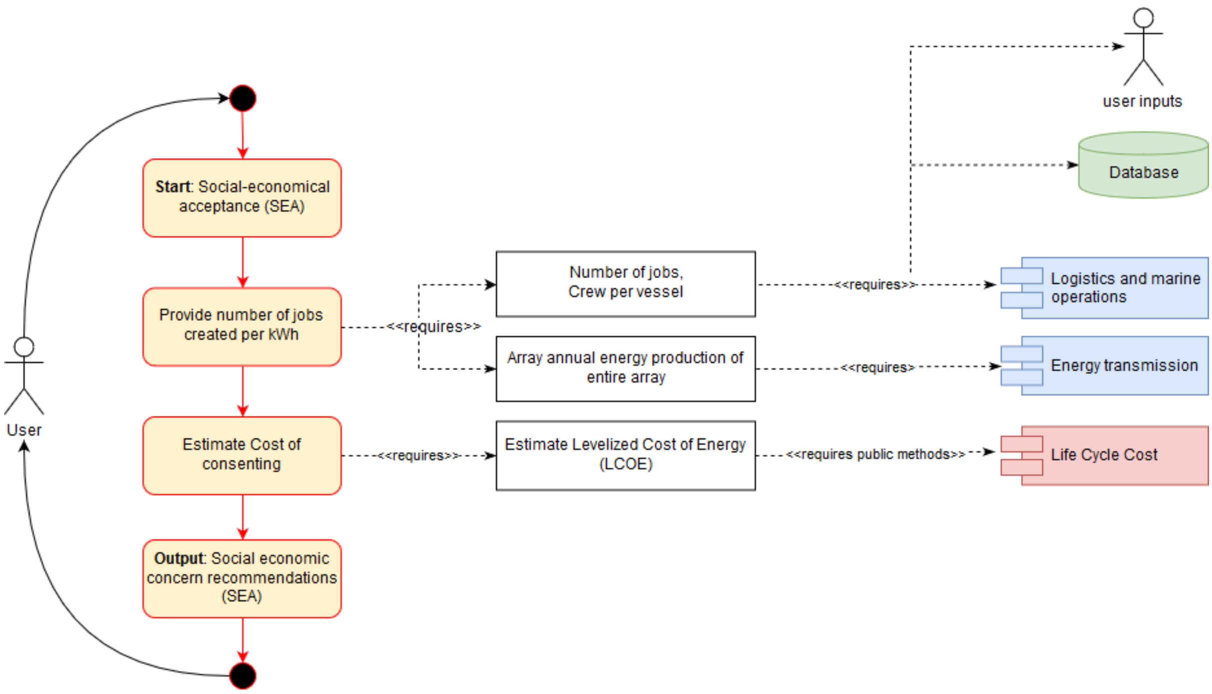


FIGURE 2.14 ARCHITECTURE AND MAIN FUNCTIONS OF ESA: DIAGRAM OF THE SOCIO ECONOMIC ACCEPTANCE

2.4.3 MAIN FUNCTIONS AND MODELS

Environmental and social acceptance module can be used by different users from technology developers to public and private investors, the three main functionalities of the tool are:

1) To assess and reduce environmental impacts of the project
2) To assess the carbon footprint of the project and compare it to other energy mix
3) To assess and provide recommendations to increase social acceptance of the project

Technology developers and **project developers** can assess and reduce environmental impact of developed technologies using the **Environmental Impacts Assessment** mode that includes different functions considering different stress induced by the design on the potential receptors identified. This mode can also be used to produce an initial environmental status prior to the project.

The CFP mode assesses **the Carbon Foot Print** of the design. This metric can be used by **project developers** to assess carbon production induced and compare the technology with other energy mix. CFP is useful for **public communication**, it is a well-known metric and can be used to enhance social acceptance as well. Along with the global score, user can access different levels of information to identify CFP at the different MRE development phase.

The **Social Economic acceptance** mode is used to increase social acceptance. Two functions help assess social acceptance: the number of jobs needed to support the project and the estimation of Levelised Cost of Energy (LCOE). **Project developers or public/private investors** can evaluate social economic impacts on local communities and communicate on this metrics to increase social acceptance.

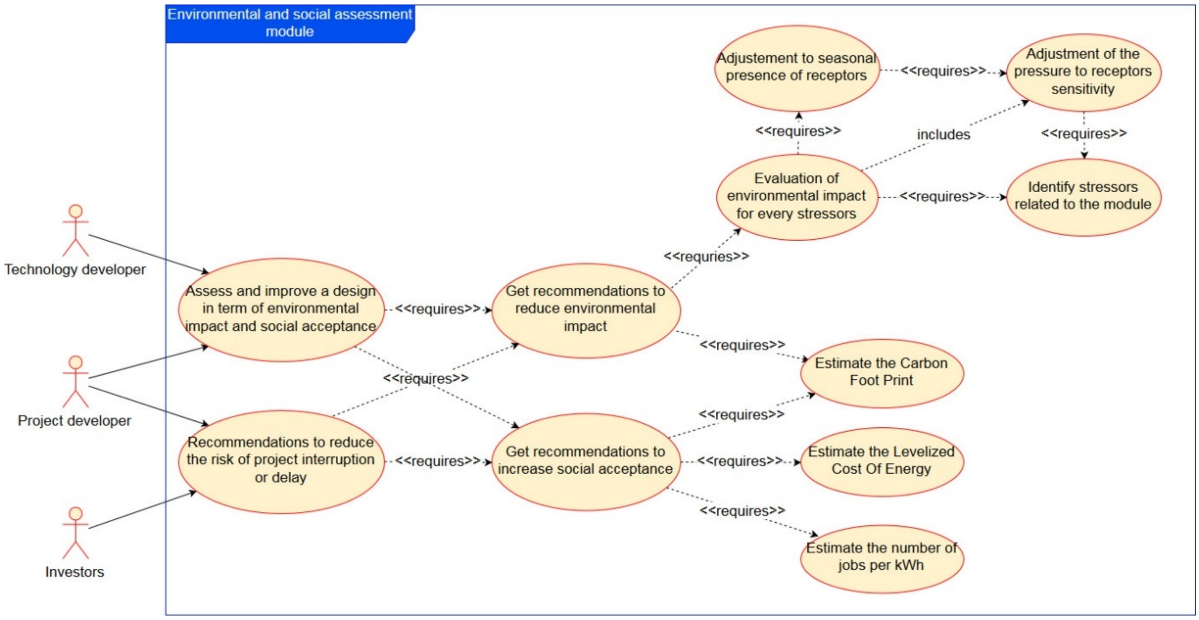


FIGURE 2.15 USE-CASE DIAGRAM OF ESA

2.4.4 DATA REQUIREMENTS

The main inputs and outputs have been identified in Task 7.1 for environmental and social acceptance module (ESA). The following UML diagrams offers an overview of the ESA data requirements to run the module. Two diagrams are shown below, one for the data requirements for environmental impact assessment (Figure 2.16) and the other is for data requirements of the carbon footprint estimation (Figure 2.17).

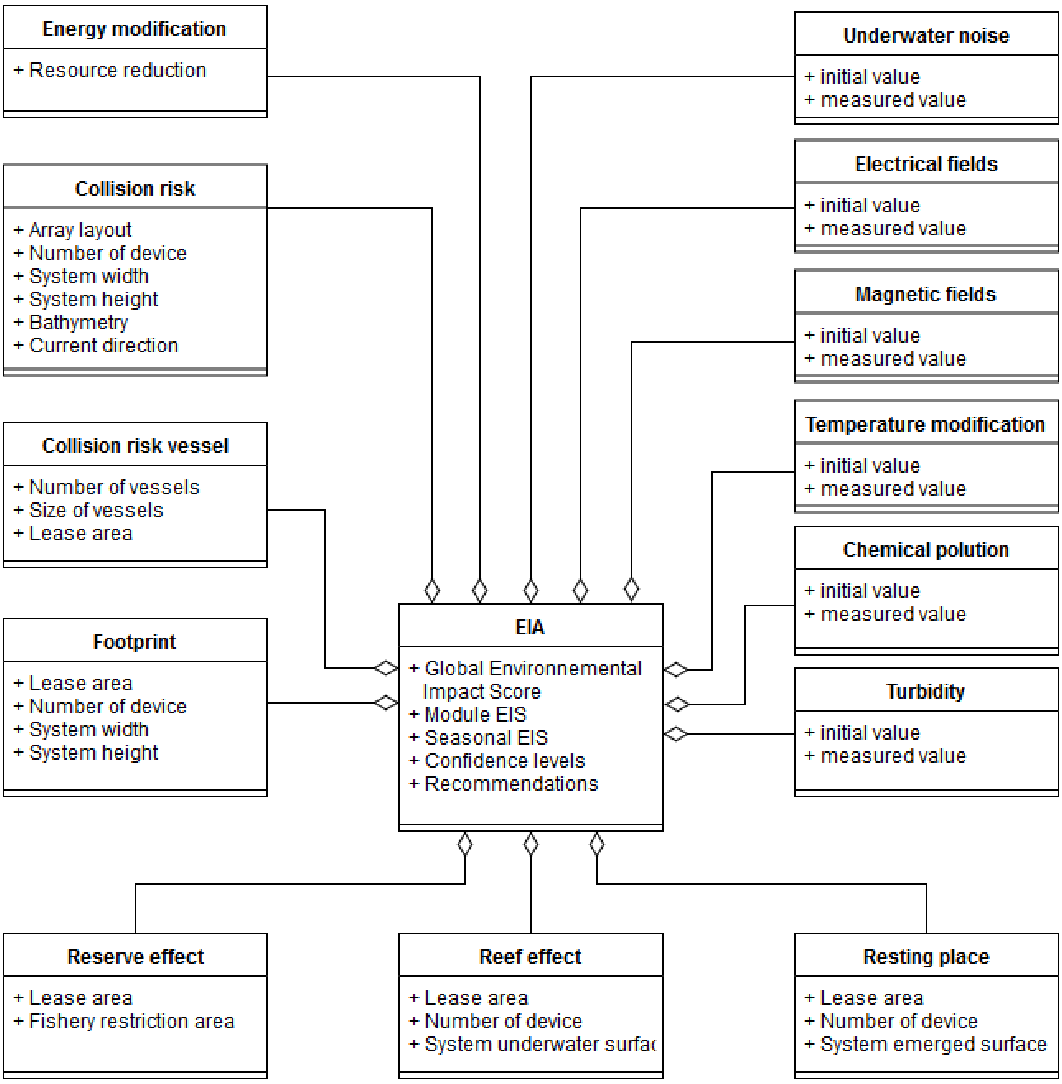


FIGURE 2.16 ESA MODULE: MAIN FUNCTIONS OF THE ENVIRONMENTAL IMPACT ASSESSMENT (EIA) INCLUDING DATA REQUIREMENTS AND OUTPUTS OF THE EIA.

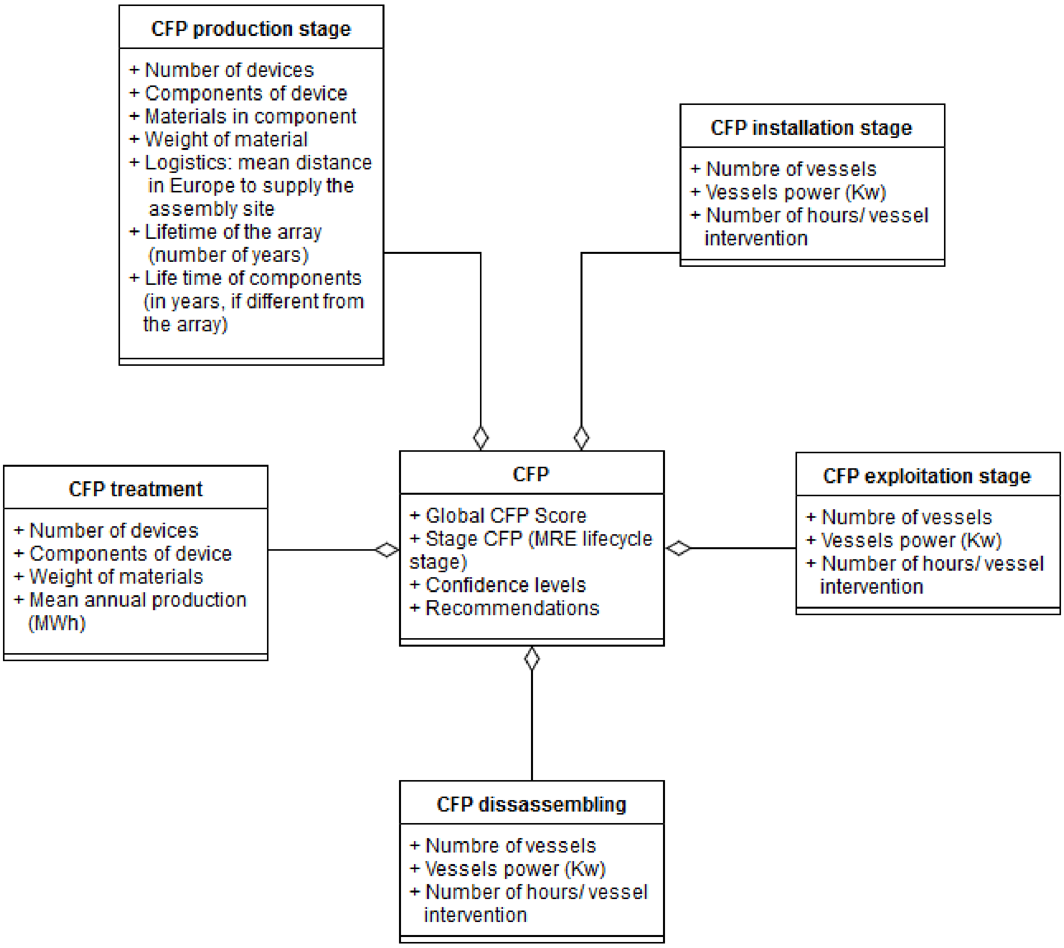


FIGURE 2.17 ESA MODULE: MAIN FUNCTIONS OF THE CARBON FOOTPRINT (CFP) INCLUDING DATA REQUIREMENTS AND OUTPUTS OF THE CFP.

2.5 INTERFACES, COMPATIBILITY AND PORTABILITY

The Digital Representation will represent the instrument to interface the Assessment 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.

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.

2.6 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, however their functionalities could be eventually improved or extended 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 these 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 DTOCEANPLUS TOOLSET

3.1 INTEGRATION WITH THE UNDERLYING PLATFORM AND THE DIGITAL REPRESENTATION

In this section, the issue of integrating the Assessment design tools 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 Assessment design tool, a diagram has been produced to show the interconnections with the other components of the toolset;
- A brief description of the database will serve to explain the interaction of the Assessment design tools with the global storage;
- The interaction of each Assessment design tools with the Deployment design tools;
- The interaction of each Assessment design tool with the other Assessment design tools, as well as with the Structured Innovation design tool and the Stage Gate design tool;
- The interaction with the User, through the User Interface.

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 in a standalone mode, without the main UI.

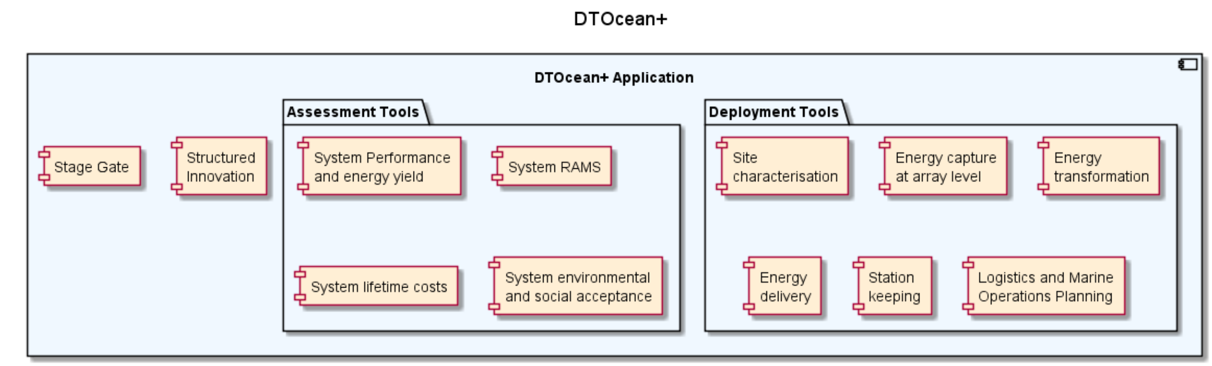


FIGURE 3.1. DTOCEANPLUS ARCHITECTURE

The main characteristics of the underlying platform and the Digital Representation are described in D5.1 (Technical Requirements for the Deployment Design Tools) Section 3.1.1, which also applies to the Assessment design tools.

3.1.2 SYSTEM PERFORMANCE AND ENERGY YIELD

The functionality of the tool evaluates the efficiencies of different energy transformation steps. Moreover, it will give indications of power quality and annual energy production considering availability at device and array level.

The following figure represents the flow of data and the integration of the system performance and energy yield with all the others entities of the DTOceanPlus software:

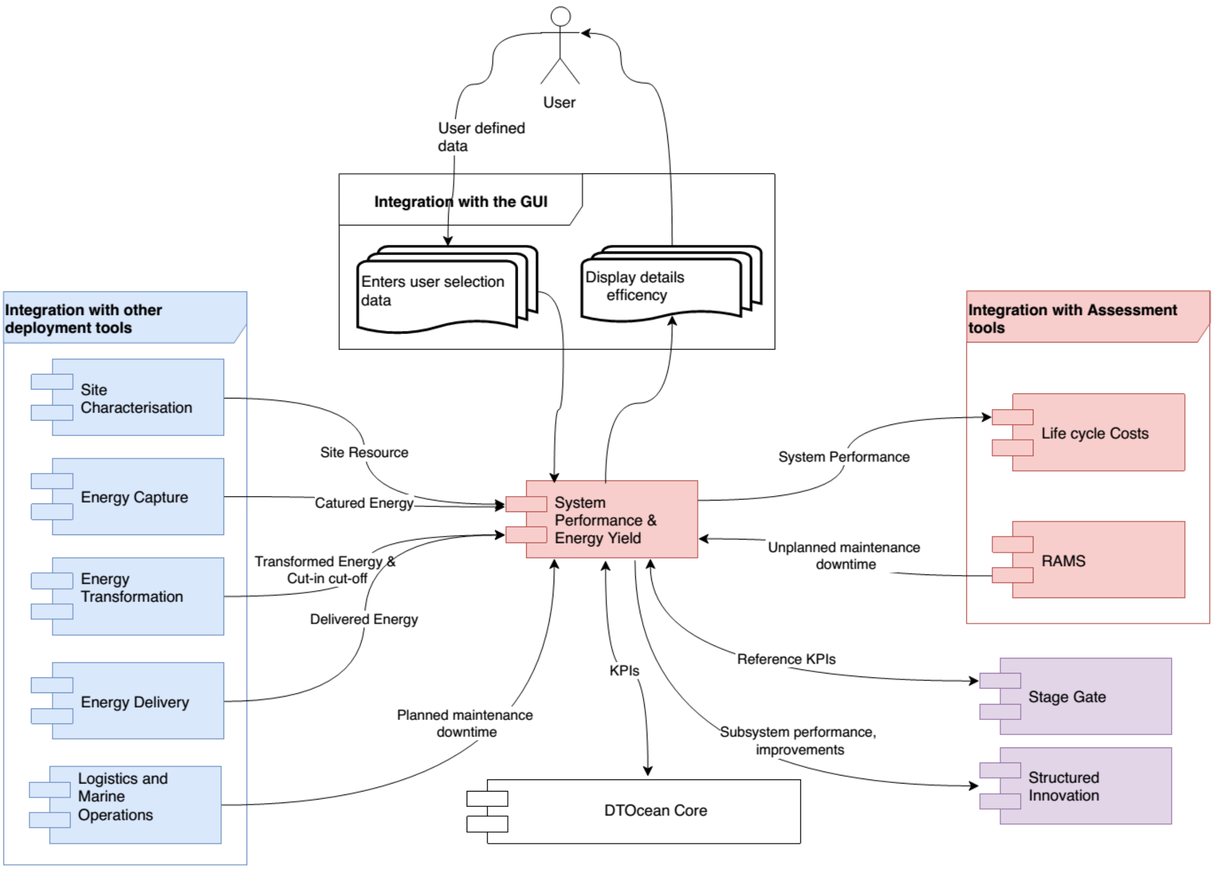


FIGURE 3.2. GLOBAL INTEGRATION OF THE SYSTEM PERFORMANCE AND ENERGY YIELD MODULE WITH THE OTHER TOOLS.

3.1.3 SYSTEM RELIABILITY, AVAILABILITY, MAINTENAIBILITY AND SURVIVABILITY

The RAMS module requires the inputs from four deployment tools, namely Energy Transformation, Energy Delivery, Station Keeping, and Logistics & Marine Operation. The Structured Innovation tool provides the RAMS module with the failure modes. Besides these deployment and stage gate tools, the users should also input some parameters to the RAMS module. The outputs of the RAMS tool can be transferred to Lifetime Cycles Costs, Logistics & Marine Operations, System Performance & Energy Yield, Environmental & Social Acceptance, and the Stage Gate tool.

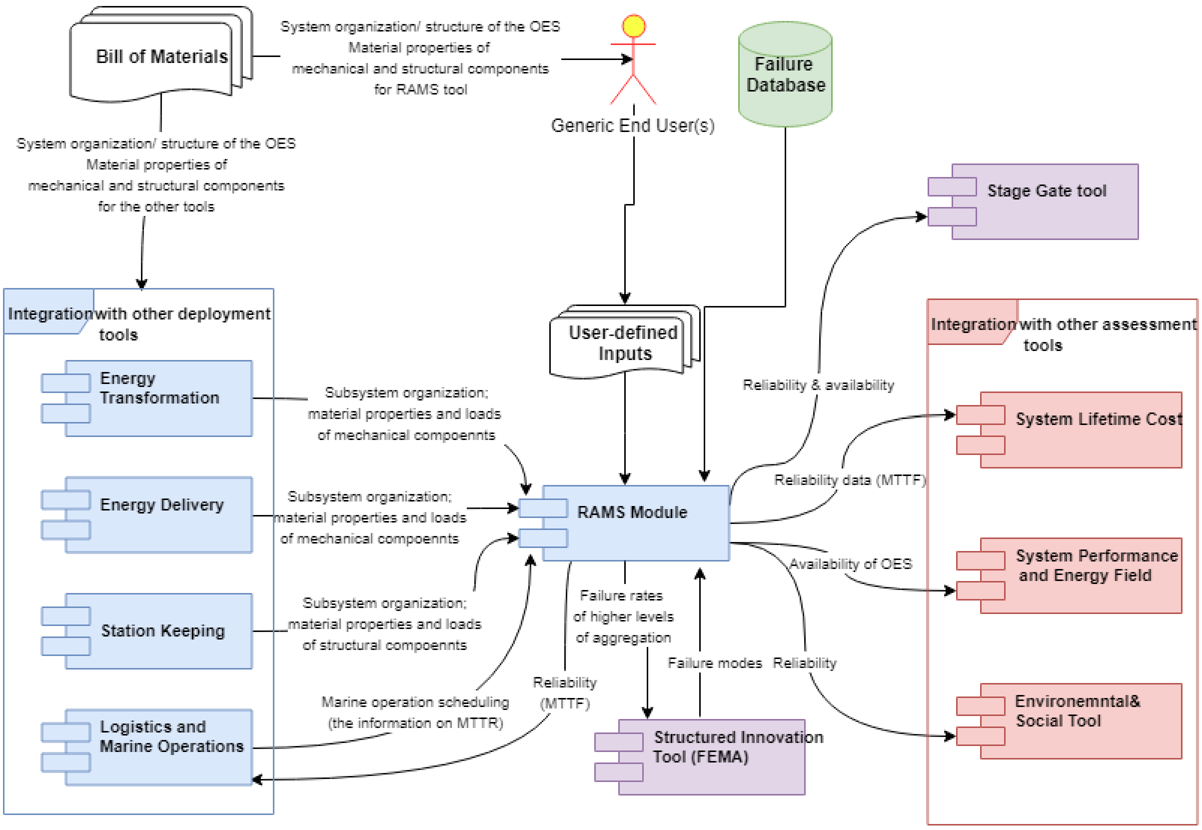


FIGURE 3.3 . GLOBAL INTEGRATION OF THE SYSTEM RELIABILITY, AVAILABILITY, MAINTENAIBILITY, SURVIVABILITY MODULE WITH THE OTHER TOOLS.

3.1.4 SYSTEM LIFETIME COSTS

The links between the different tools within DTOceanPlus is shown in Figure 3.4 below.

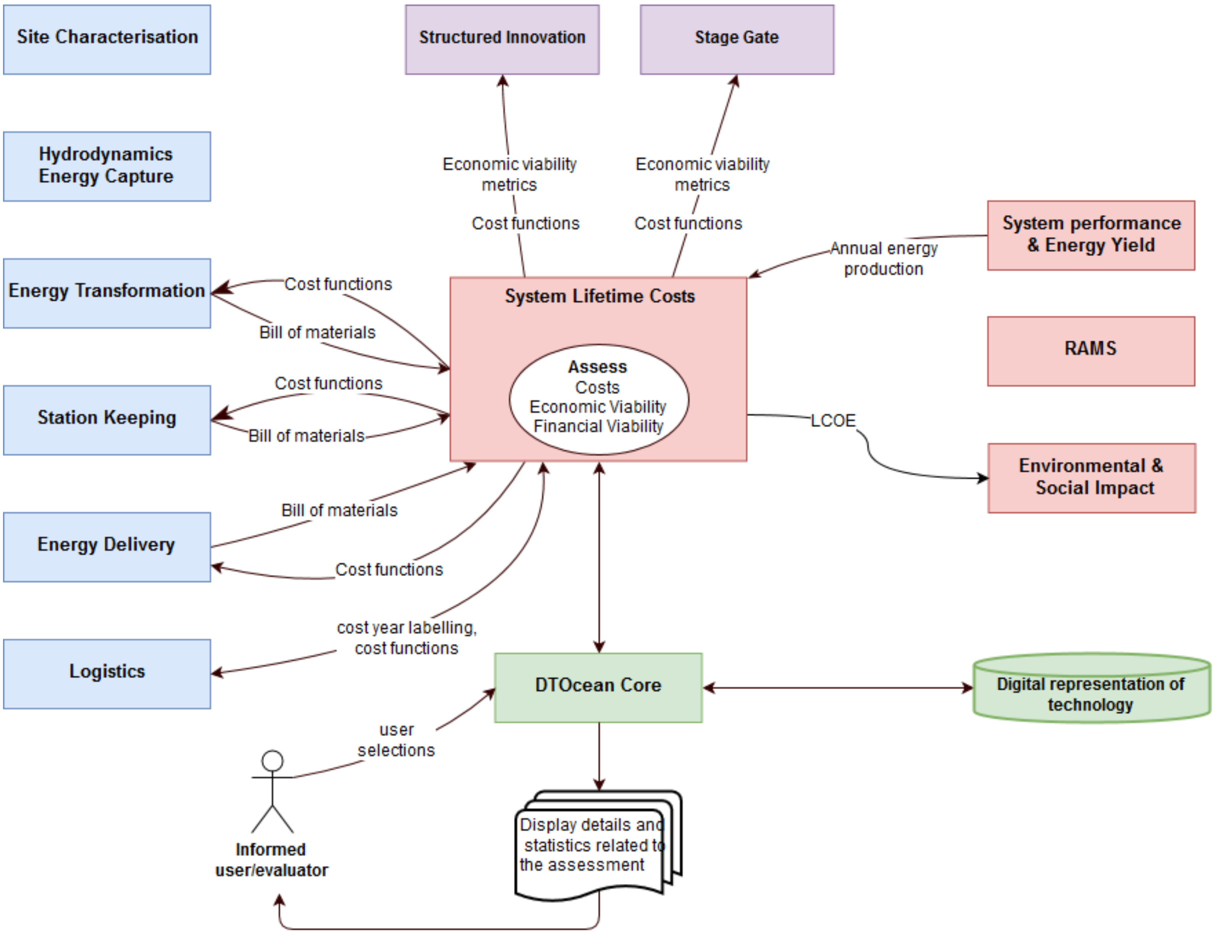


FIGURE 3.4. GLOBAL INTEGRATION OF THE SYSTEM LIFETIME COSTS MODULE WITH THE OTHER TOOLS.

Most design tools will interact with the system lifetime costs module, by using costing functions (available through public methods) to evaluate possible design choices. These design choices will be fed into the System Lifetime Costs module through a bill of materials[4] which will be used to aggregate all the costs incurred in the design under evaluation.

The functions responsible for calculating different economic metrics will also be available as public methods in order to be used by Structured Innovation and Stage Gate tools.

For the calculation of economic and financial viability metrics the annual energy production is required, which can be retrieved from the System Performance & Energy Yield tool.

[4] Possibly through the digital representation.

3.1.5 SYSTEM ENVIRONMENTAL AND SOCIAL ACCEPTANCE

Figure 3.5 represents the flow of data and the integration of the Environmental and Social Acceptance module with all the other entities of the DTOceanPlus software.

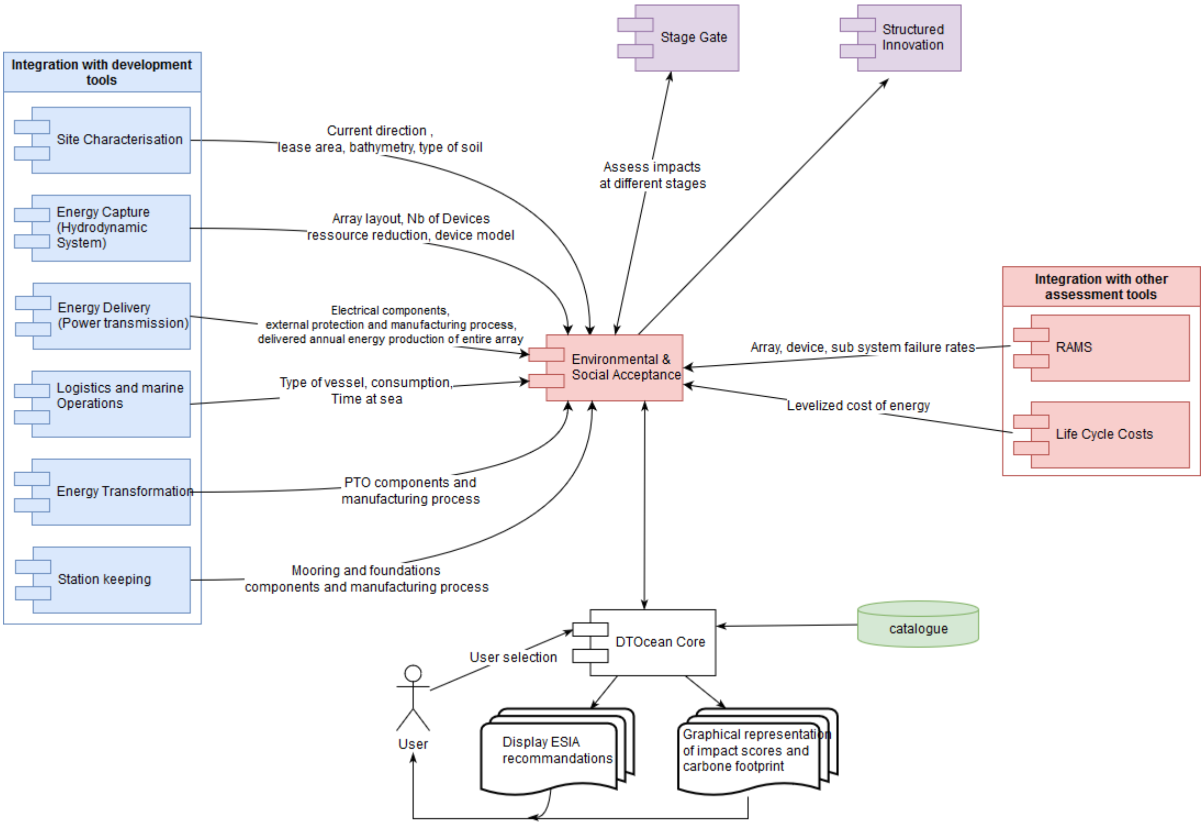


FIGURE 3.5. GLOBAL INTEGRATION OF THE SYSTEM ENVIRONMENTAL AND SOCIAL ACCEPTANCE MODULE WITH THE OTHER TOOLS.

To assess environmental impacts and social acceptance, the module will require inputs on the design from the different Deployment tools.

The user will have to make choices from the catalogue and enter other input data through the GUI.

Some public methods will be needed from other Assessment design tools to evaluate LCOE and failure rates.

The module linked to the Stage Gate design tool will be able to assess environmental and social impact at different level of precision depending on early/mid/late stage of design.

Outputs will be displayed through the GUI in different representations: graphical and text recommendations.

3.2 INTEGRATION WITH THE DATABASE

The main characteristics of the Database are described in D5.1 (Technical Requirements for the Deployment design Tools) Section 3.2. In this section, more information on how each assessment tools will interact with the database is provided. The Assessment design tools will not interact directly with the database, but they'll do it through the main platform (see Section 3.1); indeed, the access to the catalogue of components is required in order to access to information needed for the specific assessment of each tool. For example, a generic failure database can provide the RAMS module/tool with the information on the failure rates of basic units, etc…

3.3 INTEGRATION WITH THE DEPLOYMENT TOOLS

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

3.3.1 SYSTEM PERFORMANCE AND ENERGY YIELD

The System Performance and Energy Yield tool will interact with most of the Deployment tools:

- Energy Capture: SPEY assessment requires from EC design module to provide with energy captured from the resource (wave/tidal stream). It is required to provide the mean annual energy captured (AEC) at both device and array levels.
- Energy Transformation: In order to be able to assess the performance of the overall PTO of the installed devices, ET is required to provide the mean annual energy transformed (AET) at device and array level. For metrics computation the rated power of each subsystem is also required as well as the cut-in and cut-off and active and reactive power.
- Energy Delivery: The performance of umbilical cables as well as the array grid and power transmission to the electrical distribution grid (EDG) is represented by the ED module. The mean annual energy production of the array will be considered as that delivered to the EDG. Therefore, the integration with ED module consists in gathering the energy delivered to shore.
- Logistics and Marine Operations: The integration of SPEY concerns the planned maintenance scheduled in the LMO design module. It is supposed to impact the energy generation capacity since while maintenance operations are being carried out the device will not be operational.

3.3.2 SYSTEM RELIABILITY, AVAILABILITY, MAINTENAIBILITY AND SURVIVABILITY (RAMS)

The RAMS module will interact with multiple deployment tools such as the Energy Delivery, Energy Transformation, Station Keeping and Logistics & Marine Operations. Public functions developed for estimating the reliability will be shared with these deployment tools.

- **Energy Transformation, Energy Delivery, Station Keeping**: The input data include the Bill of Materials (BoM), the failure modes, the failure rates and the load/stress time series of structural components used to assess/evaluate the structural reliability. The RAMS module will import the

BoM from Energy Transformation/Energy Delivery/Station Keeping to develop a reliability diagram that demonstrates the working philosophy of the different subsystem (or called system which depends upon the hierarchy structure). The BoM should be able to provide some information on the structure/organization of each subsystem. The Structured Innovation Design Tool is assumed to provide the failure modes of the subsystems. The failure rates of basic components can be obtained from a generic failure database or be determined based upon engineering experience. With the failure rates found in a generic failure database, the failure rate of the subsystems can be calculated based upon the classical reliability theory. If the required input is unavailable, the reliability of the subsystem cannot be assessed/evaluated.

- **Logistics and Marine Operations**: The Probability of Failure (PoF) (as a function of time) or mean time to failure (MTTF) exported by the RAMS module can be an important criterion for inspection and maintenance planning. The time the calculated PoF crosses over the pre-defined target failure probability basically defines the inspection and/or maintenance time. The Logistics & Marine Operation Planning module will use the public functions developed in the RAMS module to estimate the MTTF and do the maintenance planning together with the other information on the waiting time, maintenance strategies, etc.

3.3.3 SYSTEM LIFETIME COSTS

The System Lifetime Costs tool interacts with most of the deployments tools.

Most deployment tools will be using (or have the option of using) economic values as the decision factor. For this, the tools will need to assess the economic impact of the different components/subsystems/processes being selected. This selection in likely to be in the basis of lowest capital costs. In order for the tools to make this selection, they will need access to the costing functions of the components or to the database of costs. The costing functions will be available through public methods for use of the different tools.

Furthermore, in order to calculate the total system lifetime costs, the System Lifetime Costs tool will need an inventory of all components present on the project. This will need to be shared with the tool as a Bill of Materials.

3.3.4 SYSTEM ENVIRONMENTAL AND SOCIAL ACCEPTANCE

The System Environmental and Social Acceptance tool will interact with most of the Deployment tools:

- **Site Characterisation**: The inputs taken from Site Characterisation to assess environmental impacts includes 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.
- **Energy Capture**: The inputs taken from Energy Capture are pertinent to the array topology (layout of devices), the number, the dimensions of the devices, and a measure of the resource reduction.

- **Energy Transformation**: The inputs taken from Energy Transformation will be pertinent to the main physical and mechanical characteristics of the PTO system (dimensions, weights) and so on.
- **Energy Delivery**: The inputs taken from Energy Delivery will be pertinent to the main physical and mechanical characteristics of the energy delivery system (dimensions, weights), of the electrical components and subsystems, as well as the delivered annual energy production.
- **Station Keeping**: The inputs taken from Station Keeping will be pertinent to the main physical and mechanical characteristics of the foundation and mooring components, as well as their layout and footprint.
- **Logistics and Marine Operations**: The inputs taken from Logistics and Marine Operation will be all the characteristics of the operations: equipment and logistics (number of vessels, travel distance, fuel consumption, and duration of operations) as well as the characteristics of the operations.

3.4 INTEGRATION WITH THE OTHER ASSESSMENT TOOLS

In this section, the interaction of each tool with the other Assessment design tools is described. In general, the connection between two different Assessment tools will be done through sharing public methods, allowing to run each tool independently.

3.4.1 SYSTEM PERFORMANCE AND ENERGY YIELD

The SPEY tool will interact essentially with System RAMS and Lifetime Costs.

Since RAMS is in charge of assessing the failure of array-device-system-subsystem probability, there will be a downtime related with the unplanned maintenance strategies. This downtime is to be accounted for when defining the overall availability of the devices and the total net power production. In a similar fashion, the System Lifetime Costs will require a measure of the Annual Energy Production (AEP) in order to assess the LCOE of the project.

3.4.2 SYSTEM RELIABILITY, AVAILABILITY, MAINTENAIBILITY AND SURVIVABILITY (RAMS)

The RAMS module can have interfaces with such assessment tools as System Performance and Energy Yield, System Lifetime Costs and Environmental and Social Acceptance.

The failure rates/PoF/MTTF of various subsystems or devices can be imported to the aforementioned assessment tools. These assessment tools can access the public functions to obtain the failure rates/PoF/MTTF.

Besides the failure rates/PoF/MTTF, the public functions are developed to estimate the availability of the array and individual devices which may be required by the System Lifetime Costs.

3.4.3 SYSTEM LIFETIME COSTS

For the calculation of the Levelised Cost of Energy (LCOE) the amount of electricity produced each year (or an annual average) must be provided. For lower complexity metrics, an efficiency metric, such as capture width, would suffice. These values are computed within the system performance and energy yield tools, and should be available to the system lifetime costs tool as a public method.

The Environmental and Social acceptance tool requires the LCOE metric. The function and value will be available through public methods.

3.4.4 SYSTEM ENVIRONMENTAL AND SOCIAL ACCEPTANCE

The tool of Environmental and Social Acceptance Assessment will require public methods to estimate the failure rates of component/device/array, shared by RAMS, as well as public methods to estimate the LCOE will be shared by Lifetime Assessment module.

3.5 INTEGRATION WITH THE STRUCTURED INNOVATION DESIGN TOOLS

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 design tools. The output data from each assessment tool will vary in complexity and level of detail at the various stages of the project development (i.e. early, mid, and late stage).

A high-level summary of the requirements for the 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 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.

Further details about the interaction of each assessment tool within a Structured Innovation can be found in D3.1 Technical Requirements for the implementation of Structured Innovation in Ocean Energy systems.

3.5.1 SYSTEM PERFORMANCE AND ENERGY YIELD

At the earliest stage of development, the System Performance and Energy Yield (SPEY) will provide estimates of average energy production based on high level assessments. The SPEY tool will provide to the Structured Innovation tool, basic energy yield information on the efficiency of all the subsystems, and estimation of mean power production per device or array. Outputs from the SPEY assessment tool will be used by the Structured Innovation design tool to inform potential improvements within all the subsystems in terms of energy yield, efficiency, power quality and availability of the system.

3.5.2 SYSTEM RELIABILITY, AVAILABILITY, MAINTENAIBILITY AND SURVIVABILITY (RAMS)

From its FMEA module, the Structured Innovation design tool will provide the RAMS module with failure modes data of the required subsystems and functions (e.g. well-defined hierarchy structures for the RAMS to easily develop the reliability models). Along with inputs from the other tools, the RAMS module will generate the failure rates of subassembly and higher levels of aggregation needed for the assessment of the proposed concepts within the Structured Innovation tool. The RAMS module will use the failure rates of components from its generic failure database. The failure rate of the different levels of aggregation (subsystems, device or array) can also be calculated based upon the classical reliability theory.

3.5.3 LIFECYCLE COSTS

The Structured Innovation design tool will interact with the system Lifetime Cost tool by using costing functions (available through public methods) to evaluate possible design choices. These design choices will be fed into the system lifetime costs through a bill of materials which will be used to aggregate all the costs incurred in the design under evaluation. The functions to calculate different economic metrics will also be available as public methods for use by the Structured Innovation tool.

For the calculation of economic and financial viability metrics, the relevant design parameters will be retrieved from the deployment tools (e.g. the annual energy production from the SPEY tool) to generate costs information such as cost proxies at the earliest stages of assessment that provide qualitative cost rankings, allowing the selection of the less costly solutions.

3.5.4 ENVIRONMENTAL AND SOCIAL ACCEPTANCE

The Environmental and Social Acceptance tool will interact with the Structured Innovation tool by passing the outputs of the environmental impact assessment (EIA), the estimation of the carbon footprint (CFP) in terms of CO_2 greenhouse gas emission and the estimation of social acceptance (ESA) index such as number of jobs and LCOE.

Depending on the level of complexity of the assessment, the assessments within the Environmental and Social Acceptance tool could be simplified to produce basic estimates or thresholds of the carbon footprints. Some of these parameters could be the carbon dioxide emissions (kg/MW), effect on marine life (collision risk and electric fields) and underwater noise (increase in dB level) for environmental tools, and number of jobs created (jobs/MW) and cost of energy for social tools.

3.6 INTEGRATION WITH THE STAGE GATE DESIGN TOOLS

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 subsystems, 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 design tools are used to provide design information based on the technology, aggregation level and context choices made by the user
- The Assessment design tools take all of this information and calculate key metrics which are fed back in to the stage gate design tool
- The Structured Innovation design 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, aspects of which 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 interacts with the Assessment design tools by requesting metrics to be computed and returned as required, at the appropriate level of complexity. The metrics computed by each assessment design tool as a function of the level of complexity of the project are reported in the set of Tables 4-7, displaying:

- The design information which is provided by each of the Deployment design tools at the specific level of complexity; Early/Mid/Late, and
- The Metrics which are calculated for each of these stages to support the Stage Gate assessment.

Table 8 in D4.1 Technical Requirements for the implementation of a world-class Stage Gate Assessment Framework in Ocean Energy summarises the key metrics passed from the assessment tools to the Stage Gate design tools.

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 MODULE GRAPHICAL USER INTERFACE

The DTOceanPlus toolset will interact with the user through 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 (UI) for the main platforms and the tools, as well as some mock-ups and idea will be shown. The content of this section is mostly approximate, as it represents just the initial approach to the User Interfaces and it is assumed that the concepts will evolve and maybe differ in its final form what herein presented. In particular, over the following subsections different styles and formats for the UI have been proposed by each module developer. Of course, once collected all the requirements by the module developers, all the UI for all the modules will be all aligned in terms of style, tools and management of space.

The main characteristics and technical requirements of the User Interface of the main platform are reported in Section 3.7.1 of D5.1 Technical Requirements of the Deployment Design Tools.

3.7.1 SYSTEM PERFORMANCE AND ENERGY YIELD

The graphic user interface should consist of a section where the metrics obtained are represented as well as main performance variables. Other sections should be represented to make the assessment gather the necessary data and the devices to be plotted. Finally, a figure to plot the selected results is to be included so that devices/KPIs/performance can be visually represented.

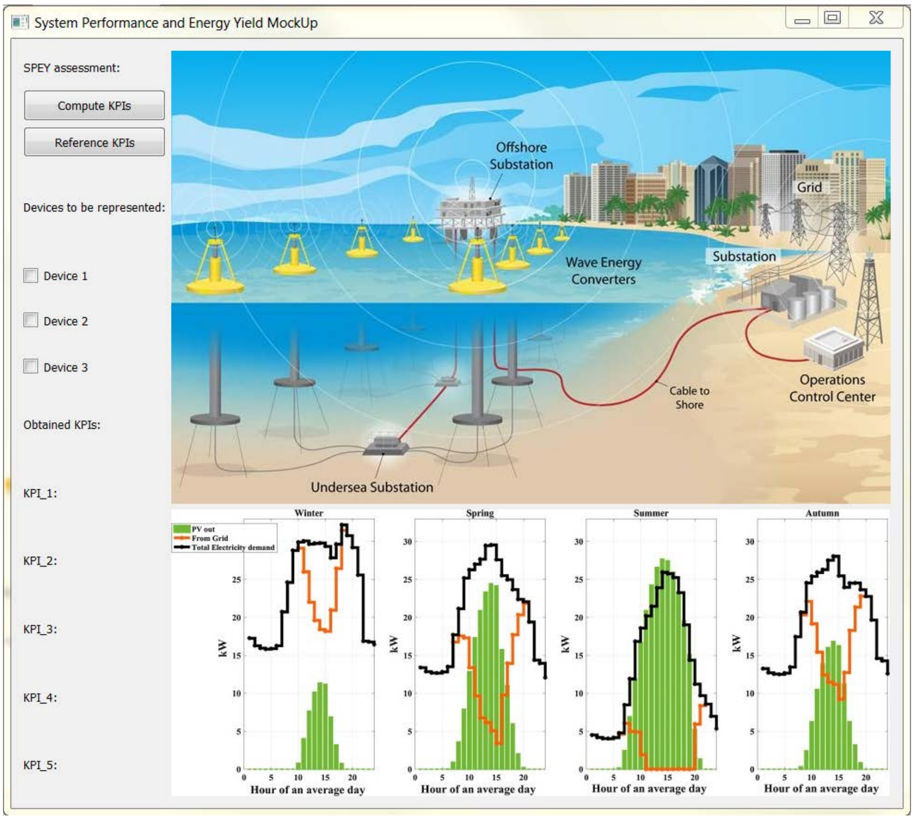


FIGURE 3.6 EXAMPLE OF GUI FOR THE SPEY MODULE.

3.7.2 SYSTEM RELIABILITY, AVAILABILITY, MAINTENAIBILITY AND SURVIVABILITY (RAMS)

The RAMS tool could be run standalone tool or integrated into the overall assessment tool as one module. The functions, sub-routines and library developed in the RAMS tool should not only fulfil all the functionality requirements, but also provide access for the other tools to call the public codes (could be some functions, subroutines and library). A preliminary layout of the Graphic user interface (GUI) of the RAMS module/tool for the standalone version is illustrated in Figure 3.7.

The GUI is composed of six major parts. The main menu includes the set-up for integration with other deployment and assessment tools, e.g. import the inputs, export the outputs, activate the public. There are two groups of list boxes used to choose the specific components in each subsystem and specific failure mode in each subsystem. The user can choose various possible combinations of components and failure modes to simulate all the possible failure scenarios in reality.

The user will use the panel to specify some analysis options (Check Box 1), to determine which intermediate results should be illustrated (Check Box 2) and to choose the format of the PoF as a function of time, illustrated for the structural subsystem (Check Box 3). Beside these check boxes, there are two buttons, which are used to load the failure rates from a generic database and to start the analysis. The intermediate results can be plotted on Canvas, when the analysis is finished. Message list box reports the messages during the execution of analysis, for example error/warning messages, the notification of successful execution of a submitted analysis task, etc.

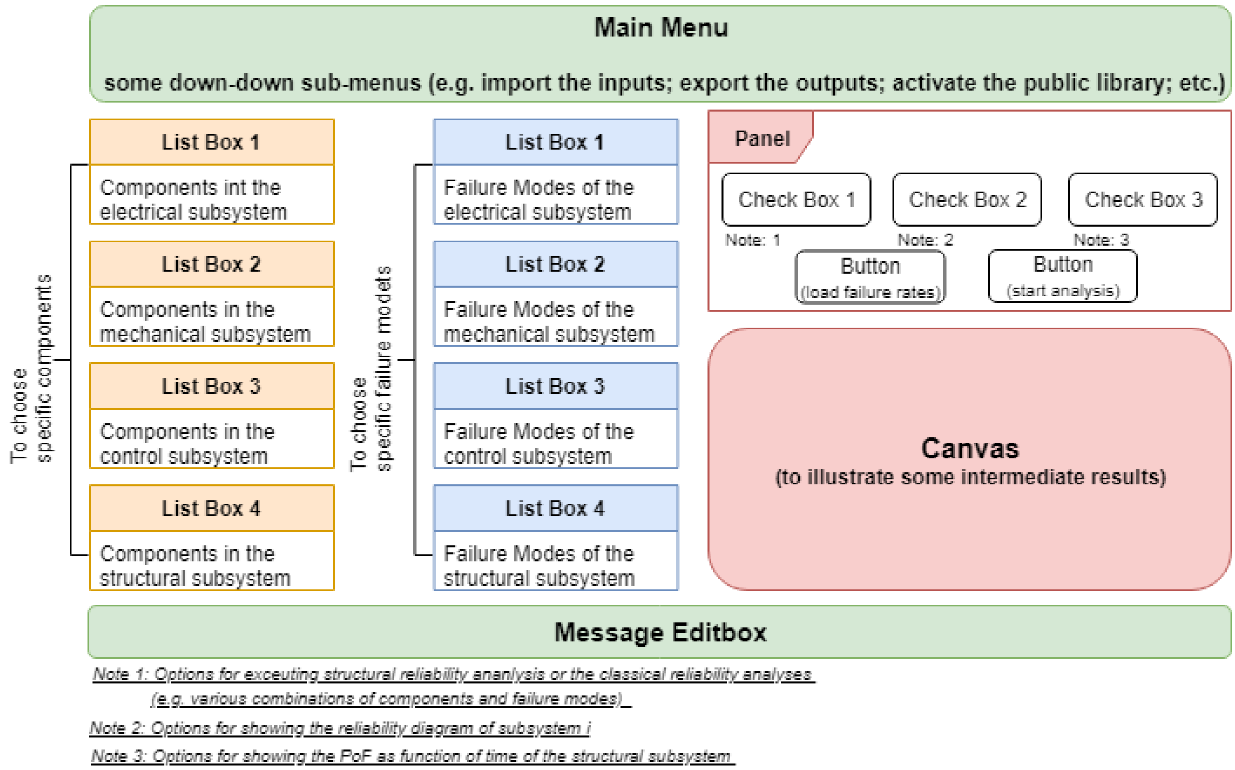


FIGURE 3.7. EXAMPLE OF GUI FOR THE RAMS MODULE.

3.7.3 SYSTEM LIFETIME COSTS

The System Lifetime Costs tools should allow the user to view and edit the underlying information used for the analysis, as well as a view of the results.

For data input and editing, a tabular format (akin to a spreadsheet) will provide a comprehensive view of the underlying assumptions and a way to change price information and date information. Collapsible sections allow the user to focus on different areas of the project (e.g., electrical infrastructure, moorings, etc.). Figure 3.8 shows how this could be presented.

+ Station Keeping			**31.870.528**
	Quant.	*Unitary Cost (€/unit)*	*Total Cost (€)*
- Energy Delivery			**6.837.827**
- Offshore electrical equipment			**6837631**
Umbilical	2	200.000	384.000
Connectors	32	30.000	960.000
Dynamic Cable Inter-array	3	80.000	274.733
Junction boxes	4	262.907	1.051.627
Static Cable Interrarray	0	40.000	7.200
Offshore Substation	0	3.500.000	0
Export cable	34	123.079	4.160.070
+ Onshore Electrical Equipment			**196.012**
	Quant.	*Unitary Cost (€/unit)*	*Total Cost (€)*
- Installation			**9.168.615**
+ Station Keeping			**1.349.955**
+ Energy Delivery			**1.269.649**

FIGURE 3.8 MOCK-UP OF BILL OF MATERIALS WITH COSTS DISPLAY

- For user inputs, blank input boxes are needed. In some cases, these can be pre-filled with default values.
- For the selection of which analysis are to be run, either dropdown boxes or check boxes can be used.
- For the presentation of results, plot space is required, as well as a table space for more detailed results.
- For import/export proposes, a data loading and saving input box is necessary.

3.7.4 SYSTEM ENVIRONMENTAL AND SOCIAL ACCEPTANCE

There will be three main parts in the ESA module: EIA (Environmental impact assessment), CFP (Carbon Footprint) and SEA (Socio economical acceptance). Each part provides different assessment functions. Through the left part of the GUI, users may choose to process certain functions for one or several parts of the module.

When the user chooses a function, associated inputs needed are specified in the inputs section. If the parameter is already provided by any deployment tool, the value is already entered. If not, the user is asked to provide it, either unique values, select from list or import tabs depending on the type of data. For EIA, there is three steps of inputs corresponding to the three steps of the functions. The first one is mandatory. If the user does not have information for the two other steps, default values are provided, and the level of confidence is lower.

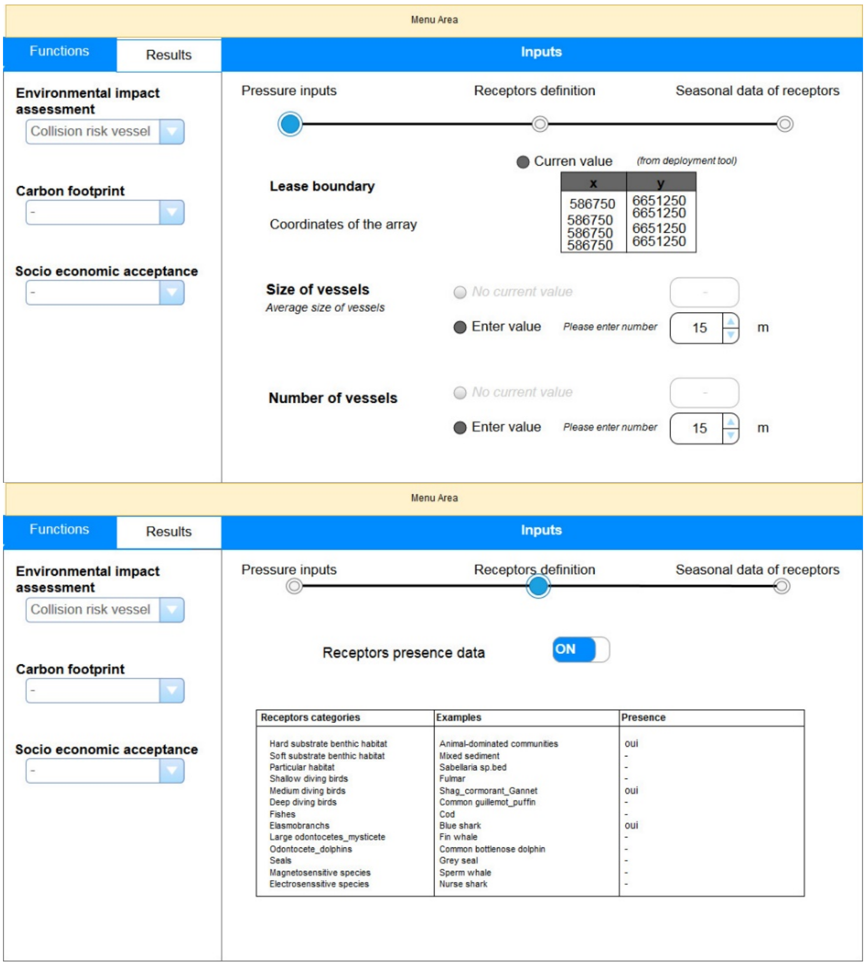


FIGURE 3.9 EXAMPLE OF GUI FOR THE ESA MODULE.

For the outputs, user will have access to different levels of display for each parts of the module:

- Global: the module provides general values, a histogram to present values per stage and one detailing values per module. Recommendations to decrease environmental impact or increase social acceptance are provided in text format.
- Per module: Users can choose to display specific results to one module. Display is similar to the global.
- Per stage: Users can choose to display specific results to one stage of the life cycle of the ORE array. Display is similar to the global.
- Other energy: user can compare the MRE array to other energy sources.

4. CONCLUSIONS

4.1 KEY FINDINGS

The present report (D6.1) has collected the main technical requirements of the Assessment 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 Assessment design tools consist in a set of requirements of 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 assessment tool (System Performance and Energy Yield, System RAMS, System Lifetime Costs, and System Environmental and Social Acceptance) could satisfy the functional requirement addressing an on 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 Assessment design tools require access to catalogues to provide adequate design at different level 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 Gate tool 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 and describes, still 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. T6.3-6.6 are aimed at producing the alpha version of the code for the Assessment design tools. The alpha version of the software will cover all the functionalities that are supposed to be implemented. The work done in T6.2 will supervise that the implemented code follows the technical requirements in D6.1. Moreover, it guarantees that all the modules within the Assessment design tools will be developed in a consistent manner; parallel tasks in WP3 (T3.2), WP4 (T4.2), WP5 (T5.2) and WP7 (T7.3) guarantee that all the software produced could be integrated in a unique platform. Approaches based on Agile programming concepts, such as for example Continuous Integration/Development, will be adopted to reduce the occurrence of risk of inconsistencies

The final task T6.7 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 its 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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