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

Deliverable D6.6

Testing and verification results of the Assessment Design tools – beta version

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EXECUTIVE SUMMARY

The objective of Task 6.7 was to carry out the testing of the Assessment Design tools in order to verify that it meets all the previously defined requirements (detailed in WP6). This report documents the outcome of T6.7 "Verification of the Assessment Design tools."

The goal of the verification task was to ensure that the tools:

- respond correctly to a varied set of inputs,
- perform their functions in an acceptable time and reasonable use of computational resource,
- are adequate in terms of usability, and,
- are verified against control data.

The following actions were completed for all tools as part of the verification and are described in detail in this report:

- Definition of the Verification Cases and evaluation criteria.
- Organisation of training sessions (for technical and industrial partners).
- Collection of data for each Verification Case.
- Running the Verification Cases (by technical and industrial partners).
- Analysis of the results based on quantitative and qualitative assessments.
- Creation of a task list of changes that could improve the tool to improve performance.

A stable beta version of the tools in now available that is fully documented with a technical manual and a user manual. The tools will be further validated and demonstrated using real data from the first pilot experiences in WP7.

According to the quantitative results the end-users involved in evaluating the Assessment Design tools are very satisfied with the usability and performance of all modules described in this report. The categories user-friendliness and value obtained a slightly less positive feedback (though not for all modules) but in general they satisfied the end-users' requirements. The qualitative assessment feedback gathered some improvements that were compiled and categorised. As a result of this, a certain number of high-priority improvements (15 for System Performance and Energy Yield (SPEY), 25 for System Lifetime Costs (SLC), 9 for Reliability, Availability, Maintainability, and Survivability (RAMS), and 26 for Environmental and Social Acceptance (ESA) were selected to be implemented in the final release of the DTOceanPlus suite of design tools.

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ABBREVIATIONS AND ACRONYMS

AD	Assessment Design
AEP	Annual Energy Production
ACCW	Average Climate Capture Width
BL	Business Logic
BOM	Bill of Materials
CCE	Characteristic Capital Expenditure
CED	Cumulative Energy Demand
DD	Deployment Design
DO	Design Objective
EA	Evaluation Area
ED	Energy Delivery
EPP	Energy Payback Period
ESA	Environmental and Social Acceptance
ET	Energy Transformation
FLS	Fatigue Limit State
FMEA	Failure Mode and Effects Analysis
FT	Fault Tree
GWP	Global Warming Potential
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCOE	Levelised Cost of Energy
LMO	Logistics and Marine Operations
MC	Machine Characterisation
MTTF	Mean Time to Failure
MTTR	Mean Time to Repair
O&M	Operation and Maintenance
PoF	Probability of Failure
PTO	Power Take Off
RAMS	Reliability Availability Maintainability Survivability
RM	Reference Model
RMP	Reference Model Project
SG	Stage Gate
SI	Structured Innovation
SK	Station Keeping
SLC	System Lifetime Costs
TTF	Time to Failure
TTR	Time to Repair
ULS	Ultimate Limit State
US	User Stories
VC	Verification Case
VS	Verification Scenario
WEC	Wave Energy Converter

DEFINITION OF TERMS

Module/Tool	Software that can be run in standalone mode: alpha versions.
Features	The functionality provided by the software to the user and relates to the identified requirements from the user consultation exercise captured in WP2
Software route	Each of the possible trajectories to cover all the business logic of the tool (e.g., new concept/improvement cycle, ...).
Verification Scenarios	A set of independent input/output data to be provided to the end-user for the verification. It comprises of the Design Objective, Verification Cases and User Stories.
User stories	Short, simple descriptions of a feature. A partial design objective (e.g., As a <type of user>, I want <some goal> so that <some reason>).
Verification Cases	Design variants covering one trajectory and ending up in one or multiple Features/User Stories.
Design Objectives	Short descriptions of a relevant design case for ocean energy, non-confidential, which has been addressed by other tools/methods, and applicable to part or all the Verification Cases.
Evaluation Areas	The areas in which the user measures the success of ocean energy technology to demonstrate progress and performance.
Metrics	The parameters used to evaluate how well a technology performs in the Evaluation Areas. These are outputs of the Deployment and Assessment tools and are summarised in the Metrics section below.

1. INTRODUCTION

1.1 SCOPE AND OUTLINE

This report documents the methodology and results of the verification of the **Assessment Design (AD)** tools beta version. The verification tasks described in this report were designed to assess whether the tools:

- respond correctly to a varied set of inputs,
- perform their functions in an acceptable time and with a reasonable use of computational resource,
- are adequate in terms of usability, and,
- can be verified against control data.

Verification is a critical step in software development – it determines whether the software satisfies the functional requirements and is essential to ensure the development phase is being carried out accurately.

Verification Scenarios (VSs) are a set of independent input/output data to be provided to the end-user for the verification.

To perform the verification of the AD tools, two *Verification Scenarios* were created by using Reference Models (RM) 1 and 3 from Sandia [1]. For some modules (RAMS and ESA) these scenarios were strictly followed. For SPEY it was considered a tidal array of 10 devices using Sandia's RM1 (VS1) and a wave array of 10 devices using Sandia's RM3 (VS2). In the case of SLC, RM1 and RM3 were also used to set up VS1 and VS2, but some parameters were adapted to match with the functionalities of the module (cost breakdowns for example).

After receiving demonstrations and interactive training on how to use the tools, the technical verifiers as well as the industrial verifiers were given access to an online version of the beta version of the AD tools. They were then asked to run through each of the VS and complete a Software Evaluation Form designed to perform the verification. Table 1.1. shows the full list of developers, technical and industrial verifiers for all the AD modules. This report describes:

- the Verification Cases (VCs) and Software Evaluation Forms collecting feedback
- the demonstration and training sessions that were provided to the verifiers of the tool,
- the results of the verification, including quantitative and qualitative assessments of each VS, and
- any recommended changes or additional functionality that would add value to the tools.

TABLE 1.1: ASSESSMENT DESIGN TOOLS DEVELOPERS, TECHNICAL AND INDUSTRIAL VERIFIERS

Module	Developer	Technical verifier	Industrial verifiers
SPEY	Tecnalia	WES	Sabella, EDP, FEM, EGP, BV
RAMS	AAU	FEM	OMP, Sabella, Idom, WavEC, EGP, EDP
SLC	WavEC	UEDIN	OMP, Sabella, ESC, Tecnalia, EGP
ESA	FEM	ESC	OMP, Sabella, WES, EGP

The remainder of this section provides short summaries of the DTOceanPlus project and of the Assessment Design tools. For further information and background on the project, the reader is directed towards previous deliverables, e.g. [1], [2], [3].

Section 2 outlines the methodology adopted for the verification activities, to later review the Verification Cases. Then, attention has been paid to the data used to run the VCs. The training sessions organised both for the technical and the industrial partners are also illustrated in this section. Finally, the Evaluation Criteria used to evaluate the tools' functionalities are presented.

In **Section 3** the user flow and experience and the approach of the User Stories adopted to go through the features of the AD tools are explained, and the complete set of VCs is illustrated.

Section 4 illustrates the assessments resulting from the verification process, divided between quantitative and qualitative. A list of actions to improve the AD tools functionalities, according to the evaluations received, is also present at the end of this section.

In **Section 5** the conclusions of the verification process are listed.

Annex I. provides an overview of the user manual that is being developed alongside the tools.

Annex II. contains the software evaluation forms used for the verification tasks.

Annex III. summarises the scores and anonymous comments from the verification tasks.

1.2 SUMMARY OF DTOCEANPLUS

The Assessment Design tools belong to the suite of tools that DTOceanPlus project is developing for ocean energy technologies. 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 levels: sub-system, device, and array.

At a high level, these include:

- **Structured Innovation (SI) tool**, for concept creation, selection, and design.
- **Stage Gate (SG) tool**, using metrics to measure, assess and guide technology development.
- **Deployment Design (DD) tools**, supporting optimal device and array deployment:
  - *Site Characterisation (SC)*: to characterise the site, including metocean, geotechnical and environmental conditions.
  - *Machine Characterisation (MC):* to characterise the prime mover.
  - *Energy Capture (EC):* to characterise the device at an array level.
  - *Energy Transformation (ET):* to design PTO and control solutions.
  - *Energy Delivery (ED):* to design electrical and grid connection solutions.
  - *Station Keeping (SK):* to design moorings and foundations solutions.
  - *Logistics and Marine Operations (LMO):* to design logistical solutions and operations plans related to the installation, operation, maintenance, and decommissioning operations.
- **Assessment Design (AD) tools**, used by the other tools to quantify key parameters:
  - *System Performance and Energy Yield (SPEY):* to evaluate projects in terms of energy performance.
  - *System Lifetime Costs (SLC):* to evaluate projects from the economic perspective.
  - *System Reliability, Availability, Maintainability, Survivability (RAMS):* to evaluate the reliability aspects of a marine renewable energy project.
  - *Environmental and Social Acceptance (ESA):* to evaluate the environmental and social impacts of a given wave and tidal energy projects.

The main linkages between DTOceanPlus modules are outlined in Figure 1.1.

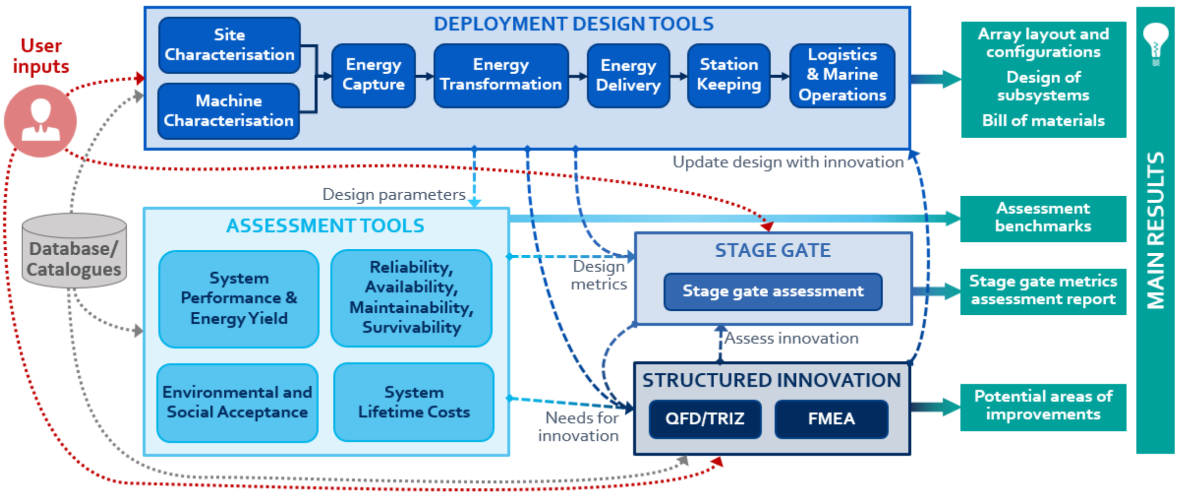

FIGURE 1.1: DTOCEANPLUS MODULES, MAIN LINKAGES, AND OUTPUTS

1.3 ASSESSMENT DESIGN TOOLS

Structured in four modules, the **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 tools [1].

The tools mentioned above are the following:

- **System Performance and Energy Yield (SPEY):** used in the evaluation of main Key Performance Indicators. This module allows the comparison between different technologies, or same technologies but located in different sites. The main features of this module are computing the performances matrix, estimating the energy production (at an array and device level), and assessment of the power quality (both of active and reactive power delivered to the grid).
- **System Reliability, Availability, Maintainability, and Survivability (RAMS)**: used to compute the RAMS of components and systems of the farms. Outputs of this module include: MTTF (Mean Time to Failure) and annual probabilities of failures, computing the availability of each device, estimate of the probability that failed components may be repaired within a given time window, estimate of the probabilities that the critical structural/mechanical components can survive the ultimate and fatigue loads during the design lifetime.
- **System Lifetime Costs (SLC)**: which estimates costs for the ocean energy project, together with its economic and financial viability. The main features of this module are: Bill of Materials (BOM) compilation, computation of economic and financial metrics to evaluate economics, bankability and financial attractiveness of a given ocean energy project, benchmarking of economic and financial attractiveness against reference values.
- **Environmental and Social Acceptance (ESA):** which, for each lifecycle operation of a given marine renewable energy project, estimates the potential environmental and social impacts of the project, providing also recommendations to reduce the potential environmental impact and to increase social acceptance. This module can identify potential endangered species and estimate the carbon footprint of the project.

All the tools have been divided into different levels of complexity (low, mid, and high complexity), with corresponding level of detail inputs and outputs.

2. METHODOLOGY

2.1 OVERVIEW

The principal aim of the verification task was for the technical and industrial verifiers to evaluate the functionalities of the AD tools. In order to achieve this, the following actions were completed:

- **Definition of the VCs and VSs**: this has been achieved by analysing the key features of the AD tools and the associated User Stories accounting for levels of complexity, standalone mode, wave and tidal scenario, array layout and network topologies (see Section 3).
- **Collection of data**: a collection of input/output (I/O) control data and project data (from catalogues and default data) have been defined and collected (see Section 3).
- **Organisation of training session:** training sessions on the use of tools have been provided to both the technical verifiers and the industrial partners (see Section 2).
- **Definition of Evaluation Criteria**: a common Software Evaluation Form was developed and used in the verification of every DTOceanPlus module. The Software Evaluation Form is divided into sections assessing the Usability, User-friendliness, Performance and Accuracy and perceived Value of the tool (see Section 2).

After the delivery of the training sessions, the technical and industrial verifiers were provided with the VSs, reference data, and Software Evaluation Form. They then assessed each of the VCs in turn, testing the appropriate features of the software and completing the Software Evaluation Form. The quantitative and qualitative results from the Software Evaluation Form completed by each verifying partner were collected, collated, and analysed. The results of this analysis are presented in **Section 4**.

2.2 DATA DEFINITION

Verification Case scenarios have been adapted in accordance with available data produced by the Reference Model Project (RMP) sponsored by the U.S Department of Energy Wind and Water Power Technologies Program. The goal of this project is producing non-proprietary Reference Models (RM) of technology designs as study objects for open-source research and development programs [3].

RMs used as part of DTOceanPlus' verification activities are RM1 and RM3: for both power performance and velocity measurements were collected to assess their interaction with the surrounding environment. The outputs of the tests have been used as inputs for the modules developed under DTOceanPlus, as showed in Figure 2.1.

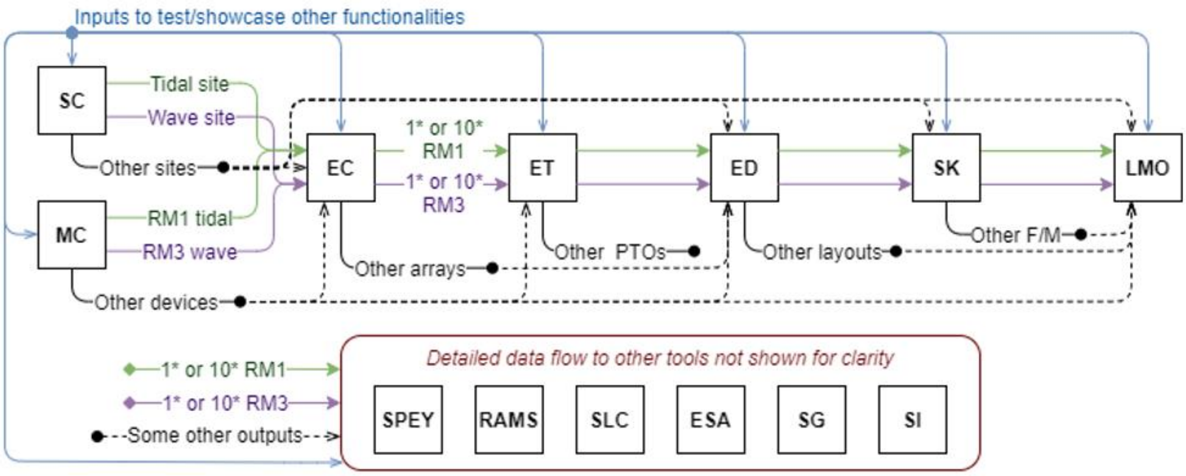

FIGURE 2.1: FLOW OF REFERENCE CASES/DATA BETWEEN THE TOOLS

2.2.1 RM1 TIDAL TURBINE

The RM1 device is a dual variable-speed variable-pitch axial-flow tidal turbine device. The rated power for the dual rotor unit is 1.1 MW. The main dimensions of the RM1 device are illustrated in Figure 2.2.

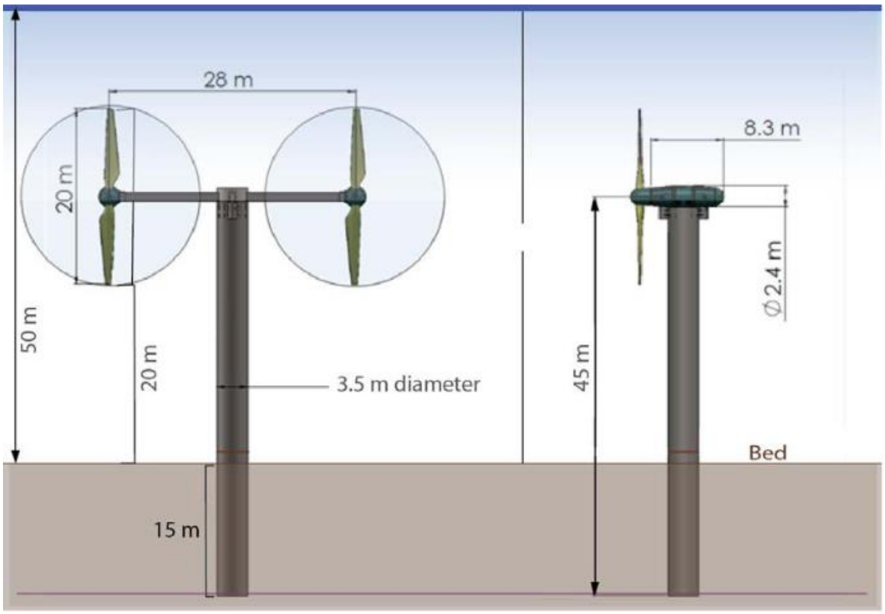

FIGURE 2.2: RM1 DEVICE PROFILE AND PLAN VIEWS DIMENSIONS

The main source of data for this validation scenario is the publication [4]. The study case in the paper has been conducted with the aid of the DTOcean software, v2.0[1]. The resulting cable and turbine layout are represented in Figure 2.3.

[1] Available from: https://github.com/DTOcean/dtocean.github.io/releases/tag/v2.0.0

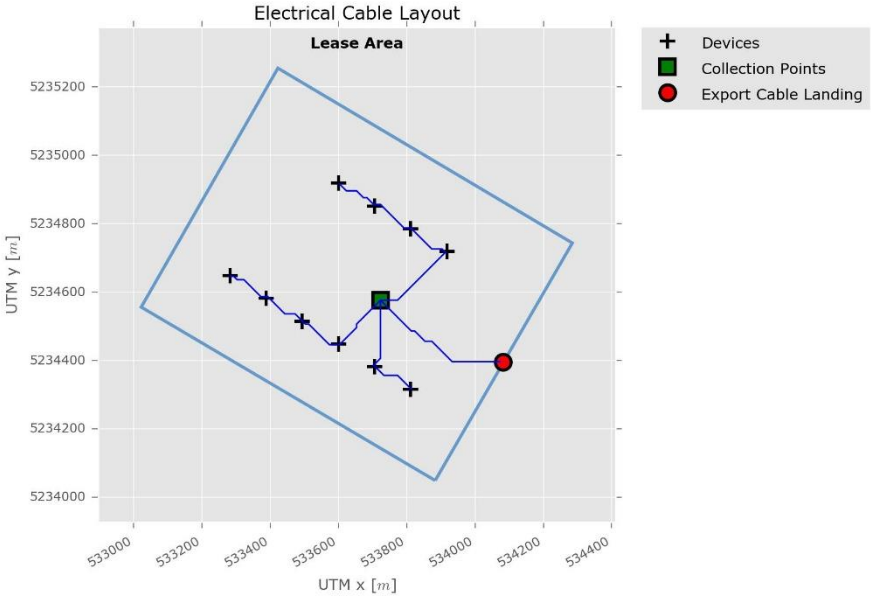

FIGURE 2.3: CABLE AND TURBINE LAYOUT FOR THE VALIDATION SCENARIO 1

The tidal energy resource for RM1 was developed from site information on the Tacoma Narrows tidal site in Puget Sound. For sake of convenience, a tidal location in Europe with similar site characteristics was considered. The black line in Figure 2.4 denotes the reference current speed frequency histogram selected for the reference model (mean of all sites), with U_{max}=3 m/s.

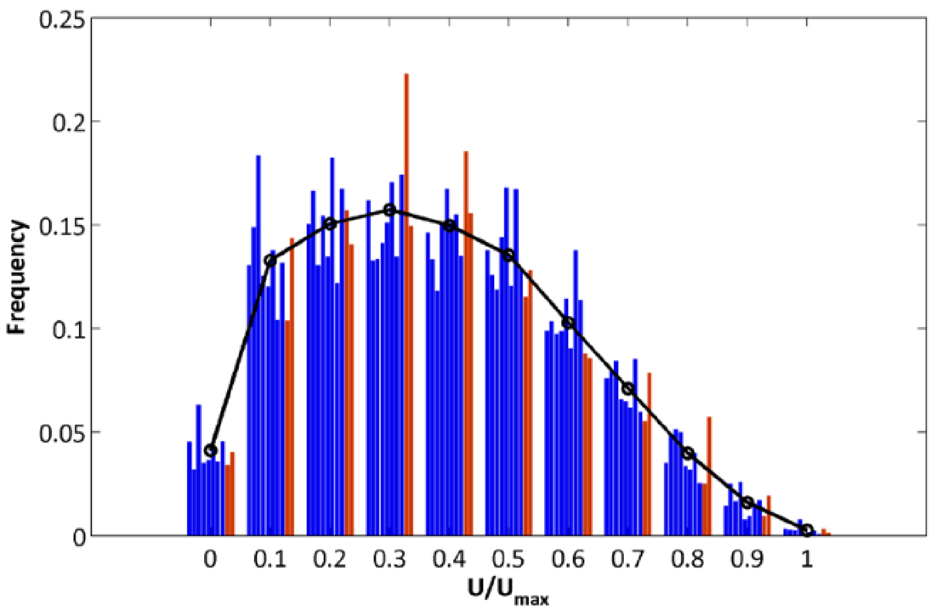

FIGURE 2.4: NON-DIMENSIONAL MID-DEPTH CURRENT SPEED FREQUENCY HISTOGRAMS FOR PUGET SOUND [6]

2.2.2 RM3 WAVE ENERGY CONVERTER

Wave Energy Converters (WECs) are based on Sandia's Reference Model 3 (RM3). The RM3 device is a heaving point absorber, also referred to as a wave power buoy. RM3 uses a Hydraulic PTO whose components are located inside the vertical column. The rated capacity of this unit is 260 kW, with a conversion efficiency of 80% from mechanical to electrical energy. The overall design and dimensions of the RM3 device are illustrated in Figure 2.5.

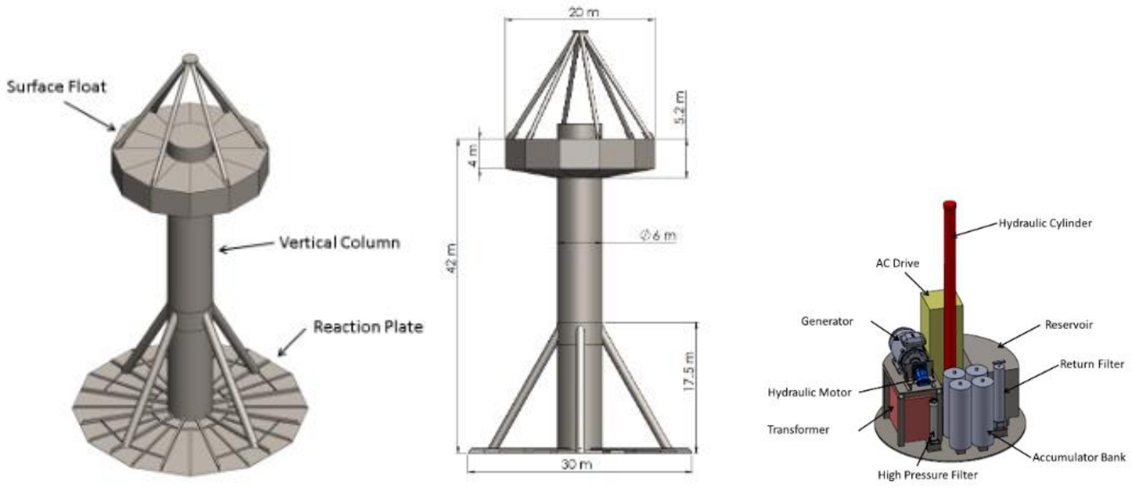

FIGURE 2.5: RM3 DEVICE DESIGN AND DIMENSIONS

The main source of data for this validation scenario is based on the example that can be downloaded from DTOcean software, v2.0[2]. The resulting cable and turbine layout are represented in Figure 2.6.

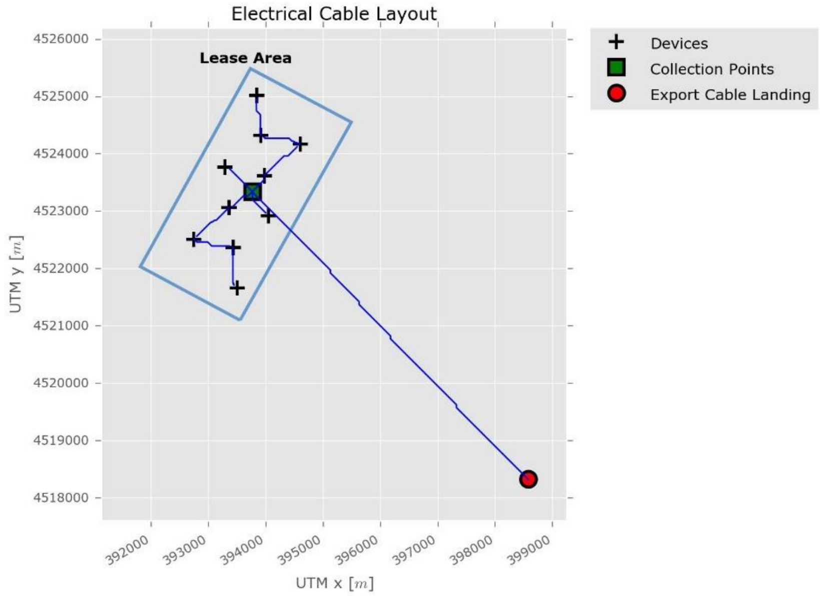

FIGURE 2.6: CABLE AND TURBINES LAYOUT FOR THE VALIDATION SCENARIO 2

[2] Available from https://github.com/DTOcean/dtocean.github.io/releases/tag/v2.0.0

The reference wave energy resource for RM3 was developed from site information collected near Eureka, in Humboldt County, California. Again, for the sake of convenience, a wave location in Europe with similar site characteristics is considered. The mean reference site wave energy density is 33.5 kW/m.

Joint Probability Plot (%)																	
		Te															
		4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	19.5
	0.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	0.75	0.0%	0.0%	0.6%	0.8%	0.5%	0.5%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	1.25	0.0%	1.0%	2.7%	3.7%	4.1%	2.9%	1.5%	0.4%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	1.75	0.0%	1.0%	4.4%	4.3%	4.1%	3.4%	2.0%	1.1%	0.6%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	2.25	0.0%	0.2%	3.5%	4.2%	3.6%	4.1%	3.1%	1.5%	1.2%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	2.75	0.0%	0.0%	1.5%	2.5%	1.9%	3.2%	3.3%	1.8%	1.1%	0.4%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%
	3.25	0.0%	0.0%	0.1%	0.9%	0.9%	2.0%	2.4%	1.4%	0.8%	0.4%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
	3.75	0.0%	0.0%	0.0%	0.1%	0.2%	1.0%	1.9%	1.5%	0.5%	0.3%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%
	4.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	1.0%	1.3%	0.5%	0.3%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%
Hs	4.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.4%	0.4%	0.2%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%
	5.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.3%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
	5.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
	6.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	6.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	7.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	7.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	8.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	8.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	9.25	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	9.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

FIGURE 2.7: WAVE SCATTER DIAGRAM FOR EUREKA, HUMBOLDT COUNTY, CALIFORNIA [6]

2.3 DEMONSTRATION AND TRAINING SESSIONS

2.3.1 TRAINING SESSIONS FOR THE TECHNICAL PARTNERS

Before running the first round of VCs, the technical verifiers received detailed training materials and tutorials. The main form of the training was provided through a set of video conference calls where a walkthrough of all the features of each module was given. The conference calls facilitated technical discussions between the developers and the technical verifiers.

A set of dedicated deliverables [7] [8] [9] [10] describing all the potential uses of SPEY, RAMS, SLC and ESA is also available for consultation. These documents present: use cases and functionalities for each module, their implementation, the business logic of the code, and a set of extensive examples to provide the reader with an overall view of the capabilities of each module.

2.3.2 TRAINING SESSIONS FOR THE INDUSTRIAL PARTNERS

A similar walkthrough of the tools was provided to the industrial partners on a separate video conference call. The industrial partners were also provided with links to the previous Assessment Design tools documentation and a list with the VCs.

2.4 EVALUATION CRITERIA

Potential users and other stakeholders have been consulted to identify and clarify their needs and requirements on the Assessment Design tools.

The outcome of the previous user groups analysis [2] has been used to inform the functional requirements for the development of the DTOceanPlus tools and subsequently set out the Evaluation Criteria. Most of the respondents reported that **comparing devices**, **locations** and **combined arrays of different devices and technologies** are all important features.

The inputs coming from the user-groups consultation and the **technical requirements** set out for the Assessment Design tools [1] delineated the Evaluation Criteria used throughout the Verification activities. These criteria include a numeric (see Table 2.1) and qualitative assessment for each one of the tools' functionalities. Regarding the numeric assessment, a scale ranging from 1 to 5 has been used, where 1 represents the most negative assessment and 5 the most positive one.

TABLE 2.1: SCORING SCALE USED IN THE NUMERIC ASSESSMENT

Score	1	2	3	4	5
Description	Strongly disagree	Disagree	Undecided	Agree	Strongly agree

A common Software Evaluation Form was developed and used in the verification of every DTOceanPlus module. The Software Evaluation Form was divided into four sections assessing the:

- usability,
- user-friendliness,
- performance and accuracy and
- perceived value of the tools.

The individual Evaluation Criteria that were included in the Software Evaluation Form are shown in the results of the evaluation in Section 4, categorised under these four headings. When each technical or industrial verifier completed the Software Evaluation Form, they were required to assign a score of 1 – 5 (see Table 2.1) to each of the individual evaluation criterion.

The Evaluation Criteria for the *Performance and accuracy* section are evaluated for each feature of the software.

The completed Software Evaluation Forms are included as Annex II of this report.

3. VERIFICATION CASES

3.1 SYSTEM PERFORMANCE AND ENERGY YIELD (SPEY)

3.1.1 USER FLOW AND EXPERIENCE

The System Performance and Energy Yield (SPEY) module assesses the performance of the system in terms of **energy yield** during all the stages of the resource-to-wire conversion, including the downtime of the system.

It also computes the **efficiencies** at the different stages of the transformation, assesses the **power quality** at the delivery point, and produces a set of **alternative metrics** against a set of technical parameters.

In standalone mode, the user first sets up a study, providing a name and a brief description. An identifier (SpeyId) will be automatically created. Then the user will enter inputs for the characterisation of the machine and site, the hydrodynamic interaction, the effects of PTO and control strategy, the electrical dispatch infrastructure, and the downtime hours per device, per month and per year during the lifetime. Once these inputs are complete, the user can run the design process, and then view the results. In integrated mode, all the inputs come from other modules.

SPEY's functionalities include:

1. Collating inputs from the user (standalone) or other modules.
2. Calculating the efficiency.
3. Calculating Alternative metrics.
4. Calculating power quality metrics.
5. Calculating energy production.
6. Exposing to the user the main results.
7. Filling the assessments in terms of Energy Production of the Digital Representation of the system.

The main outputs of this module (computed both at array and device level) are:

1. A set of dimensionless metrics (efficiencies).
2. A set of dimensional metrics (Alternative Metrics) as a function of cable lengths, mass, rated power, and other characteristic dimensions.
3. Estimation of the power quality delivery per sea state.
4. Estimation of the net (monthly, yearly, lifetime) Energy Production, accounting for the downtime of the system.

3.1.2 USER STORIES

There are two main user stories for the SPEY module, corresponding to the simple and full functionalities, which can be expressed as follows:

1. **Simple mode:**
    a. As a *project* or *device developer* I would like to get a *quick estimate* of the *costs* and *performance* of a *typical electrical network* for a deployment.
2. **Full design mode:**
    a. As a *device developer* I would like to understand the *performance* of my device in a range of *electrical networks*.
    b. As a *project developer* I would like to design an optimal electrical architecture for the array project I am designing.

3.1.3 DEFINITION OF THE VERIFICATION CASES

Four basic Features can be identified in order to assess the performance and accuracy of this module:

- **Calculate Energy Production**: an estimate of the gross and net energy production, during the lifetime, as well as the average annual and monthly production due to the downtime of the system.
- **Calculate Efficiency**: a set of dimensionless parameters expressing how well the overall system, as well as the different sub-systems, perform with respect to the available resource and the other subsystems, at both array and device level of aggregation.
- **Calculate Alternative Metrics**: a set of dimensional parameters expressing how well the overall system, as well as the different sub-subsystems, perform with respect to the other parameters, as for example the lease area, the wetted surface of the prime mover, the mass, the rated power of the device, the characteristic length, and the length of the cabling, both at array and at device level of aggregation.
- **Calculate Power Quality**: an estimate of the active power production with respect to reactive power can be estimated for different subsystems and levels of aggregation.

The Verification Cases were duplicated for two of these features in order to account for wave and tidal scenarios. This led to a total of six Verification Cases, as shown in Table 3.1.

TABLE 3.1: SPEY FEATURES AND VERIFICATION CASES

Feature	Complexity Levels	Scenario	Total Cases
Calculate Energy Production	1	1	1
Calculate Efficiency	1	2	2
Calculate Alternative Metrics	1	2	2
Calculate Power Quality	1	1	1

The six VCs can be grouped into two independent **Verification Scenarios** for the verification of SPEY Features.

- A Tidal Array of 10 devices using Sandia's Reference Model 1 (RM1)
- A Wave Array of 10 devices using Sandia's Reference Model 3 (RM3)

3.1.3.1 VALIDATION SCENARIO 1: TIDAL ARRAY OF 10 DEVICES

This Verification Scenario aims to assess the performance and energy yield of an array of 10 tidal turbines. The tidal turbines are based on the SANDIA Reference Model 1 (RM1) [3]. However, for the verification of the SPEY module, the results of a simulation run in DTOcean v2.0 was used; in order to homogenise the results of that simulation with the inputs of SPEY, a set of 22 sea states was considered, based on power levels. The associated histogram is shown in Figure 3.1.

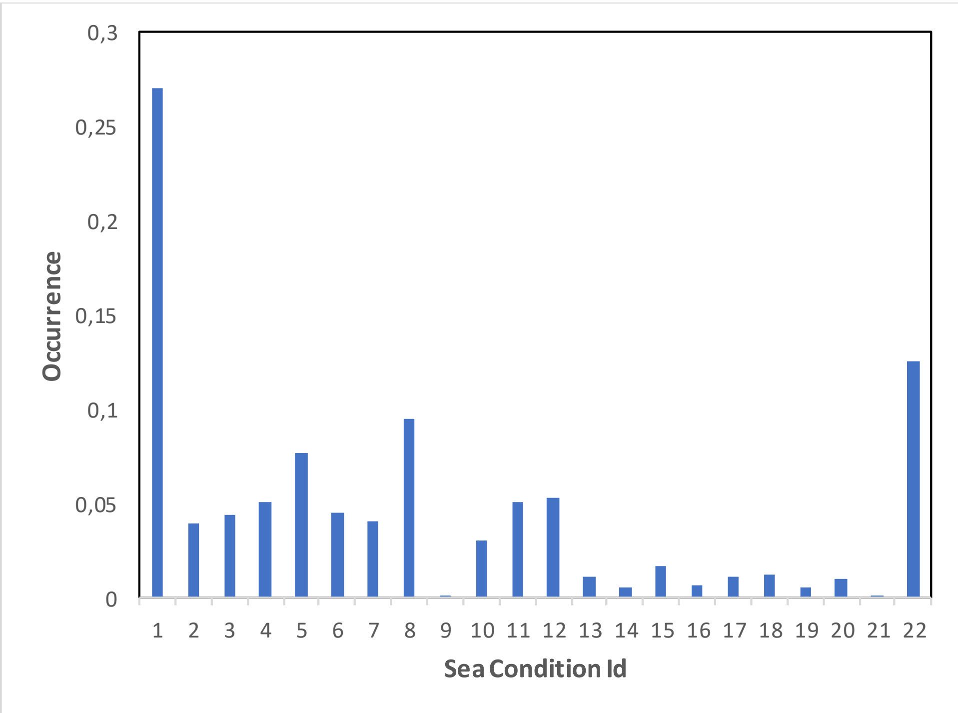

FIGURE 3.1: HISTOGRAM OF THE POWER LEVELS FOR THE VALIDATION SCENARIO 1 IN SPEY

Assumptions in this Verification Scenario (not included in the simulation run in DTOcean v2.0 but needed to show the functionalities of SPEY) were:

- At the device output, all the power is active.
- At the Onshore Collection point, the active power is 97.5% of the apparent power.
- The efficiency of the transmission system equals to 100%.
- The efficiency of the delivery system is 95%.

3.1.3.2 VALIDATION SCENARIO 2: WAVE ARRAY OF 10 DEVICES

This Verification Scenario aims to assess the performance and energy yield of an array of 10 wave energy converters (WECs). The WECs are based on the Sandia Reference Model 3 (RM3).

However, for the verification of the SPEY module, the results of a simulation run in DTOcean v2.0 was used; in order to homogenise the results of that simulation with the inputs of SPEY, a set of 22 sea states were considered, based on power levels. The associated histogram is in Figure 3.2.

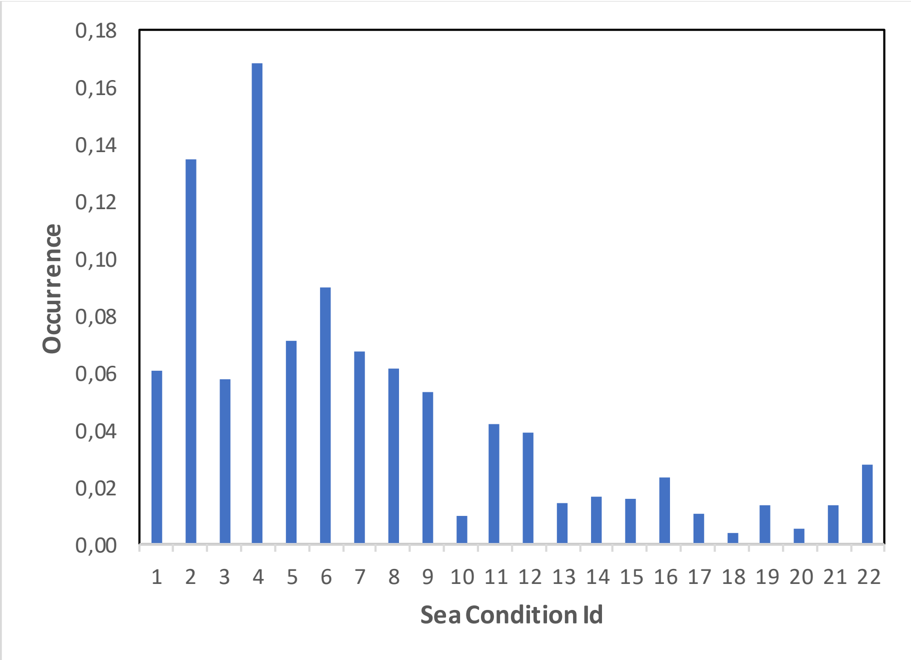

FIGURE 3.2: HISTOGRAM OF THE POWER LEVELS FOR THE VALIDATION SCENARIO 2 IN SPEY

Assumptions in this Verification Scenario (not included in the simulation run in DTOcean v2.0 but needed to show the functionalities of SPEY) are:

- At the device output, all the power is active.
- At the Onshore Collection point, the active power is 97.5% of the apparent power.
- The efficiency of the transmission system equals to 80%.
- The efficiency of the delivery system is 95%.

3.1.4 COLLECTION OF DATA REQUIRED

The data required for SPEY to run has been categorised in six groups, namely the modules that would provide the information in the integrated mode. The GUI in SPEY also reflects this organisation of the inputs in standalone mode.

The inputs in terms of Machine Characterisation for the VS 1 and VS 2 are reported in Table 3.2.

TABLE 3.2: DEVICE CHARACTERISTIC PARAMETERS

Device characteristic parameters	Units	Value for VS1	Value for VS2
Technology (wave/tidal)	-	Tidal	Wave
Rated capacity of the OEC	kW	1100	286
Mass of the prime mover	kg	219370	1000000
Wetted surface of the prime mover	m^2	330	861
Characteristic dimension	m	20	6

The inputs in terms of Site Characterisation for the VS 1 and VS 2 are reported in Table 3.3, Table 3.4, and Table 3.5.

TABLE 3.3: SITE CHARACTERISTIC PARAMETERS

Site characteristic parameters	Units	Value for VS1	Value for VS2
Average Energy Flux (Wave)	kW/m	—	28.57
Average Energy Flux (Tidal)	kW/m^2	2.617	—
Lease Area Extension	km^2	0.8	66.12
Monthly occurrence Matrix (Wave)	—	—	See Table 3.4
Monthly Current Scenarios Matrices (Tidal)	—	See Table 3.5	—

TABLE 3.4: MONTHLY OCCURRENCE MATRIX (WAVE)

id	January	February	March	April	May	June	July	August	September	October	November	December
1	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
3	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
4	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
5	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
6	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
7	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
8	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
9	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
10	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
11	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
12	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
14	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
15	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
16	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
17	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
18	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
19	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
20	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
21	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
22	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04

TABLE 3.5: MONTHLY CURRENT SCENARIO MATRICES (TIDAL)

id	January	February	March	April	May	June	July	August	September	October	November	December
1	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
2	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
3	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044
4	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
5	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077
6	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
7	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041
8	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095
9	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
10	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
11	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051
12	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
13	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
14	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044
15	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
16	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077
17	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
18	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041
19	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095
20	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
21	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
22	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051

The inputs in terms of Energy Capture are reported in Table 3.6–Table 3.10. The q-factor is the ratio between the actual energy production at device/array level and the energy production of the array/device if all the devices were isolated, with no hydrodynamic interaction among them.

TABLE 3.6: ENERGY CAPTURE PARAMETERS

Energy Capture parameters	Units	Value for VS1	Value for VS2
Annual Energy Production - Array	kWh	32551826.84	8856000
Annual Energy Production - Devices	kWh	See Table 3.7	See Table 3.8
Number of Devices	-	10	10
q-factor - Array	-	1	0.995
q-factor - Device	-	See Table 3.9	See Table 3.10

TABLE 3.7: CAPTURED ANNUAL ENERGY PRODUCTION PER DEVICE (VS1)

Device id	Annual Energy Production (kWh)
1	3930570.80
2	3918916.51
3	3659166.76
4	3042552.03
5	1749501.41
6	950385.76
7	2200704.71
8	3994573.72
9	4465244.96
10	4593879.71

TABLE 3.8: CAPTURED ANNUAL ENERGY PRODUCTION PER DEVICE (VS2)

Device id	Annual Energy Production (kWh)
1	932198.75
2	936446.25
3	973986.25
4	939000
5	941871.25
6	914413.75
7	946738.75
8	944575
9	923123.75
10	928072.5

TABLE 3.9: Q-FACTOR PER DEVICE (VS1)

Device id	q-factor
1	1
2	1
3	1
4	1
5	1
6	1
7	1
8	1
9	1
10	1

TABLE 3.10: Q-FACTOR PER DEVICE (VS2)

Device id	q-factor
1	0.992001024
2	1
3	1
4	0.993422966
5	0.997850226
6	0.966629201
7	1
8	0.992510207
9	0.9794555
10	0.990933099

The inputs in terms of Energy Transformation are reported in Table 3.11–Table 3.15. The reactive power at the outputs of the device is supposed to be zero.

TABLE 3.11: ENERGY TRANSFORMATION PARAMETERS

Energy Transformation parameters	Units	Value for VS1	Value for VS2
Annual Energy Production-Array	kWh	32551826.8	7499202.97
Annual Energy Production - Devices	kWh	See Table 3.12	See Table 3.13
Active power per sea state	kW	See Table 3.14	See Table 3.15
Reactive power per sea state	kVAr	Matrix of zeroes	Matrix of zeroes.

TABLE 3.12: TRANSFORMED ANNUAL ENERGY PRODUCTION PER DEVICE (VS1)

Device id	Annual Energy Production (kWh)
1	3927196.006
2	3935597.923
3	3619125.719
4	3029591.214
5	1800110.703
6	1042537.859
7	2210404.313
8	3953802.077
9	4436912.3
10	4596548.722

TABLE 3.13: TRANSFORMED ANNUAL ENERGY PRODUCTION PER DEVICE (VS2)

Device id	Annual Energy Production (kWh)
1	745759
2	749157
3	779189
4	751200
5	753497
6	731531
7	757391
8	755660
9	738499
10	742458

TABLE 3.14: TRANSFORMED ACTIVE POWER PER SEA STATE PER DEVICE (VS1)

Sea State	Device 1	Device 2	Device 3	Device 4	Device 5	Device 6	Device 7	Device 8	Device 9	Device 10
1	19.53	19.53	19.53	22.78	29.88	54.1	22.78	22.78	19.53	19.5
2	114	114	180	114	114	114	0	0	0	0
3	0	0	0	0	434.78	27.17	172.1	172.1	271.74	172.1
4	587.03	121.84	0	265.82	0	387.66	265.82	0	0	121.8
5	0	328.13	328.13	393.75	393.75	215.63	590.63	0	0	0
6	0	137.5	137.5	0	0	0	825	825	825	0
7	0	0	609.38	482.42	0	0	482.42	609.38	0	1066.4
8	591.44	591.44	591.44	591.44	792.79	591.44	0	0	0	0
9	0	0	0	0	0	4250	0	0	0	0
10	0	1212.77	960.11	0	1364.36	0	0	0	1212.77	0
11	792.45	0	0	528.3	297.17	0	2080.19	1551.89	0	0
12	0	658.13	0	1004.52	0	0	0	0	1628.01	2459.3
13	3392.86	0	2857.14	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	6750	0	0
15	2188.68	2188.68	0	273.58	0	0	0	2599.06	0	0
16	0	0	0	0	0	0	0	0	0	7750
17	0	0	0	0	0	0	0	0	8250	0
18	0	0	0	0	709.46	0	1182.43	6858.11	0	0
19	0	0	0	0	0	0	0	0	0	9250
20	0	0	9750	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	10250	0	0
22	1887.4	1887.4	1039.44	1039.44	27.35	27.35	27.35	1039.44	1887.4	1887.4

TABLE 3.15: TRANSFORMED ACTIVE POWER PER SEA STATE PER DEVICE (VS2)

Sea State	Device 1	Device 2	Device 3	Device 4	Device 5	Device 6	Device 7	Device 8	Device 9	Device 10
1	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
2	20.53	17.31	16.01	20.53	20.44	20.44	20.53	16.96	21.83	20.44
3	28.46	41.09	46.21	28.46	28.83	28.83	28.46	42.48	23.35	28.83
4	47.34	47.3	30.86	47.34	47.34	47.3	46.46	46.47	47.3	47.3
5	56.17	56.29	99.59	50.71	49.32	57.66	53.38	53.36	57.68	50.83
6	72.91	72.87	17.11	63.92	62.03	102.15	61.55	88.56	74.65	99.25
7	91.36	77.45	153.68	91.78	96.87	43.17	95.21	50.83	86.51	58.14
8	82.95	100.59	95.18	110.83	110.83	126.71	77.21	105.34	82.53	82.84
9	118.33	118.33	99.9	108.82	108.77	64.7	151.63	93.62	122.12	118.78
10	29.37	30.23	381.16	87.56	87.84	184.48	95.5	272.32	39.02	27.53
11	138.72	137.46	134.46	138.72	138.72	152.08	130.04	124.99	131.08	138.72
12	142.52	129.7199	140.27	160.12	142.47	89.79	152.88	167.4	209.89	159.94
13	200.65	243.1144	233.42	148.36	200.78	148.88	176.41	124.11	0.39	148.88
14	85.74	240.8558	88.32	181.44	85.74	181.44	183.53	184.02	342.46	181.44
15	280.54	110.9536	287.13	175.91	280.54	177.53	198.51	197.97	0	175.91
16	258.34	218.8123	143.13	192.89	192.89	256.95	115.42	115.42	263.01	258.14
17	114.73	201.5374	358.86	196.18	190.6	120.78	360.72	366.3	128.93	106.35
18	72.24	88.66195	145.14	275.18	290.94	365.16	323.12	616.04	1.31	97.2
19	278.01	278.0084	278.01	278.01	278.01	180.93	278.01	0	278.01	278.01
20	257.72	257.7181	0	118.83	118.31	482.51	118.31	686.22	376.55	118.83
21	281.91	253.0603	310.75	338.72	338.94	186.41	246.72	138.33	231.43	338.72
22	260.54	275.5891	302.61	261.68	261.68	260.54	309.8	340.35	260.54	261.68

The inputs in terms of Energy Delivery are reported in Table 3.16–Table 3.18.

TABLE 3.16: ENERGY DELIVERY PARAMETERS

Energy Delivery parameters	Units	Value for VS1	Value for VS2
Annual Energy Production	kWh	31738031.2	6951735.57
Active power per sea state	kW	See Table 3.17	See Table 3.18
Reactive power per sea state	kVAr	See Table 3.17	See Table 3.18
Intra array cable length	m	1561.19	5987
Export cable length	m	426.36	7012

TABLE 3.17. DELIVERED ACTIVE/REACTIVE POWER PER SEA STATE (VS1)

Sea State	Active Power (kW)	Reactive Power (kVAr)
1	238	54
2	716	163
3	1188	271
4	1678	382
5	2139	487
6	2614	596
7	3090	704
8	3579	816
9	4040	921
10	4515	1029
11	5010	1142
12	5466	1246
13	6024	1373
14	6417	1462
15	6945	1583
16	7367	1679
17	7843	1787
18	8318	1896
19	8793	2004
20	9269	2112
21	9744	2221
22	10265	2339

TABLE 3.18: DELIVERED ACTIVE/REACTIVE POWER PER SEA STATE (VS2)

Sea State	Active Power (kW)	Reactive Power (kVAr)
1	62	14
2	181	41
3	301	69
4	421	96
5	542	123
6	662	151
7	783	178
8	903	206
9	1024	233
10	1144	261
11	1264	288
12	1385	316
13	1505	343
14	1626	370
15	1746	398
16	1866	425
17	1987	453
18	2107	480
19	2228	508
20	2348	535
21	2468	563
22	2589	590

The inputs in terms of Logistics and Marine Operation planning are reported in Table 3.19. In Table 3.20 and Table 3.21 the total downtime hours per device during all the lifetime are shown, however in SPEY the breakdown per month and per year have been included.

TABLE 3.19: LOGISTICS AND MARINE OPERATION PLANNING PARAMETERS

Logistics and marine operations parameters	Units	Value for VS1	Value for VS2
Project Life	years	20	20
Downtime hours per device	hours	See Table 3.20	See Table 3.21

TABLE 3.20: DOWNTIME HOURS PER DEVICE (VS1)

Device id	Downtime hours
1	710
2	1082
3	1614
4	936
5	710
6	864
7	895
8	1014
9	866
10	1202

TABLE 3.21: DOWNTIME HOURS PER DEVICE (VS2)

Device id	Downtime hours
1	1260
2	1270
3	1069
4	1084
5	1128
6	1070
7	1457
8	1218
9	1412
10	990

3.2 SYSTEM LIFETIME COSTS (SLC)

3.2.1 USER FLOW AND EXPERIENCE

The main purpose of the System Lifetime Costs (SLC) module is to assess the economic performance and financial attractiveness of a given ocean energy project, benchmarking against reference projects. SLC's functionalities include:

1. **Compile Bill of Materials (BOM)**: it compiles an inventory of materials, assemblies, and components, including the quantities of each, as well as the installation operations required to construct a given ocean energy farm.
2. **Financial assessment**: it evaluates the financial attractiveness of the project from the perspective of the investor, assessing project profitability.
3. **Economic assessment**: it performs a techno-economic assessment, estimating the LCOE of the farm, or using other alternative metrics for early-stage technologies.
4. **Benchmark analysis**: it compares the economic and financial results of the project against reference values from wave and tidal projects.

All assessments produced by the System Lifetime Costs module are carried out based on the design outputs of the Deployment design tools together with project characteristics introduced by the user, energy production estimates generated by the System Performance and Energy Yield, and a catalogue of reference cost-breakdowns of ocean energy projects at different development stages.

In standalone mode, the user first sets up a study, before entering inputs of the project. Once these inputs are complete, the user can run the assessment process, and then view the results. The main outputs of the analysis are economic and financial parameters, the compiled bill of materials, and benchmark metrics that allow comparing different renewable energy projects.

3.2.1.1 FUNCTIONALITIES NOT FULLY IMPLEMENTED

There are a number of functionalities that are not fully implemented in the version being used for the verification tasks. These will require further updates and testing to the business logic, back end, or GUI, but will not require updates to other modules.

1) Presently, introducing other recurrent costs (e.g. insurances not considered on the O&M planning) that are incurred on an annual basis is not possible. This will be implemented afterwards.
2) Visual representation of the cashflows and payback time.

3.2.2 USER STORIES

There are four main user stories for the System Lifetime Costs module, corresponding to the four functionalities, which can be expressed as follows:

1. **Bill of materials compiler**:
    a. As a *project developer* I would like to get the *total list of components and installation procedures required to commissioning my project*, featuring quantities and costs.
2. **Economic assessment**:
    a. As a *policy maker / project developer / technology developer,* I would like to obtain *standard economic metrics* (e.g. CAPEX, OPEX, average OPEX per year, LCOE) that allow me to evaluate the project.
    b. As a *project or technology developer* I want to be able to compute these *economic metrics at an early project phase*, where uncertainty and data gaps are high.
3. **Finance assessment**:
    a. As an *investor / policy maker / project developer / technology developer,* I would like to obtain *standard financing metrics* (e.g. Internal Rate of Return, Net Present Value, Payback Period) in order to evaluate the project in respect to investment attractiveness.
4. **Benchmark assessment**:
    a. As an *investor / policy maker / project developer / technology developer,* I would like to compute *project agnostic cost benchmarking metrics* that *allow me to compare this project to reference ones* as well as different renewable energy technologies.

3.2.3 DEFINITION OF THE VERIFICATION CASES

A set of verification cases was developed to cover the range of functionalities of the SLC module. As previously mentioned, the calculation logic is agnostic to the technology type (WEC/TEC) and to device topology (i.e. fixed or floating), although it takes the former into consideration when benchmarking against reference projects.

A range verification cases were defined with different device types, number of devices, and project parameters were defined, aligned with the Sandia reference models (RM1 & RM3) where possible. Additionally, the tool should be tested at both low and full complexity, with scenarios to allow comparison between these cases.

To consider every permutation of these would result in an unmanageably large number of verification cases, so a smaller subset was chosen to cover as much of the variation as possible. The final list of twelve verification cases, six for RM1 test cases and six for RM3, were listed in Table 3.22 and Table 3.23, respectively.

Cost breakdowns from the Sandia studies were used. However, given that the cost breakdown structure of the Sandia study does not exactly match the one of the SLC module, the cost data had to be reformatted in order to generate comparable inputs. A variable called "other costs" was considered which aggregates CAPEX costs not discretized in SLC, which include all the costs in Table 3.24 and Table 3.25 (and not produced by other modules).

TABLE 3.22: LIST OF VERIFICATION CASES OF SYSTEM LIFETIME COSTS RELATED TO RM1

Test number	VS1_VC1	VS1_VC2	VS1_VC3	VS1_VC4	VS1_VC5	VS1_VC6
Complexity	3	3	3	3	2	1
Number of project years	20	20	20	20	20	20
Project discount rate	7.25%	7.25%	7.25%	7.25%	7.25%	N.D.
Device type	Tidal	Tidal	Tidal	Tidal	Tidal	Tidal
Device topology	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Device Rated power (kW)	1,115	1,115	1,115	1,115	1,115	1,115
Number of devices	1	10	50	100	10	10
Total device structural costs (€)	716,059	4,609,531	19,199,597	36,189,654	4,609,531	4,609531
Unit device structural costs (€)	716,059	460953	383,992	361897	460953	460,953
Other costs (€)	23,704,237	31,681,033	55,318,804	83145673	31681033	31,681,033
Energy market price (€/kWh)	0.06	0.06	0.06	0.06	0.06	N.D.
Grant financing	None	None	None	None	None	N.D.
Feed-in tariff value (€/kWh)	0.200	0.200	0.200	0.200	0.200	N.D.
Number of years of FIT	20	20	20	20	20	N.D.
Average Capture Width Area (ACCW)	4.2					
Surface area (m2)	2520					
Structural mass of device (kg)	800,000					
Struct. Thickness (m)	0.04					
Cost of manufacture (€/kg)	3.00					
Annual Energy Production (kWh)	2,727,000	27,270,000	136,350,000	272,700,000	27,270,000	27,270,000
Cost of ET system (€)	1,908,099	16,785,485	77,144,340	156,571,396	16,785,485	16,785,485
Cost of ED system (€)	43,200	175,200	811,200	1,579,200	175,200	17,5200
Cost of SK system (€)	558,491	4,190,536	19,274,506	38,126,339	4,190,536	419,0536
Cost Inst. devices (€)	872,215	1,992,899	6,973,719	13,629,725	1,992,899	1,992,899
Cost Inst. Anchors & foundations (€)	6,128,696	6,733,683	9,422,517	12,783,558	6,733,683	6,733,683
Cost Inst. moorings (€)	-	-	-	-	-	-
Cost Inst. cables (€)	1,628,674	2,850,626	8,281,526	11,449,551	2,850,626	2,850,626
Cost inst. CP (€)	-	-	-	-	-	-
Other inst costs[3] (€)	667,000	767,200	1,534,000	2,301,600	767,200	767,200
OPEX /yr (€)	1,599,527	3,333,230	6,176,040	9,471,187	3,333,230	3,333,230
Cost of Equipment (€)	3,225,849	25,760,753	116,429,643	232,466,589	25,760,753	25,760,753

[3] Included in Other Costs

TABLE 3.23: LIST OF VERIFICATION CASES OF SYSTEM LIFETIME COSTS RELATED TO RM3

Test number	VS2_VC1	VS2_VC2	VS2_VC3	VS2_VC4	VS2_VC5	VS2_VC6
Complexity	3	3	3	3	2	1
Number of project years	20	20	20	20	20	20
Project discount rate	7.25%	7.25%	7.25%	7.25%	7.25%	N.D.
Device type	Wave	Wave	Wave	Wave	Wave	Wave
Device topology	Float	Float	Float	Float	Float	Float
Device Rated power (kW)	286	286	286	286	286	286
Number of devices	1	10	50	100	10	10
Total device structural costs (€)	2,939,052	20,674,690	91,548,379	177,933,334	20,674,690	20,674,690
Unit device structural costs (€)	2,939,052	2,067,469	1,830,968	1,779,333	2,067,469	2,067,469
Other costs (€)	7,451,139	22,747,083	51,132,679	87,953,619	2,2747,083	22,747,083
Energy market price (€/kWh)	0.06	0.06	0.06	0.06	0.06	N.D.
Grant financing	None	None	None	None	None	N.D.
Feed-in tariff value (€/kWh)	0.200	0.200	0.200	0.200	0.200	N.D.
Number of years of FIT	20	20	20	20	20	N.D.
Average Capture Width Area (ACCW)	4.2					
Surface area (m2)	2520					
Structural mass of device (kg)	800,000					
Struct. Thickness (m)	0.04					
Cost of manufacture (€/kg)	3.00					
Annual Energy Production (kWh)	700,735	7,007,352	35,036,762	70,073,523	7,007,352	7,007,352
Cost of ET system (€)	623,464	4,936,833	21,684,569	41,283,900	4,936,833	4,936,833
Cost of ED system (€)	990,000	990,000	3,696,000	9,570,000	990,000	990,000
Cost of SK system (€)	524,775	4,722,975	23,614,875	47,229,750	4,722,975	4,722,975
Cost Inst. devices (€)	255,203	916,275	3,854,375	7,527,000	916,275	916,275
Cost Inst. Anchors & foundations (€)	-	-	-	-	-	-
Cost Inst. moorings (€)	3,193,834	3,904,559	7,063,961	11,013,214	3,904,559	3,904,559
Cost Inst. cables (€)	1,507,534	2,280,165	4,503,815	7,283,377	2,280,165	2,280,165
Cost inst. CP (€)	-	-	-	-	-	-
Other inst costs[4] (€)	951,953	1,980,975	6,109,075	12,036,000	1,980,975	1,980,975
OPEX/yr (€)	1,166,779	61,172,579	207,098,652	389,794,193	61,172,579	61,172,579
Cost of Equipment (€)	5,077,291	31,324,499	140,543,823	276,016,984	31,324,499	31,324,499

[4] Included in Other Costs

TABLE 3.24: OTHER COSTS TABLE FOR RM1

Farm size	1	10	50	100
Development Costs (€)	5.0E+06	7.6E+06	9.9E+06	1.1E+07
Infrastructure Costs (€)	1.4E+07	1.4E+07	1.4E+07	1.4E+07
Subsystem Integration & Profit Margin Costs (€)	3.2E+05	2.6E+06	1.2E+07	2.3E+07
Installation: Cable shore landing (€)	6.7E+05	7.7E+05	1.5E+06	2.3E+06
Installation: Transport to staging site (€)	-	-	-	-
Contingency costs (€)	3.2E+06	6.3E+06	1.8E+07	3.2E+07
Total other costs (€)	**2.37E+07**	**3.2E+07**	**5.5E+07**	**8.3E+07**

TABLE 3.25: OTHER COSTS TABLE FOR RM3

Farm size	1	10	50	100
Development Costs (€)	4.6E+06	8.8E+06	1.1E+07	1.1E+07
Infrastructure Costs (€)	0.0E+00	3.9E+06	3.9E+06	7.7E+06
Subsystem Integration & Profit Margin Costs (€)	3.6E+05	2.6E+06	1.1E+07	2.2E+07
Installation: Cable shore landing (€)	6.7E+05	7.7E+05	7.7E+05	1.5E+06
Installation: Transport to staging site (€)	3.0E+04	3.0E+05	1.5E+06	3.0E+06
Installation: Commissioning (€)	2.6E+05	9.2E+05	3.9E+06	7.5E+06
Contingency costs (€)	1.6E+06	5.6E+06	1.9E+07	3.5E+07
Total other costs (€)	**7.45E+06**	**2.3E+07**	**5.1E+07**	**8.8E+07**

3.2.4 COLLECTION OF DATA REQUIRED

Running the verification cases in the System Lifetime Costs module requires a set of input data, which were mostly collated from the Sandia reports, and in some cases, synthetic data sets were produced where real data was not available.

The data requirements for the SLC module can be summarised as follows:

- General inputs: inputs related to the device and project characteristics (see Table 3.26).

Financial inputs: electricity selling price, financing strategies (grant, feed-in tariffs and durations, market price), as shown in

- Table 3.27.
- ACE inputs: optional inputs to calculate the ACE metric as a proxy for the LCOE (see Table 3.28).
- External inputs: inputs produced from other modules, such as the BOMs, the hierarchies and AEP (see Table 3.29).
- Catalogue of reference projects: CAPEX, OPEX, LCOE and cost breakdowns for different project development maturities.

TABLE 3.26: GENERAL PROJECT INPUTS

Project parameters	Default	Data origin	Units
Discount rate (suggested value)	10%	User	%
Project lifetime	20	User/LMO	years
Device type (WEC/tidal)	Required	User/MC	-
Device topology (floating/fixed)	Required	User/MC	-
Device rated power	Required	User/ET	kW
Device structural costs	Required	User	€/unit
Number of devices	Required	User/MC	-
Other CAPEX costs	Required	User	€

TABLE 3.27: FINANCIAL INPUTS

Financial input parameters	Default	Data origin	Units
Electricity market price	Required	User	€/kWh
Grant value	Optional	User	€
FIT price	Optional	User	€/kWh
Years of FIT	Optional	User	years

TABLE 3.28: ALTERNATIVE ECONOMIC METRICS (ACE)

Alternative economic metrics	Default	Data origin	Units
Average Climate Capture Width (ACCW)	Optional	User	m
Total surface area	Optional	User	m²
Structural thickness	Optional	User	m
Material density	Optional	User	years
Cost of manufacture per unit mass	Optional	User	€/kg

TABLE 3.29: EXTERNAL MODULE INPUTS

External module inputs	Default	Data origin	Units
Energy Transformation Bill of Materials	Required	ET	-
Energy Delivery Bill of Materials	Required	ED	-
Station Keeping Bill of Materials	Required	SK	-
Logistics and Marine Operations Bill of Materials	Required	LMO	-
Annual Energy Production	Required	SPEY	kWh/year
Maintenance solution	Required	LMO	-

3.3 RELIABILITY, AVAILABILITY, MAINTAINABILITY AND SURVIVABILITY (RAMS)

3.3.1 USER FLOW AND EXPERIENCE

The Reliability Availability Maintainability, and Survivability (RAMS) module assesses the following metrics:

- **Reliability**: the ability of a structure or structural member to fulfil the specified requirements, during the working life, for which it has been designed.
- **Availability**: the probability that a system or component is performing its required function at a given point in time or over a stated period of time when operated and maintained in a prescribed manner. In engineering applications, the availability of a device is the ratio of the uptime to the sum of uptime and downtime during the design lifetime. The availability of the array is the arithmetic average of that of all devices in the array.
- **Maintainability**: the ability of a system to be repaired and restored to service when maintenance is conducted by personnel using specified skill levels and prescribed procedures and resources.
- **Survivability**: the probability that the critical structural and mechanical components can survive the ultimate and fatigue loads during the design lifetime.

The RAMS module requires outputs from the Deployment design tools plus user-defined data. Reliability, Maintainability, and Survivability assessments involve the theoretical probabilistic analysis. The theoretical basis for reliability assessment is the Fault Tree (FT) method, which graphically represents the logic dependencies of all the units in a system. The theoretical basis for maintainability is the classic reliability assessment method, which assumes that the time to repair (TTR) follows a probabilistic distribution. The theoretical basis for survivability assessment is the classic structural reliability analysis, which estimates the probability of failure (PoF) for the pre-defined failure mode based upon the limit state function. Compared to the other three, availability is relatively simple, without employing complicated theory.

The four assessments are independent from each other in the RAMS module. In standalone mode, the user should first define the basic inputs of a project. The user can choose to assess all of them or some of them. For each assessment, the user uploads the input files and enters the user-defined parameters, then checks the input summary, finally runs the assessment.

RAMS's functionalities include:

- **Reliability assessment**
  - Estimating the maximum, mean and standard deviation of time to failure (TTF) of basic components in Energy Delivery (ED), Energy Transformation (ET) and Station Keeping (SK) subsystems.
  - Estimating the maximum, mean and standard deviation of TTF of the ED, ET, SK subsystems and the array.
  - Calculating the maximum annual probabilities of failure (PoFs) of the ED, ET, SK subsystems and the array.

- **Availability assessment**
  - Calculating the availability of all the devices and the average availability of the array.
- **Maintainability assessment**
  - Calculating the probability that the damaged components can be successfully repaired or replaced in a period of time, given the equipment and the resources.
- **Survivability assessment**
  - Calculating the probability that the critical structural/ mechanical components can survive the ultimate loads/ stresses during the design lifetime.
  - Calculating the probability that the critical structural/ mechanical components can survive the fatigue loads/ stresses during the design lifetime.

The main outputs of this module are:

- The maximum, mean, and standard deviation of time to failure (TTF) of basic components in Energy Delivery (ED), Energy Transformation (ET) and Station Keeping (SK) subsystems.
- The maximum, mean, and standard deviation of TTF of the ED, ET, SK subsystems and the array.
- The maximum annual probabilities of failure (PoFs) of the ED, ET, SK subsystems and the array.
- The availability of all the devices and the average availability of the array.
- The probability that the damaged components can be successfully repaired or replaced in a period of time, given the equipment and the resources.
- The survival probability under the ultimate limit state (ULS).
- The survival probability under the fatigue limit state (FLS).

3.3.2 USER STORIES

RAMS verification needs to take into account the following user stories, which respectively correspond to four assessments. It is assumed that the user has the technical competency and knowledge.

- **Reliability**:
  1. The user has designed an array which mainly comprises the ED, ET, and SK subsystems.
  2. The user would like to know how long it will take before basic components fail (namely mean TTF) and the uncertainties of TTF (the standard deviation of TTF and the maximum TTF).
  3. The user would like to know how long it will take before the subsystems fail (namely mean TTF) and the uncertainties of TTF (the standard deviation of TTF and the maximum TTF).
- **Availability**:
  1. The user has designed an array composed of *M* devices. The user would like to know how many hours each device can work normally and the average normal working hours of the array.
- **Maintainability**:
  1. There is such a scenario in which a basic component fails. Suppose it is a critical component, the mean time to repair (TTR) is μ_{repair} (assumed to be in a begin weather) and the available time window for repairing it is t_{ava} hour. Based upon the engineering experience, the time

to repair follows the Gaussian distribution. The technician is expected to repair it in a begin weather and is given all the necessary spare parts and tools. The user would like to know the probability that the technician can successfully repair it within t_{ava}.

- **Survivability**:
  1. Suppose that the user only cares about the structural integrity of the array, e.g. mooring lines, PTOs.
  2. The user has performed structural analyses to obtain the ultimate loads or stresses and the fatigue stress ranges of critical components. The user would like to know the probabilities that these critical components can survive the ultimate loads or stresses and the fatigue stress ranges during the design lifetime.

3.3.3 DEFINITION OF THE VERIFICATION CASES

The RAMS module, as an assessment tool, requires the outputs of the Deployment tools, namely the ED, ET, SK and LMO modules. Therefore, the scenarios in the verification cases should be aligned with those chosen by these modules as much as possible in order to give logically consistent assessment results.

There are six verification cases defined to test the reliability, availability, maintainability, and survivability assessments (see Table 3.30). In the column "Level of Complexity", "1 or 2 or 3" is added for reliability, availability and maintainability, because the code in Business Logic Is the same. For Complexity 1, the code for Survivability (ULS and FLS) assessment only includes the Monte Carlo Simulation approach, while First Order Second Moment (FORM) is added for Complexity 2& 3 besides the Monte Carlo Simulation approach. FORM is an analytical solution involving calculation of the multi-variate gradients, which might cause the numerical problem for few highly nonlinear limit state functions. Therefore, the Monte Carlo Simulation approach is used for verification.

TABLE 3.30: FEATURES AND TOTAL NUMBER OF VERIFICATION CASES FOR RAMS

Feature	Levels of complexity	Other option	Total cases
Availability	1 or 2 or 3	n/a	1
Maintainability	1 or 2 or 3	n/a	1
Reliability (component)	1 or 2 or 3	n/a	1
Reliability (system)	1 or 2 or 3	n/a	1
Survivability (ULS)	1	X	1
Survivability (FLS)	1	X	1

Reliability contains two cases representing the component-level and the system-level assessments. Survivability contains two cases representing the assessments from the ULS and FLS perspectives. Basically, these verification cases are chosen based upon the US DoE reference models (RM1 & RM3). As aforementioned, the layout, including the type and number of marine energy converters, should be aligned with that in the verification cases of the Deployment tools, as summarized below.

- A Tidal Array of 1 device using Sandia's Reference Model 1 (RM1).
- A Wave Array of 1 device using Sandia's Reference Model 3 (RM3).

3.3.4 COLLECTION OF DATA REQUIRED

The input data has been categorised in four groups corresponding to the four assessments.

3.3.4.1 REQUIRED INPUTS FOR RELIABILITY ASSESSMENT

Reliability assessment requires the hierarchies of the ED, ET, and SK subsystems, the number of simulations and the waiting time, as summarized in Table 3.31.

TABLE 3.31: SUMMARY OF INPUTS FOR RELIABILITY ASSESSMENT

External module inputs	Default	Data origin	Units
ED hierarchy	Required	ED or user-defined	-
ET hierarchy	Required	ET or user-defined	-
SK hierarchy	Required	SK or user-defined	-
Number of simulations	Required	User-defined	-
Average waiting time	Required	User-defined	hour

The data structure of these inputs is described as follows:

- **Hierarchy**: A hierarchy is a 2-D table array storing the information on the working philosophy and the interrelationship of the units at different levels reflected in a fault tree. See the template in Table 3.32. The first column gives the subsystem or system to be analysed. All failure events are considered nodes in the hierarchy. The second column, 'Name of Node', gives the names of these failure events. The third column, 'Design Id', gives the identification labels of the basic components and other units. The column, 'Node Type', defines the levels of a hierarchy. The column, 'Node SubType', defines the additional information the design modules use to identify the corresponding node. The column, 'Category', defines which levels the nodes in the 'Name of Node' column belong to in the fault tree. The columns 'Parent' and 'Child' define the dependencies of units at various levels. Each entry in 'Parent' defines the label of the higher-level unit which the current unit in the column 'Name of Node' belongs to. Each entry in 'Child' defines the labels of lower-level units which belong to the current unit. Based upon the aforementioned descriptions, the units in the column 'Child' are connected through a specific logic gate to the higher-level unit. The logic gates are given in the column 'Gate Type'. The logic gate in each entry of this column is used to connect the unit in the column 'Name of Node' and the units in the column 'Child'. The last two columns give the failure rates of basic components for two failure modes.

TABLE 3.32: EXAMPLE HIERARCHY TABLE

System	Name of Node	Design Id	Node Type	Node Subtype	Category	Parent	Child	Gate Type	Failure Rate Repair [1/hour]	Failure Rate Replacement [1/hour]

- **Number of simulations**: It is a scalar (integer). The Monte Carlo Simulation approach is used to estimate the time to failure (TTF) of basic components, namely the nodes on the bottom most level of the fault tree. The TTF of the subsystem can be further estimated, based upon the logic dependencies in the hierarchy. The TTF of basic components are randomly sampled, which means there is uncertainty. With the aim to quantify the uncertainty, a large number of simulations is needed.

- **Average waiting time**: It is a scalar (float). When a certain number of components fail, the subsystem fails. It takes time to repair or replace failed components and recover the subsystem. The time duration between the subsystem failure and the subsystem recovery is called waiting time (or called downtime in some textbooks; to avoid misunderstanding, waiting time is used).

Further details are provided in the theoretical background of the RAMS alpha deliverable [10] and a corresponding academic paper [11]

3.3.4.2 REQUIRED INPUTS FOR AVAILABILITY ASSESSMENT

Availability assessment requires the downtime of all the devices in an array, as summarized in Table 3.33.

TABLE 3.33: SUMMARY OF INPUTS FOR AVAILABILITY ASSESSMENT

External module inputs	Default	Data origin	Units
Downtime	Required	LMO or user-defined	-

The data structure of downtime for one device is described as follows:

- **Downtime**: It is a dictionary containing such keys as 'year' and the first three letters of twelve calendar months (e.g. 'jan' represents January). The content of 'year' is a 1D list containing the labels of calendar years starting from 0. The content of calendar month is a 1D list containing the downtime of this month in different years in the list of 'year'.

3.3.4.3 REQUIRED INPUTS FOR MAINTAINABILITY ASSESSMENT

Maintainability assessment requires the downtime of all the devices in an array, as summarized in Table 3.34.

TABLE 3.34: SUMMARY OF INPUTS FOR MAINTAINABILITY ASSESSMENT

External module inputs	Default	Data origin	Units
Available time	Required	User-defined	hour
Probability distribution of repair time	Required	User-defined	-
Standard deviation of repair time	Required	User-defined	hour
MTTR	Required	LMO or user-defined	hour
Technologies	Required	LMO or user-defined	-

The data structure of these inputs is described as follows:

- **Available time**: It is a scalar (float). It refers to the available time that is available for the technician to repair or replace the failed component.
- **Probability distribution of repair time**: It is a string. It refers to the chosen probability distribution of repair time.
- **Standard deviation of repair time**: It is a scalar (float). The repair time is a stochastic variable. The standard deviation is needed to define the probability distribution.
- **MTTR**: It is a 1D list containing the mean time to failure of failed components.
- **Technologies**: It is a 1D list containing the names of failed components.

3.3.4.4 REQUIRED INPUTS FOR SURVIVABILITY ASSESSMENT

Survivability assessment requires many inputs, as summarized in Table 3.35. Other parameters required are elaborated on in Table 3.36.

TABLE 3.35: SUMMARY OF INPUTS FOR SURVIVABILITY ASSESSMENT

External module inputs	Default	Data origin	Units
Stress_sk.json	Required	SK or User-defined	-
Stress_et.json	Required	ET or User-defined	-
Other parameters	Required	Default or User-defined	-

TABLE 3.36: EXPLANATION OF OTHER PARAMETERS FOR SURVIVABILITY ASSESSMENT

Parameters	Format	Explanation
cov_a	float	The coefficient of variance of the S-N curve parameter a
cov_l	float	The coefficient of variance of the extreme/ultimate load
cov_q	float	The coefficient of variance of the scale parameter of the 2-parameter Weibull distribution (assumed that the long-term stress ranges follow the 2-parameter Weibull distribution)
cov_r	float	The coefficient of variance of the resistance (maximum breaking load, MBL) of the mooring lines
cov_ufl	float	The coefficient of variance of the uncertainty factor associated with the load
cov_ufr	float	The coefficient of variance of the uncertainty factor associated with the resistance
mu_ufl	float	The mean value of the uncertainty factor associated with the load
mu_ufr	float	The mean value of the uncertainty factor associated with the resistance
n_sim_fls	integer	The number of simulations for the survivability assessment (fatigue limit state, FLS)
n_sim_uls	integer	The number of simulations for the survivability assessment (ultimate limit state, ULS)
option_fls	string	The method used for assessing the survivability (FLS), option 1 – 'Monte Carlo' (for complexity 1, 2 & 3); option 2 – 'FORM' (for complexity 2 & 3)
option_uls	string	The method used for assessing the survivability (ULS), option 1 – 'Monte Carlo' (for complexity 1, 2 & 3); option 2 – 'FORM' (for complexity 2 & 3)
pd_a	string	The probability distribution of the S-N curve parameter a
pd_h	string	The probability distribution of the shape parameter of the 2-parameter Weibull distribution (assumed that the long-term stress ranges follow the 2-parameter Weibull distribution)
pd_l	string	The probability distribution of the load
pd_m	string	The probability distribution of the S-N curve parameter m
pd_n	string	The probability distribution of the number of stress range cycles
pd_q	string	The probability distribution of the scale parameter of the 2-parameter Weibull distribution (assumed that the long-term stress ranges follow the 2-parameter Weibull distribution)
pd_r	string	The probability distribution of the resistance
pd_ufl	string	The probability distribution of the uncertainty factor associated with the load
pd_ufr	string	The probability distribution of the uncertainty factor associated with the resistance

It should be noted that: if Log-normal is chosen for a stochastic variable, the mean and standard deviation should be those of logged variable. For example, suppose a stochastic variable X following the Log-normal distribution. $\mu_{\ln(X)}$ and $\sigma_{\ln(X)}$ should be the inputs. The relationship of mean and standard deviation between X and log(X) can be given as follows:

With μ_X and σ_X known, $\mu_{\ln(X)}$ and $\sigma_{\ln(X)}$ are expressed as:

$$\sigma_{\ln(X)} = \sqrt{\ln\left[1 + \left(\frac{\sigma_X}{\mu_X}\right)^2\right]}$$

$$\mu_{\ln(X)} = \ln(\mu_X) - \frac{1}{2}\sigma_{\ln(X)}^2$$

The data structure of stress_sk.json and stress_et.json are described as follows:

- stress_sk.json: It is a json file, which contains the following data relevant for survivability assessment in Table 3.37.

TABLE 3.37: EXPLANATION OF THE DATA IN STRESS_SK.JSON

Data	Key Name in stress_sk.json
The ultimate loads on the mooring lines	devices[i][“uls_results”][“mooring_tension”]
The maximum breaking loads (MBL) of the mooring lines	devices[i][“uls_results”][“mbl_uls”]
The stress ranges on the mooring lines	devices[i][“fls_results”][“cdf_stress_range”]
The cumulative distribution functions (CDFs) of the stress ranges	devices[i][“fls_results”][“cdf”]
The S-N curve parameter a	devices[i][“fls_results”][“ad”]
The S-N curve parameter m	devices[i][“fls_results”][“m”]
The number of stress range cycles	devices[i][“fls_results”][“ n_cycles_lifetime”]

- stress_et.json: It is a json file, which contains the following data relevant for survivability assessment in Table 3.38.

TABLE 3.38: EXPLANATION OF THE DATA IN STRESS_ET.JSON

Data	Key Name in stress_et.json
The label of the critical device	“device_id”
The mean of the S-N curve parameter a	“mu_a”
The standard deviation of the S-N curve parameter a	“std_a”
The S-N curve parameter m	“m”
The shape parameter of the 2-p Weibull distribution for the long-term stress ranges	“h”
The mean scale parameter of the 2-p Weibull distribution for the long-term stress ranges	“mu_q”
The standard deviation of scale parameter of the 2-p Weibull distribution for the long-term stress ranges	“mu_q”
The mean of the ultimate load	“mu_l”
The standard deviation of the ultimate load	“std_l”
The number of cycles of stress ranges	“n”

It should be re-iterated that the inputs in stress_et.json (summarised in Table 3.38) are only for the purpose of stand-alone verification. The data format of inputs can be changed/improved, because of updates in the ET module. See the details in Annex I (Section 7.4.3).

The readers, who are interested in knowing details, can refer to the theoretical background of the RAMS alpha deliverable [10] and the textbook Methods of Structural Safety [12].

3.4 ENVIRONMENTAL AND SOCIAL ACCEPTANCE (ESA)

3.4.1 USER FLOW AND EXPERIENCE

The Environmental and Social Acceptance module (ESA) aims to assess the environmental and social impacts generated by the various technology choices and array configurations of wave or tidal devices. It has four main objectives:

1. Identify the potential presence in the area of endangered species classified as such by the IUCN[5] and listed in international conventions and European directives [namely, Barcelona Convention[6]; Berne Convention[7]; Bonn Convention[8]; Helcom Convention[9]; Ospar Convention[10]; Washington Convention[11]; Habitat Directive[12]; Birds Directive[13]; and Marine Strategy Framework Directive[14]].
2. Assess the environmental impacts generated by the various technology choices and array configurations of wave or tidal devices, in terms of pressure existence (e.g. chemical pollution or collision risk with marine fauna) and associated receptor sensitivity (e.g. marine mammals or sensitive seafloor habitats).
3. Perform a life cycle assessment of a project following the structure of Life Cycle Assessment (LCA) process defined by the standards ISO 14040 and ISO 14044. Estimate the carbon footprint of the project at the different phases of the project (*i.e.* production, installation, maintenance, decommissioning, and treatment) in terms of two mid-point indicators, namely the Global Warming Potential (GWP) and the Cumulative Energy Demand (CED).
4. Provide insight on social acceptance of the project in terms of cost of consenting and jobs creation during the farm lifetime.

Environmental and Social Acceptance evaluation is carried out based on the design outputs of deployment design tools with project characteristics and preferences introduced by the user.

In standalone mode, the user first sets up a study, before entering inputs of the project. Once these inputs are complete, the user can run the module and view the results of the assessment for which the main outputs include:

- **Endangered species**: Provides a list of taxonomic information on endangered species potentially present in the area. For each species, this feature provides insight on the main risks and recommendations on mitigation measures. Even if the module has not identified any endangered species in the area, a warning is displayed that all marine birds and mammals are protected and that measures to monitor should be considered anyway.

[5] IUCN (www.iucn.org)
[6] Barcelona Convention (http://web.unep.org/unepmap/)
[7] Berne Convention (https://www.coe.int/en/web/bern-convention/presentation)
[8] Bonn Convention (https://www.cms.int/en/legalinstrument/cms)
[9] Helcom Convention (https://helcom.fi/about-us/convention/)
[10] Ospar Convention (https://www.ospar.org/convention)
[11] Washington Convention (https://www.cites.org/eng/disc/text.php)
[12] Habitat Directive (Council Directive 92/43/EEC)
[13] Birds Directive (Directive 2009/147/EC)
[14] Marine Strategy Framework Directive (Directive 2008/56/EC)

- **Carbon footprint**: Global results inform the user about the overall Carbon footprint of the project in terms of global warming potential, cumulative energy demand and energy payback period. The user can compare these results to other types of energies or other technologies GWP and EPP (Energy Payback Period).
  - For each mid-point indicators (GWP and CED), results are also displayed per phase.
- **Environmental impact assessment**: Impact of 13 pressures is quantified and a positive and a negative score is given at array level or technology group level. Recommendations for each pressure are given to help improve environmental integration of the project.
- **Social acceptance**: The feature regroups information on relevant subjects for social acceptance of the project (Cost of consenting and number of jobs).

3.4.2 USER STORIES

10 user stories can be described for the ESA module, that can be divided evenly in two main modes:

- Integrated, when the user uses all modules of DTOceanPlus to produce the inputs for ESA: this mode will not be tested during the Verification activities, but the user stories are the same as standalone mode.
- Standalone mode, in which the user will provide all needed information to run the module. This mode will be tested while running the Verification cases and includes 5 user stories:
  1. *"The user has an idea of the coordinates where the farm is to be installed. The user would like to get information on endangered species potentially present in the chosen area of the farm. The user has no prior information on the presence of one or more species, qualified as endangered or worst."*
  2. *"The user has an idea of the coordinates where the farm is to be installed. The user would like to get information on endangered species potentially present in the chosen area of the farm. The user has prior information on the presence of one or more species, qualified as endangered or worst."*
  3. *"The user is quite advance on the design of all the project: site, device, foundations, electrical parts and logistics. The user wants to assess environmental impacts of the different design choices. The user wants quantitative evaluation of the design regarding several pressures induced on receptors present in the environment."*
  4. *"The user has information on materials and manufacturing processes used in the project and information on marine operations scheduled during the lifetime of the project. The user wants to run a life cycle assessment of the whole project and to have information on potential global warming due to emissions of greenhouse gases to air (Global Warming Potential in $kgCO_{2\_eq}$) and use of non-renewable energy (Cumulative Energy Demand in MJ)."*
  5. *"The user has information on number of jobs involved in the whole project and on cost of consenting. The user wants information on how to increase social acceptance of the project."*

The verification tests of the ESA module are based on two scenarios (RM1 and RM3) and divided as follows:

- RM1 will use user story 1, 4 and 5.
- RM3 will use user story 2 and 3.

3.4.3 DEFINITION OF THE VERIFICATION CASES

The features and total number of verification cases for ESA are detailed in Table 3.39.

TABLE 3.39: FEATURES AND TOTAL NUMBER OF VERIFICATION CASES FOR ESA

Feature	Optional user inputs	Running mode (standalone/integrated)	Total cases
Endangered species	2	2	4
Carbon footprint	1	2	2
Environmental impact Assessment	1	2	2
Social acceptance	1	2	2

3.4.4 COLLECTION OF DATA REQUIRED

3.4.4.1 USER STORIES 1, 4 AND 5

The information necessary to run the verification cases for **User Stories 1**, **4** and **5** of ESA are given in Table 3.40 to Table 3.51.

SITE DATA

TABLE 3.40: FARM GENERAL INFORMATION

Inputs description	Value	Units
Coordinates of the farm	Long : -122.55° ; Lat : 47.28°	Decimal degrees
Project lifetime	20	-
LCOE	56	€/MW

DEVICE DATA

TABLE 3.41: DEVICE GENERAL INFORMATION

Inputs description	Value	Units
Type of technology	Tec	-
Number of devices	10	-
Floating device	No	-

TABLE 3.42: DEVICE MATERIAL QUANTITY

Inputs description	Value	Units
Non-allowed steel	Assumed to be 503600	kg

TABLE 3.43: DEVICE MATERIALS QUANTITY TO RECYCLE

Inputs description	Value	Units
Non-allowed steel	Assumed to be 503600	kg

FOUNDATION DATA

TABLE 3.44: FOUNDATION MATERIALS QUANTITY

Inputs description	Value	Units
Non-allowed steel	1497953.2 (calculated in RM1-SK3)	kg

TABLE 3.45: FOUNDATION MATERIALS QUANTITY TO RECYCLE

Inputs description	Value	Units
Non-allowed steel	1497953.2	kg

ELECTRICAL DATA

TABLE 3.46: ELECTRICAL GENERAL INFORMATION

Inputs description	Value	Units
Annual Energy Production	30000000	kWh

TABLE 3.47: ELECTRICAL MATERIALS QUANTITY

Inputs description	Value	Units
Copper	Assumed to be 102000	kg
Polyethylene HD	Assumed to be 61200	kg

TABLE 3.48: ELECTRICAL MATERIALS QUANTITY TO RECYCLE

Inputs description	Value	Units
Copper	0	kg
Polyethylene HD	0	kg

LOGISTICS DATA

TABLE 3.49: INSTALLATION PHASE INFORMATION

Inputs description	Value	Units
Number of passengers on board	26	-
Fuel consumptions	Assumed to be 500000	kg

TABLE 3.50: EXPLOITATION PHASE INFORMATION

Inputs description	Value	Units
Number of passengers on board	20	-
Fuel consumptions	Assumed to be 1000000	kg

TABLE 3.51: DECOMMISSIONING PHASE INFORMATION

Inputs description	Value	Units
Number of passengers on board	26	-
Fuel consumptions	Assumed to be 200000	kg

3.4.4.2 USER STORIES 2 AND 3

The information necessary to run the verification cases for **User Stories 2** and **3** of ESA are given in Table 3.52 to Table 3.61:

SITE DATA

TABLE 3.52: FARM GENERAL INFORMATION

Inputs description	Value	Units
Coordinates of the farm	-124.26; 40.77	Decimal degrees
Project lifetime	20	-

TABLE 3.53: AREA DESCRIPTION

Inputs description	Value	Units
Zone type	Open water	-
Water depth	40	m
Main current direction (theta of the max mag)	214	°
Total surface area of the farm	282743	m^2
Soil type	Medium dense sand	-

TABLE 3.54: INITIAL STATE

Inputs description	Value	Units
Initial turbidity of the site	10	mg/l
Initial underwater noise	Assumed to be 124	dB re 1 µPa
Initial electrical fields	0.000001	V/m
Initial magnetic fields	Assumed to be 0.005	µT
Initial temperature	Assumed to be 14	°C

TABLE 3.55: FISHING RESTRICTIONS

Inputs description	Value	Units
Considered fishery restriction	Complete prohibition	-

TABLE 3.56: PROTECTED SPECIES

Inputs description	Value	Units
Endangered species	*Tursiops truncatus*	Mammals

TABLE 3.57: RECEPTORS

Inputs description	Value	Units
Hard substrate benthic habitat	True	-
Soft substrate benthic habitat	False	-
Particular habitat	False	-
Shallow diving birds	True	-
Medium diving birds	True	-
Deep diving birds	True	-
Large odontocete Mysticete	False	-
Odontocete dolphins	August, September, October	-
Seals	False	-
Fishes	True	-
Bony fishes	True	-
Magnetosensitive species	True	-
Electrosensitive species	True	-
Elasmobranchs	True	-

DEVICE AND FOUNDATIONS DATA

TABLE 3.58: DEVICE GENERAL INFORMATION

Inputs description	Value	Units
Type of technology	WEC	-
Floating	True	-
Number of devices	1	-
Coordinates of device	0,0	UTM

TABLE 3.59: DEVICE DIMENSIONS

Inputs description	Value	Units
Emerged height	40	m
Largest width	30	m
Largest length	30	m
Wet area	3048	m^2
Dry area	561	m^2

TABLE 3.60: RESOURCES

Inputs description	Value	Units
Resource reduction	Assumed to be 0.97	%

TABLE 3.61: ENVIRONMENTAL MEASUREMENTS AROUND DEVICES

Inputs description	Value	Units
Measured noise due to device installation	Assumed to be 126	dB re 1 µ Pa
Measured turbidity around device	10	mg/l

TABLE 3.62: FISHERY RESTRICTIONS AROUND DEVICES

Inputs description	Value	Units
Fishery restriction surface around devices	282743	m^2

TABLE 3.63: FOUNDATION INFORMATION

Inputs description	Value	Units
Footprint	32.27	m^2
Surface of colonisable part	468.8	m^2
Measure noise around foundation	Assumed to be 129	dB re 1 µ Pa

ELECTRICAL DATA

TABLE 3.64: ELECTRICAL GENERAL INFORMATION

Inputs description	Value	Units
Colonisable surface electrical part	0.0	m^2
Footprint of electrical part	0.0	

TABLE 3.65: INSTALLATION INFORMATION

Inputs description	Value	Units
Collection point presence	No	-
Substation presence	No	-
Burial of cables	Yes	-
Fishery restriction surface around cables	Assumed to be 0.0	m^2
Measured noise	Assumed to be 124	dB re 1 µ Pa
Measured electrical field	Assumed to be 0.08	mV/m
Measured magnetic field	Assumed to be 0.038	µT
Measured temperature	Assumed to be 14.2	°C

TABLE 3.66: FISHING RESTRICTIONS AROUND CABLES

Inputs description	Value	Units
Fishery restriction surface around cables	Assumed to be 0.0	m^2

TABLE 3.67: ENVIRONMENTAL MEASUREMENTS AROUND CABLES

Inputs description	Value	Units
Measured noise	Assumed to be 126	dB re 1 µ Pa
Measured electrical field	Assumed to be 0.08	mV/m
Measured magnetic field	Assumed to be 0.038	µT
Measured temperature	Assumed to be 14.2	°C

LOGISTICS DATA

TABLE 3.68: INSTALLATION PHASE

Inputs description	Value	Units
Number of vessels	3	-
Mean size of vessels	100	m
Measured noise	Assumed to be 150	dB re 1 µPa
Measured turbidity	20	mg/l
Chemical pollutant	-	-

TABLE 3.69: EXPLOITATION PHASE

Inputs description	Value	Units
Number of vessels	2	-
Mean size of vessels	35	m
Measured noise	Assumed to be 126	dB re 1 µPa
Measured turbidity	10	mg/l
Chemical pollutant	-	-

TABLE 3.70: DECOMMISSIONING PHASE

Inputs description	Value	Units
Number of vessels	3	-
Mean size of vessels	100	m
Measured noise	Assumed to be 126	dB re 1 µPa
Measured turbidity	13	mg/l
Chemical pollutant	-	-

4. ANALYSIS OF RESULTS

A Software Evaluation Form has been used to gather all the insights coming from the first round of Verification Cases (VCs) by the technical verifier (EDP CNET). The same document has been filled by the industrial partners, who performed the second round of VCs. A completed version of this document, with the information coming from both the technical verifier and the industrial partners, is available at the end of this report (Annexes II and III). In this section, however, only the most relevant information will be presented.

Four characteristics have been evaluated while running the VCs for the S tool, namely:

- **Usability**, which deals with the high-level software experience.
- **User-friendliness**, to assess how much the software is easy to use.
- **Performance and Accuracy**, to determine the quality of results in terms of accuracy, robustness, and performance for each one of the main functionalities (features) of the software.
- **Value**, to assess the value perceived by the user.

The following subsections present the quantitative and qualitative results for each of the Assessment tools. The pagination has been spaced to keep the similar results together as much as possible.

4.1 RUNNING THE VERIFICATION CASES: SPEY

4.1.1 QUANTITATIVE ASSESSMENT

A total of five organisations completed the verification process for the different features of the SPEY tool (EDP, ENEL, BV, WES, and Sabella) and provided feedback by the Software Evaluation Form. Figure 4.1 shows the average scores across the four categories of evaluation, highlighting an overall satisfaction from using the tool, as all average scores are within the range of 3 to 5.

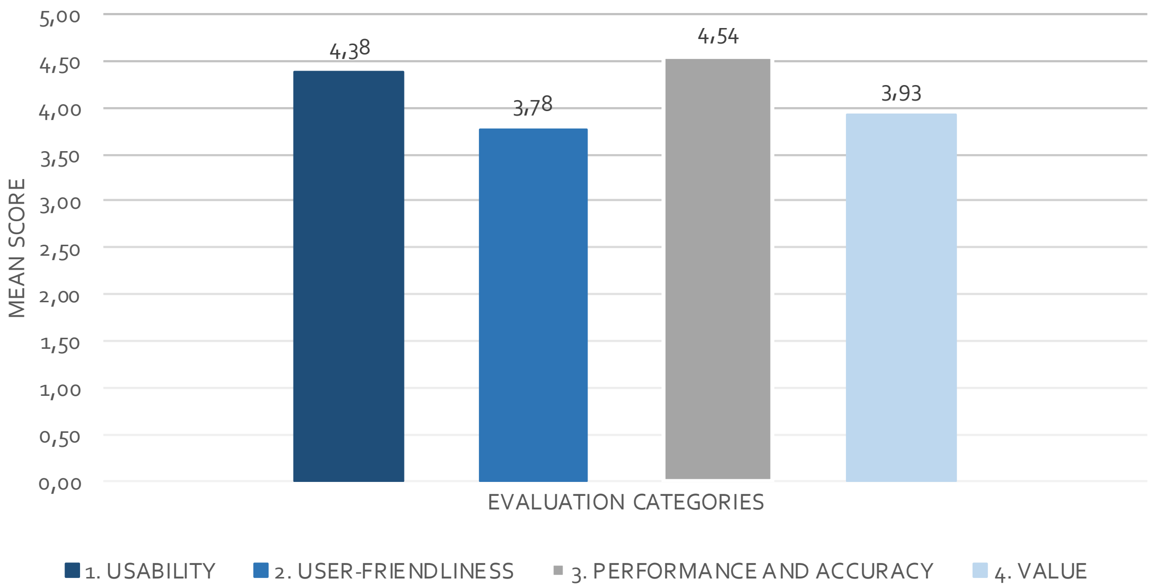

FIGURE 4.1: MEAN RATINGS OF THE EVALUATED CHARACTERISTICS

As can be seen in Figure 4.2, most of the participants of verification (84%) were satisfied with the usability of the SPEY tool. The majority of (65%) the respondents agree or strongly agree that the tool is generally user friendly. More than 85% (in average) of the respondents considered that the tool shows performance and accuracy. Around 80% of the users considered that the tool is valuable, while the remaining 20% is undecided. A further analysis on the results is described in the following sections.

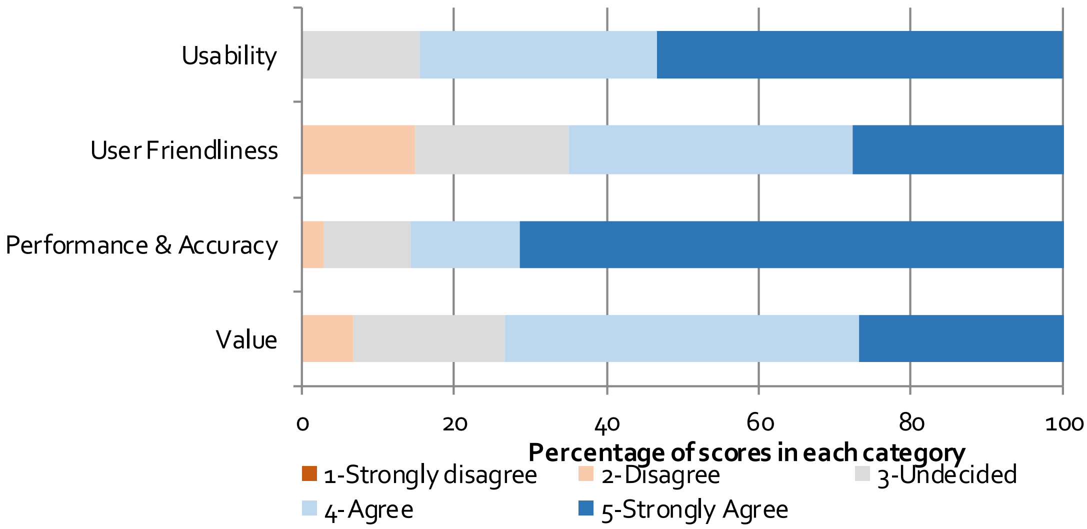

FIGURE 4.2: PERCENTAGE OF SCORES FOR THE FOUR KEY CATEGORIES

4.1.1.1 USABILITY

The following statements have been assessed in the *Usability* category.

TABLE 4.1: ASSESSED USABILITY CRITERIA

ID	Statement
1.1	The software is intuitive and easy to use in general
1.2	It is easy to create and delete a Study
1.3	It is easy to edit, save and export a Study
1.4	The process of inputting data is clear and efficient
1.5	Results are meaningful, easy to interpret and use
1.6	I could complete the process without errors
1.7	I am satisfied with the overall speed of computation
1.8	The software can be run from my computer without any issue
1.9	The training sessions and documentation are useful for learning how to use the software

Figure 4.3 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.4 using a spider chart, to highlight the mean, maximum and minimum values.

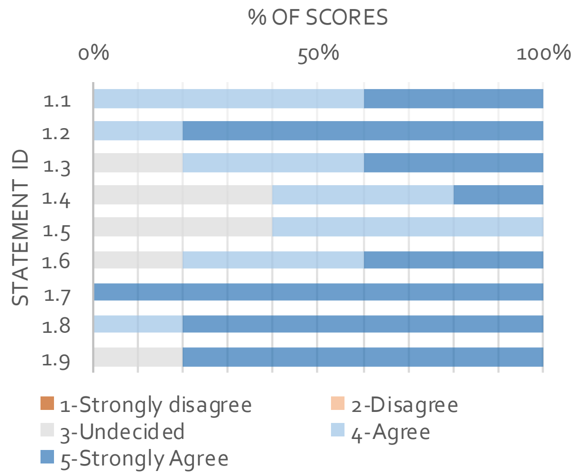

FIGURE 4.3: DISTRIBUTION OF USER SCORES PER USABILITY STATEMENT

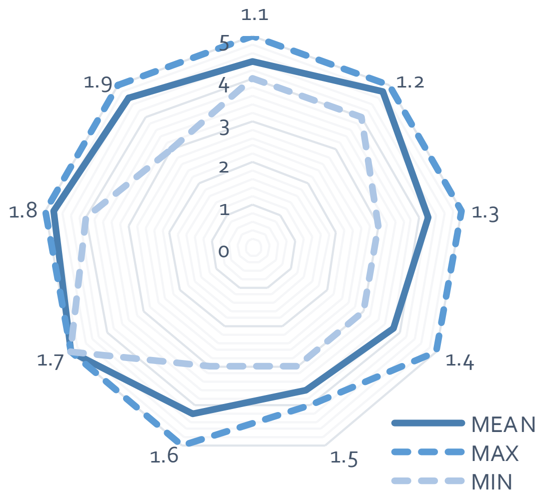

FIGURE 4.4: MEAN, MAXIMUM, AND MINIMUM SCORES PER USABILITY STATEMENT

In view of the results (Figure 4.3), the users agree unanimously that the tool is easy to use and intuitive (ID-1.1) as well as they find it very easy to create and delete a study (ID-1.2) and the users are satisfied with the speed of computation (ID-1.7) and they are able to run the software without any issue (ID - 1.8). More than half of the users (80%) found the process of editing, saving, and exporting a Study (ID-1.3) straightforward, and the same percentage could run the tool without any problem (ID-1.6). In general, the process of inputting data (ID-1.4) is clear and efficient, while the remaining 40% is undecided. More than half of the users (60%) find the results obtained meaningful and easy to interpret and use (ID-1.5), while 40% of the users are undecided.

On average the users find the documentation and the training sessions led by the software developer useful (80%) (ID-1.9, see Figure 4.4).

4.1.1.2 USER FRIENDLINESS

The following criteria in Table 4.2 were used for the *User Friendliness* category:

TABLE 4.2: ASSESSED USER FRIENDLINESS CRITERIA

ID	Statement
2.1	The user interface is simple, easy to navigate and well-organised
2.2	The user interface looks professional
2.3	It responds promptly to user actions (inputs, selections, clicks, ...)
2.4	It provides the user with enough help, indications and/or guidance throughout each process
2.5	The meaning of each data input/user selection is clear
2.6	The meaning of each data output is clear
2.7	Visualisation of results is clear and informative
2.8	The user can add further information to the Study through the interface

Figure 4.5 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.6 using a spider chart, to highlight the mean, maximum and minimum values.

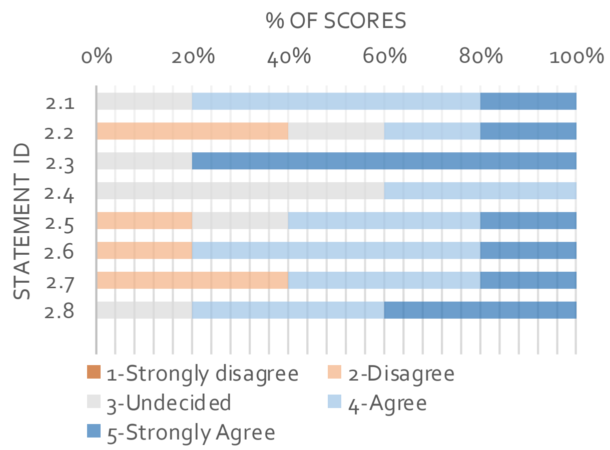

FIGURE 4.5: DISTRIBUTION OF USER SCORES PER USER-FRIENDLINESS STATEMENT

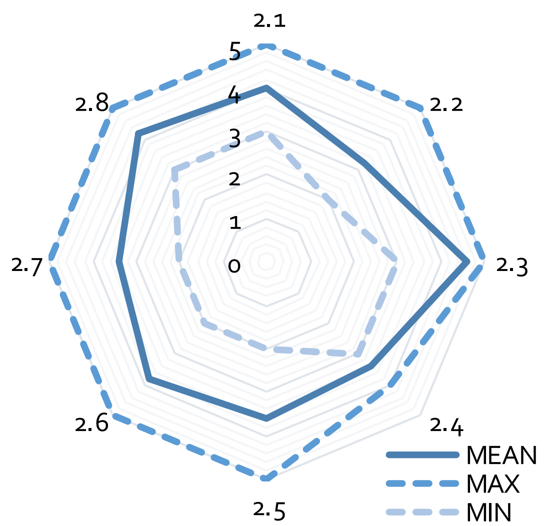

FIGURE 4.6: MEAN, MAXIMUM, AND MINIMUM SCORES PER USER-FRIENDLINESS STATEMENT

As can be seen in Figure 4.5, 80% of the respondents agree that the user interface is simple, easy to navigate and well-organised (ID-2.1), whereas the rest are undecided. It can be said that the user interface looks professional only for 40% of the users, while 20% of the users are undecided and 40% disagree with the statement ID-2.2. Similarly, for only 40% of the users the tool responds promptly to user actions, while the remaining 60% is undecided (ID-2.3). These last two areas could be seen as areas of improvement for the tool. Only 40% of the users say that the tool provides the user with enough help, indications and/or guidance throughout each process (ID-2.4), while the remaining 60% is undecided. This also can be an improvement area for the next version. The meaning of each data input/user selection and data output is clear for the users, with 60% of respondents agreeing with statements ID-2.5 and 80% agreeing with ID-2.6. The Visualisation of results is clear and informative according to respondents, with 60% agreeing with this statement (ID-2.7). The possibility of adding further information to the Study through the interface (ID-2.8) leaves only 20% of the users undecided, with the remaining 80% of the respondents agree with this statement.

The spider diagram in Figure 4.6 highlights a significant difference between the maximum and minimum scores, which may be due to the different levels of experience with similar tools or datasets by the users from different companies.

4.1.1.3 PERFORMANCE AND ACCURACY

Before the quantitative analysis is important to state that the presented results are the outcome of the test of eight different features of the tool. The statements presented on Table 4.3 were assessed regarding the *Performance and Accuracy* of the tool.

TABLE 4.3: ASSESSED PERFORMANCE AND ACCURACY CRITERIA

ID	Statement
3.1	Results are robust and not sensitive to small changes of inputs
3.2	Results are credible and trustworthy for the audience
3.3	The accuracy of results is acceptable considering the granularity/complexity of data inputs used
3.4	The accuracy of results corresponds to the user expectation for the stage of technology maturity
3.5	The computational time is adequate for the level of accuracy provided
3.6	The software did not suffer from any sort of data shortage/lack of memory during the test
3.7	The software can handle errors without crashing

Figure 4.7 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.8 using a spider chart, to highlight the mean, maximum and minimum values.

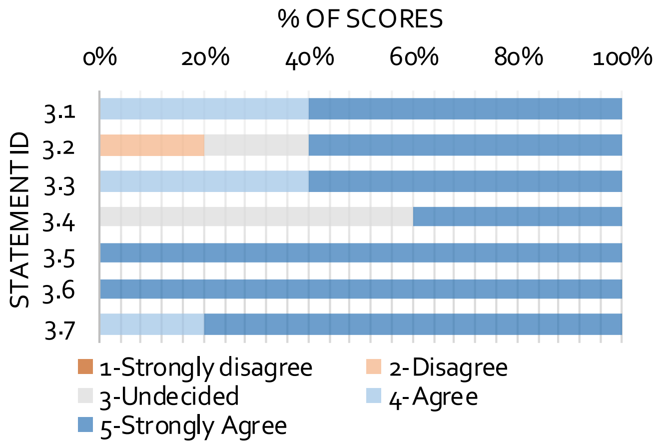

FIGURE 4.7: DISTRIBUTION OF USER SCORES PER PERFORMANCE AND ACCURACY STATEMENT

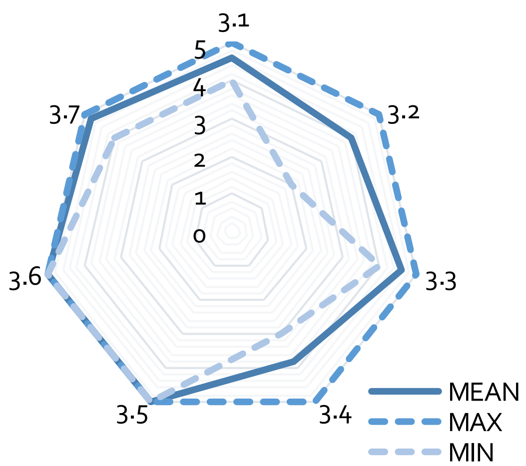

FIGURE 4.8: MEAN, MAXIMUM, AND MINIMUM SCORES PER PERFORMANCE AND ACCURACY STATEMENT

Figure 4.7 shows that unanimously the testers consider that the results are robust and not sensitive to small changes of inputs (ID-3.1); the accuracy of results is acceptable considering the quality of data inputs used (ID-3.3); the computational time is adequate for the level of accuracy provided (ID-3.5); the software did not suffer from any sort of data shortage/lack of memory during the test and that the software can handle errors without crashing. Around 30% are undecided or disagree on these criteria (ID-3.6 and ID-3.7). 60 % considered that the results are credible and trustworthy while the rest are undecided (20%) or disagree with this (20%) about this (ID-3.2). This was due also because of a typo in the data provided that caused mistrust in the software, while the responsibility relies on the bad quality of a specific piece of data. The accuracy of the results corresponds to the user expectation for the stage of the technology maturity for 40% of the users, while the rest is undecided (ID-3.4).

From the spider graph (Figure 4.8), it is possible to gauge that the mean, maximum and minimum scores are balanced regarding the performance and accuracy of this tool, apart for criterion ID3-2.

4.1.1.4 VALUE

The following criteria presented on Table 4.4 were assessed regarding the *Value* of the tool.

TABLE 4.4: ASSESSED VALUE CRITERIA

ID	Statement
4.1	The software allows the user full control of the design process
4.2	It produces results that allow easy comparisons
4.3	It provides a large range of alternatives to create/assess technologies
4.4	The user is informed about the internal processing (e.g. remaining time, log) and warned about potential inconsistencies
4.5	The software meets my expectations in terms of results, graphical options, interaction, and functionality
4.6	I would recommend the use of this software

Figure 4.9 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.10 using a spider chart, to highlight the mean, maximum and minimum values.

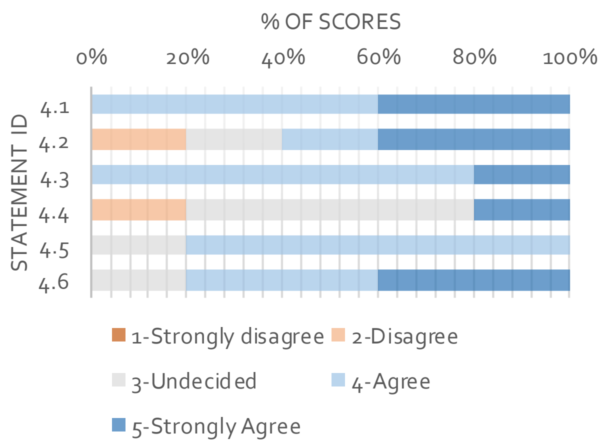

FIGURE 4.9: DISTRIBUTION OF USER SCORES PER VALUE STATEMENT

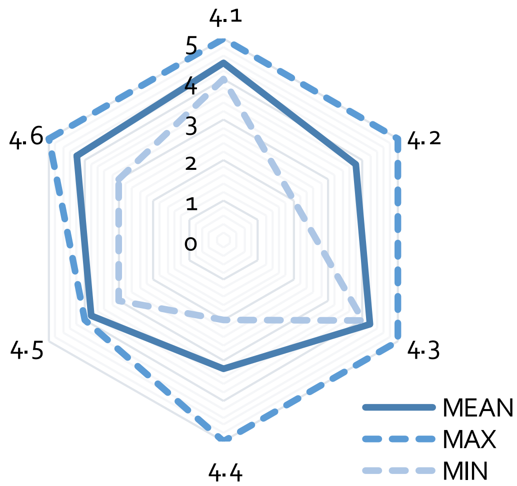

FIGURE 4.10: MEAN, MAXIMUM AND MINIMUM SCORES PER VALUE STATEMENT

Analysing Figure 4.9 it is possible to state that all the users consider that the software allows the user full control of the design process (ID-4.1). 60% agree that the tool produces results that allow easy comparisons, while around 20% disagree on this and 20% is undecided (ID-4.2). For the range of alternatives to create/assess technologies, all the users agree that the tool provides a large range. (ID-4.3). Only 20% of the users agree that the tool provides information about the internal processing (e.g. remaining time, log), 20% disagree on this and the remaining ones are undecided (ID-4.4). 80% of the respondents agree that the software meets their expectations in terms of results, graphical options, interaction and functionality while the rest of them is undecided (ID-4.5). To conclude, most of the users (80%) would recommend the use of this tool (ID-4.6).

Figure 4.10 shows that there are differences between the minimum (score 2) and maximum (score 5) scores for the same assessment criterion that can be explained with different perspectives and expectations of the respondents. The mean scores are placed between 3,2 and 4,4.

4.1.2 QUALITATIVE ASSESSMENT

4.1.2.1 OVERALL USER SATISFACTION

Generally, the feedback indicated that the tool is easy to use and straightforward to understand. Overall user satisfaction was covered in comments such as:

- The overall tool is great in terms of performances and user friendliness; Generally, it is very usable, especially the clear lists of results split up into 'Efficiency', 'Alternative Metrics', 'Energy Production' and 'Power Quality'.
- Simple, clear, straightforward in the management of the studies.
- Very quick and simple to use, input data and navigate each result.
- Excellent error checking and validation

Comments from industrial partners which indicated improvements to the tool came under the categories of:

- General Remarks,
- Performance and accuracy,
- Usability,
- User-friendliness, and
- Value.

4.1.2.2 UNINTENDED MODULE PERFORMANCE

In general terms, the tools behaved as expected, however, the following "critical" aspects were identified by some of the users:

1. The tool produced some "not realistic" results: namely, one of the efficiency parameters calculated by the module SPEY gave a value greater than 1. However, it was identified the source of the error, and it is not indeed in the tool itself, but such a behaviour was due to a typo on the input data. However, it seems reasonable to add a further extra check on the outputs of the SPEY module, warning the user that some unrealistic results have been produced.
2. In the rendering of tables, some meaningless rows were shown. We are not able to reproduce this error, but we assume that this might be due to visualization errors, maybe because of the browser used (Microsoft Edge and older are not recommended for the SPEY module of DTOceanPlus).

4.1.2.3 PROPOSALS FOR IMPROVEMENT

GENERAL REMARKS

The verifiers have identified the following areas of improvement in terms of general remarks:

1. The inputs required are not always very clear. It would be beneficial to include some "tooltip" as done for the outputs in order to fully understand their meaning and guide the user properly. It is not evident moreover which a are the optional and the required inputs.
2. The overall aspect of the tool is not very professional and it would be worth improving it.
3. Formatting of numbers is unfriendly, as several decimal digits are currently shown, it would be better to show just a number of significant digits.

PERFORMANCE AND ACCURACY

The verifiers have identified the following areas of improvement in terms of performance and accuracy:

1. Several typos have been found that should be corrected: in the description of variables, in the windows for uploading files, in the error message dialog boxes, etc.…
2. In several figures the label of the x-axis in the diagrams should be correctly shown.
3. Add more metrics in terms of Power quality, e.g. the array irregularity of produced power for energy storage estimation.
4. Make the tool work at different levels of complexity.
5. The windows for inputting data form other modules should be correctly identified with a specific title.
6. Inform the user when a chart is not available for visualisation.
7. In rendering the tables, sometimes some meaningless rows were shown (it was identified by the users but we were not able to reproduce this error) and this should be avoided.

USABILITY

The verifiers have identified the following areas of improvement in terms of usability:

1. After running a simulation, it would be useful to be addressed directly to the page of outputs of having a button to go directly.
2. The user should be able to input only the data that he/she has available for each module, as right now the user can choose which module data to input, but he/she wants to include a module, he/she has to provide the full stack of data.
3. After deleting a study, the corresponding id should be set to "null".
4. Use "." as decimal separator.
5. The export DR functionality is obscure.
6. In standalone, the input loading has some redundancy and this should be avoided.
7. Add temporary loading screens while the back-end is finishing calling the routes.
8. Change name of the Edit Button, as only change name and description of the study.
9. Some users are not familiar with the json format for exporting the files.

10. Some users would prefer a more customised input number tool, for example not increasing by one or using a slider.
11. The template for the files to input should be available.
12. Some extra material for training should be available, even if the training session was in general very good.

USER FRIENDLINESS

The users provided their ideas about improvements also in terms of user friendliness. Note that in some cases, the users provided the same comments both in terms of Usability, and for this reason they have been omitted here.

1. The visualisation of the results should be improved.
2. A brief introduction about what the tools does should be beneficial.
3. The tooltip sign should be graphically improved.
4. When uploading files, there is a bug that even if the filename is correctly displayed, the content was not actually uploaded.
5. A progression bar showing which are the “module” data that the user filled could be useful.
6. A bug about the tooltip system was identified.
7. Machine characterisation inputs are too much “wave energy” oriented, they should be tailored for the purpose.

VALUE

In terms of “value”, the users proposed to add a feature for comparing different studies.

4.1.3 IDENTIFYING AND SOLVING INCONSISTENCIES

The feedback of the industrial partners and the technical verifier were extremely useful in order to provide an improved SPEY tool when preparing the beta version.

We expect to implement most of the improvements suggested by the verifiers (high priority improvements, in Table 4.5); however, there are some others that, even if it would be useful to implement, very probably they won’t be implemented due to lack of time (lower priority improvements Table 4.6). Finally, there are some others that cannot be implemented because either they are not in the scope of the module SPEY (they are in the scope, for example of the main application) or because we are not able to reproduce the bug or because they are independent from the SPEY developers (see Table 4.7).

TABLE 4.5: HIGH PRIORITY IMPROVEMENTS TO BE IMPLEMENTED IN THE BETA VERSION OF SPEY

Issue	Resolution
The inputs required are not always very clear.	A tooltip will be added for the inputs, and it will be specified if they are mandatory or not.
Formatting of numbers is unfriendly, as several decimal digits are currently shown,	We will reduce the number of significant digits when displaying numbers.
Typos	Typos will be corrected
Labelling of axes in figures	Correct labels for x axes of figures will be included
The windows for inputting data form other modules should be correctly identified with a specific title.	A title will be added for each dialog box
Inform the user when a chart is not available for visualisation	The user will be infoormed when a chart is not available with the text "Not Available"
After running a simulation, it would be useful to be addressed directly to the page of outputs of having a button to go directly	This will be implemented
After deleting a study, the corresponding id should be set to "null"	This will be implemented
Add temporary loading screens while the back-end is finishing calling the routes	This will be implemented
Change name of the Edit Button, as only change name and description of the study	This will be implemented
The template for the files to input should be available	Templates will be provided and explained
Some extra material for training should be available	More training material will be ready soon.
A brief introduction about what the tools does should be beneficial	This will be implemented
The tooltip sign should be graphically improved	This will be implemented
When uploading files, there is a bug that even if the filename is correctly displayed, the content was not actually uploaded.	This will be implemented

TABLE 4.6: LOWER PRIORITY IMPROVEMENTS TO BE IMPLEMENTED IN THE BETA VERSION OF SPEY

Issue	Resolution
Add more metrics in terms of Power quality	It could be useful to include more metrics in terms of Power Quality, but at the moment such implementation is uncertain due to time constraints.
Make the tool work at different levels of complexity	So far, the tool already works with less or more data; the classification for Complexity Levels will be done if there is any available time.
In rendering the tables, sometimes some meaningless rows were shown	This will be implemented if we are able to reproduce the issue and understand the reason why for this behaviour

Issue	Resolution
The user should be able to input only the data that he/she has available for each module	This is a feature only for standalone; The user has already the possibility to select which module to work with; so, if they do not have the full stack of data for a module, they should not take into consideration to use data from that module
Use" ." as decimal separator	This seems to be already solved
1.In standalone, the input loading has some redundancy and this should be avoided	Further validation of data will be included if there is time.
Some users are not familiar with the json format for exporting the files.	We can think of exporting the results in XLS format, if there is time
Some users would prefer a more customised input number tool, for example not increasing by one or using a slider	We can think of switching to another widget if there is time
A progression bar showing which are the "module" data that the user filled could be useful	This will be done if there is time to implement it

TABLE 4.7: ISSUES THAT WILL NOT BE IMPLEMENTED IN THE BETA VERSION OF SPEY

Issue	Resolution and Explanation why it will not be implemented
The overall aspect of the tool is not very professional and it would be worth improving it.	This is something that has something to do with the aspect of the global toolset of DTOceanPlus suite of tools, and decision will be taken by the Consortium.
The export DR functionality is obscure	This will be implemented at a more general level
A bug about the tooltip system was identified	This is a problem depending on the library we are using. We will fix it if there are solutions available
Machine characterisation inputs are too much "wave energy" oriented, they should be tailored for the purpose.	Even in standalone, the inputs of SPEY are consistent with the standalone version of MC; for this reason, we will discuss with the developer of MC to see if there is margin to implement it.
Comparing different studies	This is something that has something to do with the aspect of the global toolset of DTOceanPlus suite of tools, and decision will be taken by the Consortium

4.2 RUNNING THE VERIFICATION CASES: SLC

4.2.1 QUANTITATIVE ASSESSMENT

A total of 6 organisations completed the verification process for the different features of the SLC module of the Assessment Design Tools (UEDIN, ESC, Tecnalia, OMP, Sabella and EGP) and provided feedback by the Software Evaluation Form. Figure 4.11 shows the average scores across the four categories of evaluation, highlighting an overall satisfaction from using the tool, as all average scores are within the range of 3 to 5.

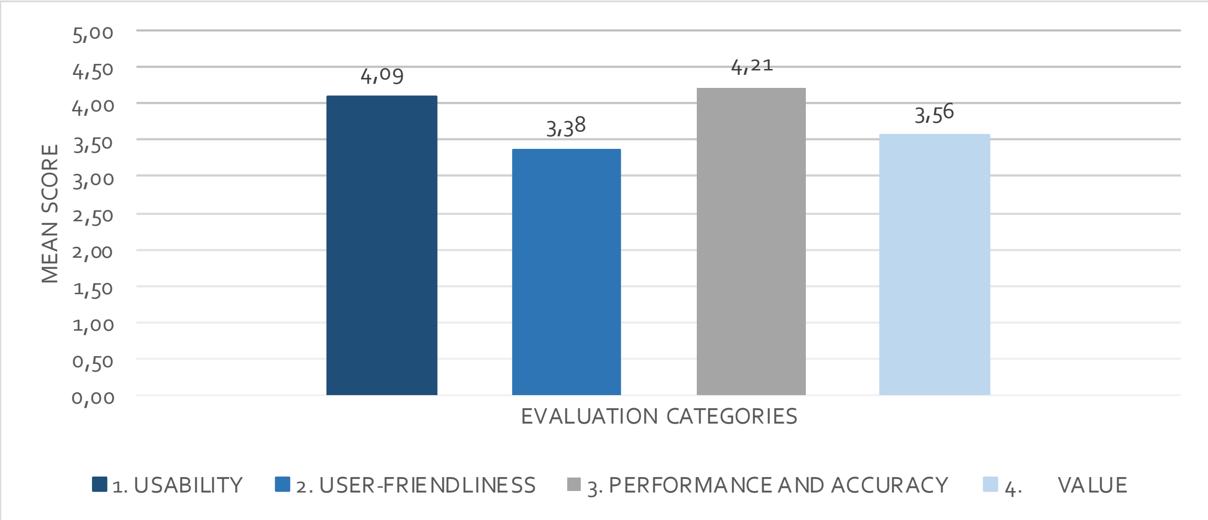

FIGURE 4.11: MEAN RATINGS OF THE EVALUATED CHARACTERISTICS

As can be seen in Figure 4.12, around 70% of the participants were satisfied with the usability of the SLC tool. A minority of the evaluators considered that the tool is not user friendly (20%) and 35% remained undecided. More than 75% of the respondents considered that the tool shows performance and accuracy. Nearly 60% of the users considered that the tool is valuable, while the remaining ones were undecided (~25%), or do not agree with this (~15%). A further analysis on the results is described in the following sections.

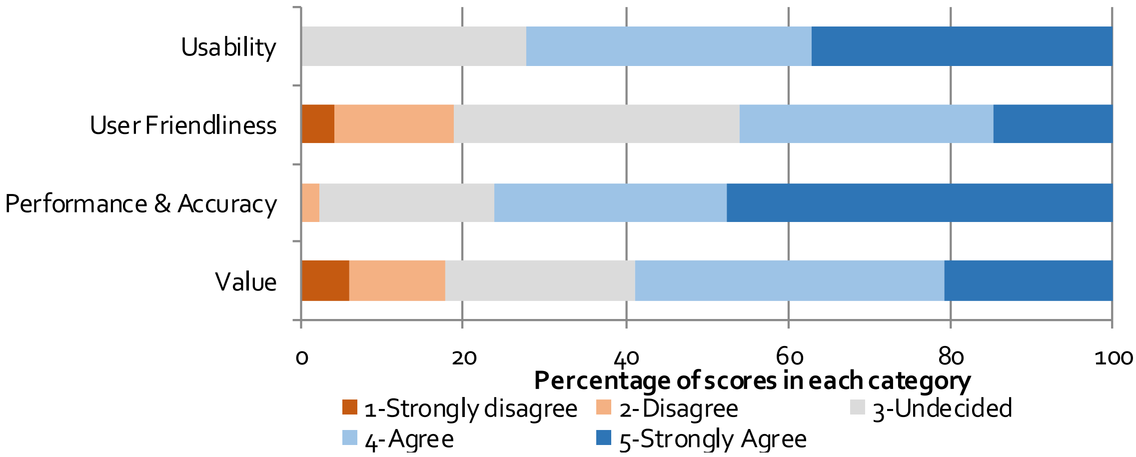

FIGURE 4.12: PERCENTAGE OF SCORES FOR THE FOUR KEY CATEGORIES

4.2.1.1 USABILITY

The criteria presented on Table 4.8 have been assessed in the *Usability* category.

TABLE 4.8: ASSESSED USABILITY CRITERIA

ID	Statement
1.1	The software is intuitive and easy to use in general
1.2	It is easy to create and delete a Study
1.3	It is easy to edit, save and export a Study
1.4	The process of inputting data is clear and efficient
1.5	Results are meaningful, easy to interpret and use
1.6	I could complete the process without errors
1.7	I am satisfied with the overall speed of computation
1.8	The software can be run from my computer without any issue
1.9	The training sessions and documentation are useful for learning how to use the software

Figure 4.13 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.14 using a spider chart, to highlight the mean, maximum and minimum values.

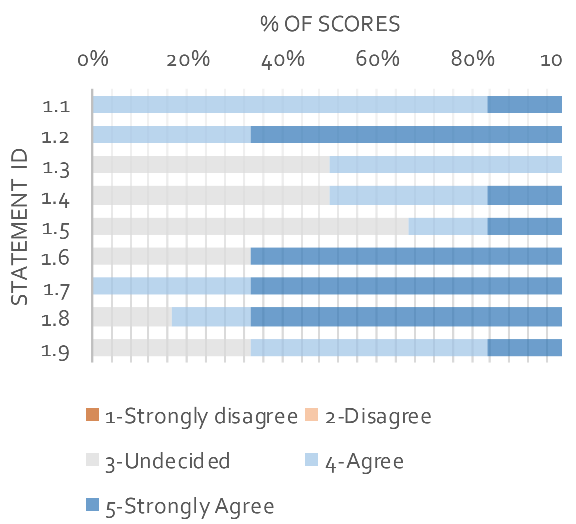

FIGURE 4.13: DISTRIBUTION OF USER SCORES PER USABILITY STATEMENT

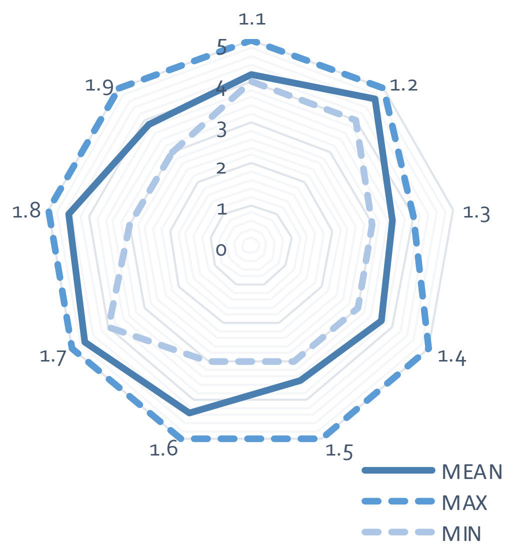

FIGURE 4.14: MEAN, MAXIMUM, AND MINIMUM SCORES PER USABILITY STATEMENT

In view of the results (Figure 4.13 and Figure 4.14), all the evaluators agree or strongly agree that SLC module is easy to use and intuitive (ID-1.1) as well as the majority of them strongly agree that is easy to create and delete a study (ID-1.2). About ease of edit, export, and save a Study (ID-1.3) and the efficiency of data inputting (ID-1.4) half of the testers agreed with it, while the other half remained undecided.

Regarding statement (ID-1.5) find the results obtained meaningful and easy to interpret and use, more than 65% of the users were undecided and the rest agreed or strongly agreed with it. On the completion of the process without errors (ID-1.6) the two thirds of the evaluators managed to do it and strongly agreed with this while the rest of them remained undecided. The computational speed (ID-1.7) was unanimously satisfactory (all the participants were satisfied or strongly satisfied with it) and almost 85% of the users managed to run of the software with any issue (ID-1.8), while the others remained undecided.

More than half of the users found the documentation and the training sessions led by the software developer useful (ID-1.9).

4.2.1.2 USER FRIENDLINESS

The criteria presented on Table 4.9 have been assessed in the *User Friendliness* category.

TABLE 4.9: ASSESSED USER FRIENDLINESS CRITERIA

ID	Statement
2.1	The user interface is simple, easy to navigate and well-organised
2.2	The user interface looks professional
2.3	It responds promptly to user actions (inputs, selections, clicks, ...)
2.4	It provides the user with enough help, indications and/or guidance throughout each process
2.5	The meaning of each data input/user selection is clear
2.6	The meaning of each data output is clear
2.7	Visualisation of results is clear and informative
2.8	The user can add further information to the Study through the interface

Figure 4.15 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.16 using a spider chart, to highlight the mean, maximum and minimum values.

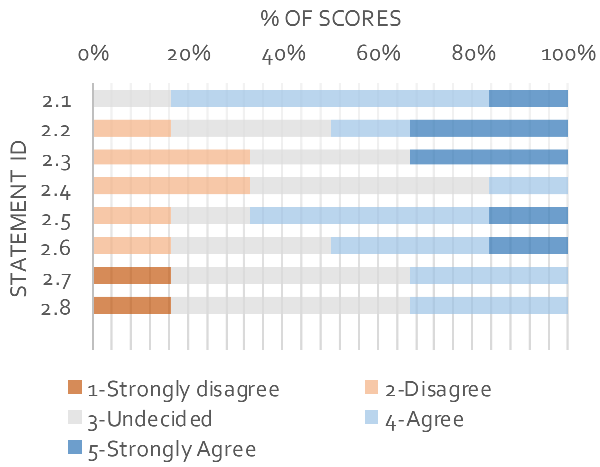

FIGURE 4.15: DISTRIBUTION OF USER SCORES PER USER-FRIENDLINESS STATEMENT

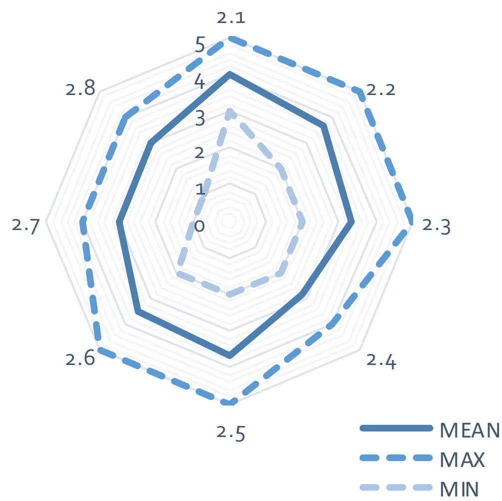

FIGURE 4.16: MEAN, MAXIMUM, AND MINIMUM SCORES PER USER-FRIENDLINESS STATEMENT

As can be seen in Figure 4.15, more than 80% of the respondents agree that the user interface is simple, easy to navigate and well-organised (ID-2.1), whereas the rest are undecided. It can be said that the user interface looks professional only for 50% of the users, while around 33% of the users are undecided and more than 16% disagree with the statement ID-2.2. One third of the users the tool responds promptly to user actions, while another third is undecided and the remaining one disagree on this statement (ID-2.3). Only 16% of the users say that the tool provides the user with enough help, indications and/or guidance throughout each process (ID-2.4), while 50% were undecided and the remaining ones disagree on this. This can be an improvement area for the next version. The meaning of each data input/user selection and data output is clear for most of the users, with more than 60% of respondents agreeing with statements ID-2.5 and 50% agreeing with ID-2.6. For the visualisation of results being clear and informative and the possibility of adding further information to the Study through the interface, one third agreed with it while 50% were undecided and the other respondents disagree with these statements (ID-2.7 and ID-2.8).

The spider diagram in Figure 4.16 highlights a significant difference between the maximum and minimum scores, which may be due to the different levels of experience with similar tools or datasets by the users from different companies.

4.2.1.3 PERFORMANCE AND ACCURACY

The criteria presented on Table 4.10 have been assessed in the *Performance and Accuracy* of the module.

TABLE 4.10: ASSESSED PERFORMANCE AND ACCURACY CRITERIA

ID	Statement
3.1	Results are robust and not sensitive to small changes of inputs
3.2	Results are credible and trustworthy for the audience
3.3	The accuracy of results is acceptable considering the granularity/complexity of data inputs used
3.4	The accuracy of results corresponds to the user expectation for the stage of technology maturity
3.5	The computational time is adequate for the level of accuracy provided
3.6	The software did not suffer from any sort of data shortage/lack of memory during the test
3.7	The software can handle errors without crashing

Figure 4.17 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.18 using a spider chart, to highlight the mean, maximum and minimum values.

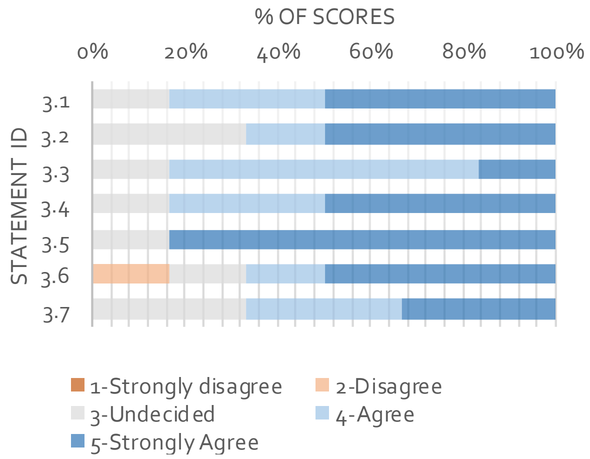

FIGURE 4.17: DISTRIBUTION OF USER SCORES PER PERFORMANCE AND ACCURACY STATEMENT

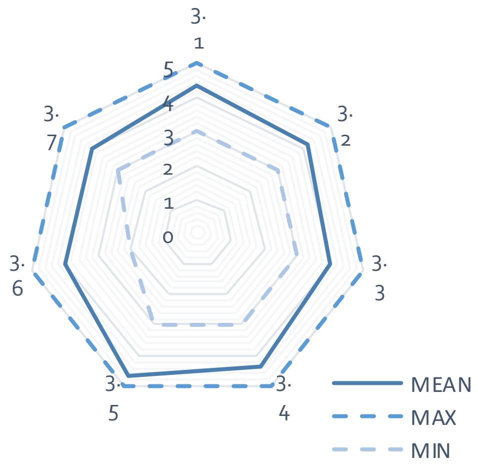

FIGURE 4.18: MEAN, MAXIMUM, AND MINIMUM SCORES PER PERFORMANCE AND ACCURACY STATEMENT

Figure 4.17 shows that more than 80% of the testers considered that the results are robust and not sensitive to small changes of inputs (ID-3.1) and the accuracy of results is acceptable considering the quality of data inputs used (ID-3.3) the others remained undecided; the computational time is adequate for the level of accuracy provided (ID-3.5) – more than 80% of the testers strongly agreed with this; the software did not suffer from any sort of data shortage/lack of memory during the test and that the software can handle errors without crashing. Around 30% are undecided or disagree on these criteria (ID-3.6 and ID-3.7). Two thirds considered that the results are credible and trustworthy while the rest are undecided about this (ID-3.2). The accuracy of the results corresponds to the user expectation for the stage of the technology maturity for more than 80% of the users, while the rest is undecided (ID-3.4).

From the spider graph (Figure 4.18), it is possible to gauge that the mean, maximum and minimum scores are balanced regarding the performance and accuracy of this module.

4.2.1.4 VALUE

The criteria presented on Table 4.11 have been assessed in the *Value* of the module.

TABLE 4.11: ASSESSED VALUE CRITERIA

ID	Statement
4.1	The software allows the user full control of the design process
4.2	It produces results that allow easy comparisons
4.3	It provides a large range of alternatives to create/assess technologies
4.4	The user is informed about the internal processing (e.g. remaining time, log) and warned about potential inconsistencies
4.5	The software meets my expectations in terms of results, graphical options, interaction, and functionality
4.6	I would recommend the use of this software

Figure 4.19 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.20 using a spider chart, to highlight the mean, maximum and minimum values.

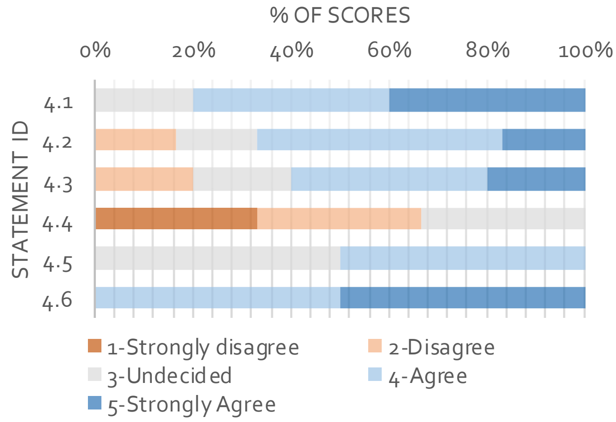

FIGURE 4.19: DISTRIBUTION OF USER SCORES PER VALUE STATEMENT

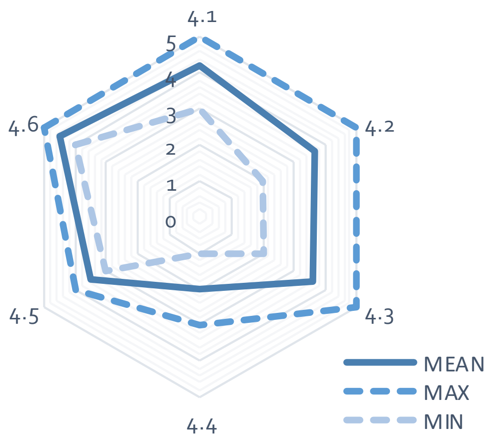

FIGURE 4.20: MEAN, MAXIMUM, AND MINIMUM SCORES PER VALUE STATEMENT

Analysing Figure 4.19 it is possible to state that the majority of the users considered that the software allows the user full control of the design process (ID-4.1), while around 16% remained undecided. More than 60% agree that the tool produces results that allow easy comparisons, while around 20% disagree on this and 20% is undecided (ID-4.2). For the range of alternatives to create/assess technologies, 60% of testers considered that the tool provides a large range. (ID-4.3). Two thirds of the users agreed that the tool did not provide information about the internal processing (e.g. remaining time, log), while the remaining ones are undecided (ID-4.4). 50% of the respondents agree that the software meets their expectations in terms of results, graphical options, interaction, and functionality while the rest of them is undecided (ID-4.5). To conclude, all the users would recommend the use of this tool (ID-4.6).

Figure 4.20 shows that there are differences between the minimum (score 2) and maximum (score 5) scores for the same assessment criterion that can be explained with different perspectives and expectations of the respondents. The mean scores are placed between 2 and 4,5.

4.2.2 QUALITATIVE ASSESSMENT

This section presents feedback from both technical and industrial verifiers, gathered from their Software Evaluation Forms. Comments have been grouped under three main categories: *Overall user satisfaction*, *Unintended tool performance*, and *Proposals for improvement*. The aim of this section is to guide the path for improvement of the System Lifetime Costs (SLC) module.

4.2.2.1 OVERALL USER SATISFACTION

Generally, the feedback indicated that overall, the tool is valuable, clear, accurate and fairly intuitive. However, the users highlighted that the tool did not provide enough help, indications and/or guidance throughout each process, and that it did not look professional yet. According to the comments received, the following can be said about the overall user satisfaction:

- In general, the tool is clear, and fairly intuitive.
- Regarding the inputting data process, it is easy and efficient in general.
- The tool runs very fast, so does not need a progress status.
- The logic of the tool is straightforward and easy to use.
- Results were as expected.

4.2.2.2 UNINTENDED MODULE PERFORMANCE

In general terms, the tools behaved as expected. However, two unexpected problems were identified by some of the users:

1. Some buttons were sometimes unresponsive (because the hyperlink was on the text and not on the button). This problem was fixed.
2. Changing input values using the GUI sliders led to very large increments. This problem will be addressed.

4.2.2.3 PROPOSALS FOR IMPROVEMENT

Comments and suggestions from technical and industrial partners were grouped into the following categories:
- Improvements on the formatting and wording of headers, buttons, large numbers, and correction of typos.
- Improvements in the user experience while introducing inputs into the GUI through:
  - The implementation of colour codes (green when inputs have been successfully filled) and an input progress bar.
  - Validation of input files uploaded by the user.
  - The implementation of detailed warning and error messages to assist in identifying the source of errors.

- The implementation of "help buttons" to provide more information to the user about certain inputs (what they include/mean), as well as the consequences of certain input selections.
- Improving the input fields, changing the increment changes and number of decimals.

- Improve visualisation and handling of outputs:
  - Improve presentation of results.
  - Provide contextual help and guidance in respect to generated outputs: "what next?".
  - Implement plots to simplify the visualisation of certain outputs (e.g. the cashflows and payback times).
- Implement functionalities that were not available at the time of the verification process:
  - Ability to compare different studies.
  - Export functionality.
  - Ability to change the project stage for benchmark analysis.
  - Implement a "other annual costs" to the user inputs.

4.2.3 IDENTIFYING AND SOLVING INCONSISTENCIES

The feedback of the industrial partners and the technical verifier were extremely useful in order to provide an improved SLC tool when preparing the beta version.

We expect to implement most of the improvements suggested by the verifiers (high priority improvements, in Table 4.12); however, there are some others that, even if it would be useful to implement, very probably won't be implemented due to lack of time (lower priority improvements in Table 4.13). Finally, there are some others that cannot be implemented because either they are not in the scope of the module SLC (they are in the scope of the main application), as shown in Table 4.14).

TABLE 4.12: HIGH PRIORITY IMPROVEMENTS TO BE IMPLEMENTED IN THE BETA VERSION OF SLC

Issue	Resolution
The inputs required are not always very clear.	A tooltip/help button will be added for the inputs, and it will be specified if they are mandatory or not.
Rename complexity levels from "low", "mid", "high" to 1,2,3 for consistency with other modules.	This will be implemented
Review Formatting and wording of headers, buttons, large numbers, and correction of typos.	This will be implemented
Formatting of numbers is unfriendly, as several decimal digits are currently shown.	We will reduce the number of significant digits when displaying numbers.
Change name of the View/Edit Button, as only change name and description of the study.	This will be implemented
Sometimes unresponsive buttons.	This will be corrected
Improve warning messages (in case of missing files) and implement personalized error messages when introducing wrong files	This will be implemented
Implement the option to export the study	This will be implemented
Change button name from "Validate"	This will be implemented
Create pop-up button with further information about each input (e.g. FIT, FIT years, typical	This will be implemented with mouse hover information icons

Issue	Resolution
ranges of discount rate). Would be good to describe how it will probably affect the results	
Show filled inputs in red or green depending whether they have been filled or not (or other type of indication)	This will be implemented
Do not allow Payback Periods to take negative values (in case of extreme Grant, e.g. 100M€)	This will be corrected
Difficulty in introducing decimal values in the input fields	This will be corrected
Reduce FIT and surface thickness increments to decimals	This will be implemented
Not able to remove a FIT once introduced	This will be corrected
Describe what device structural costs includes	This will be implemented
Reformat grant value to show thousands (it's easy to add the wrong number of zeros)	This will be implemented
Show warning and error messages for a longer time duration	This will be implemented
In the report page, it is worth also displaying the complexity level, below the Name of the study & description	This will be implemented
Present results (economic and financial) as tables instead of text.	This will be implemented
Make BOM neater, resizing tables to not truncate text. Omit parameters from the BOM that will not be shown at CPX1. Ensure consistency between CAPEX and CapEX. Format large numbers. Implement sub and grand totals.	This will be corrected
Present guidance to the user in respect to what outputs mean (e.g. the project is unprofitable)	This will be implemented
Cost over LCOE do not sum to 100% (99.9%).	This is due to rounding errors. To be implemented.
Implement an additional input field called "other annual cost" to take into consideration OPEX costs such as insurances, etc.	This will be implemented
Ability to change the project stage for benchmark analysis.	This has been corrected.

TABLE 4.13: LOWER PRIORITY IMPROVEMENTS TO BE IMPLEMENTED IN THE BETA VERSION OF SLC

Issue	Resolution
Manipulating a slider could be better than the +/- buttons, adding 1 unit per click.	We can think of switching to another widget if there is time
Adapting the steps to the expected values/range of values could be good (100 unit steps when the input magnitude is expected to be around 1000 for example).	We can think of a systematic approach if there is time.
It would also be nice to have the scope to add in a contingency on top of the other cost elements to deal with optimism bias etc.	We will implement this if there is time.
Implement commentary boxes for each input to allow the user to add further information such as source of data	We can think of this if there is time.
Lock input of project lifetime in case AEP is introduced? Otherwise request average AEP?	We will implement this if there is time.
Allow user to edit/update individual external files after having left the External input page	We will implement this if there is time.
Join output pages into a single one	We will implement this if there is time.
Represent results (e.g. Cashflows, Payback Time) graphically	We will implement this if there is time.
Provide guidance on how to interpret the results and the 'What next question'.	We will implement this if there is time.
Freeze top row of Bill of Materials while scrolling	We will implement this if there is time.
Implement progress bar.	We will implement this if there is time.

TABLE 4.14: ISSUES THAT WILL NOT BE IMPLEMENTED IN THE BETA VERSION OF SLC

Issue	Resolution and Explanation why it will not be implemented
The overall aspect of the tool is not very professional and it would be worth improving it.	This has to do with the aspect of the global toolset of DTOceanPlus suite of tools, and decision will be taken by the Consortium.
The export DR functionality is obscure	This will be implemented at a higher level
Comparing different studies	This is something that has something to do with the aspect of the global toolset of DTOceanPlus suite of tools, and decision will be taken by the Consortium
Left hand panel is not intuitive	This has to do with the aspect of the global toolset of DTOceanPlus suite of tools, and decision will be taken by the Consortium.

4.3 RUNNING THE VERIFICATION CASES: RAMS

4.3.1 QUANTITATIVE ASSESSMENT

A total of 6 organisations completed the verification process for the different features of the RAMS module (EDP, FEM, Idom, OMP, Sabella, WavEC) and provided feedback by the Software Evaluation Form. Figure 4.21 shows the average scores across the four categories of evaluation, highlighting an overall satisfaction from using the tool, as all average scores are within the range of 3 to 5. Figure 4.22 gives an overview of the users' satisfaction with the RAMS module.

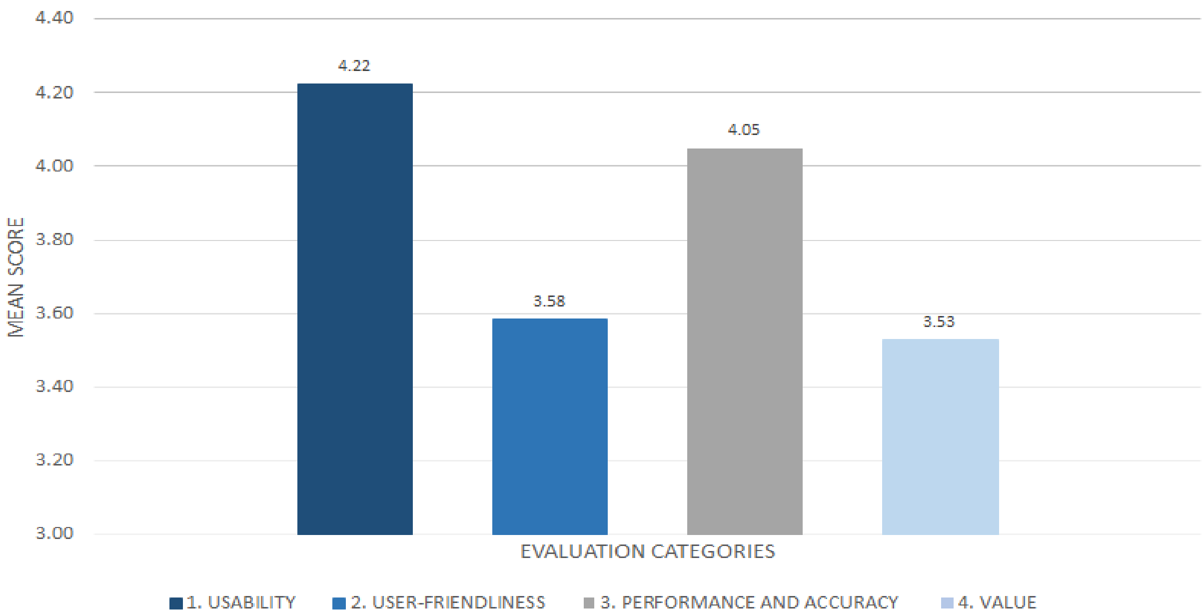

FIGURE 4.21: MEAN RATINGS OF THE EVALUATED CHARACTERISTICS

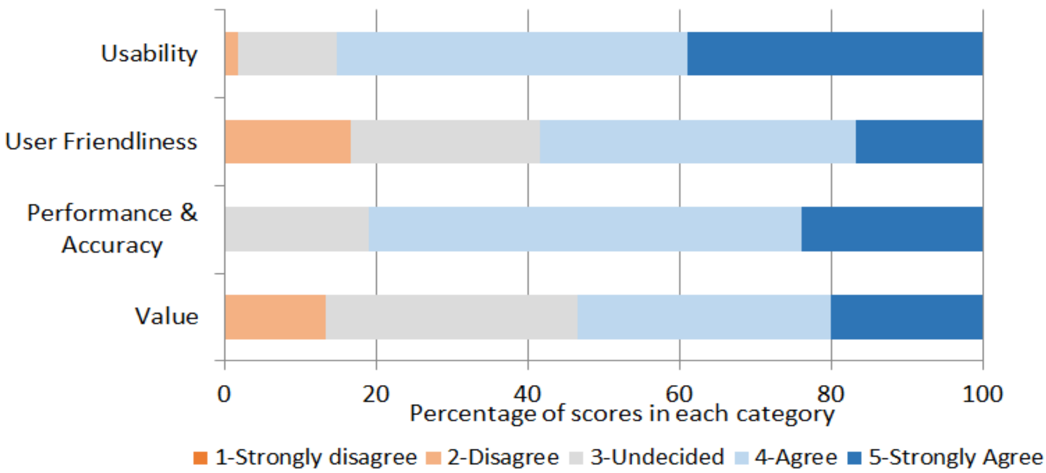

FIGURE 4.22: PERCENTAGE OF SCORES FOR THE FOUR KEY CATEGORIES

4.3.1.1 USABILITY

The following statements have been set as criteria for assessing the RAMS tool in terms of the *Usability* category.

TABLE 4.15: ASSESSED USABILITY CRITERIA - RAMS

ID	Statement
1.1	The software is intuitive and easy to use in general
1.2	It is easy to create and delete a Study
1.3	It is easy to edit, save and export a Study
1.4	The process of inputting data is clear and efficient
1.5	Results are meaningful, easy to interpret and use
1.6	I could complete the process without errors
1.7	I am satisfied with the overall speed of computation
1.8	The software can be run from my computer without any issue
1.9	The training sessions and documentation are useful for learning how to use the software

The overview is shown in Figure 4.23 and Figure 4.24.

Basically, all the users give a positive feedback to most of the evaluation items in the feature "Usability". All the users strongly agree or agree with the statements in ID-1.1, ID-1.2, ID-1.6, ID-1.8 and ID-1.9. Five users strongly agree or agree with the statements in ID-1.3 and ID-1.7.

The lower scores (2~3) are given to ID-1.4 and ID-1.5, especially ID-1.4. They (two of six users) may think the process of inputting data is not very clear and efficient, which should be improved.

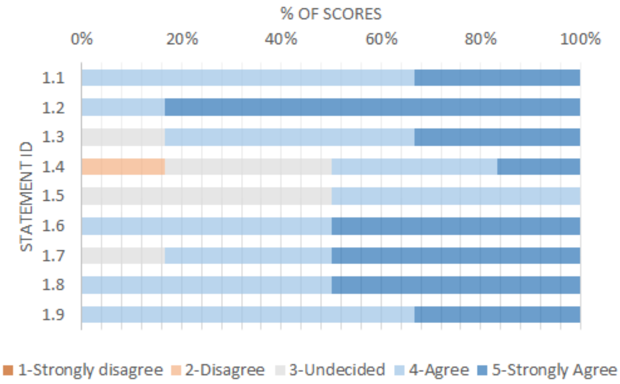

FIGURE 4.23: DISTRIBUTION OF USER SCORES PER VALUE STATEMENT

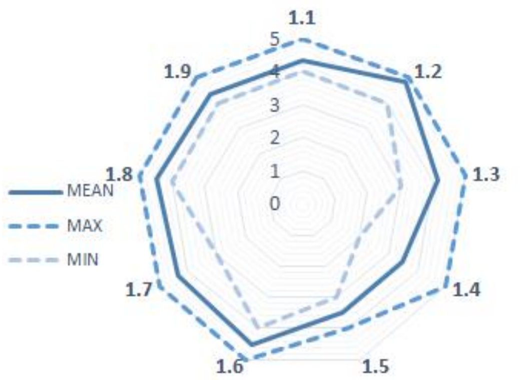

FIGURE 4.24: MEAN, MAXIMUM, AND MINIMUM SCORES PER VALUE STATEMENT

4.3.1.2 USER FRIENDLINESS

The following statements have been set as criteria for assessing the RAMS tool in terms of the *User Friendliness* category:

TABLE 4.16: ASSESSED USER FRIENDLINESS CRITERIA - RAMS

ID	Statement
2.1	The user interface is simple, easy to navigate and well-organised
2.2	The user interface looks professional
2.3	It responds promptly to user actions (inputs, selections, clicks, ...)
2.4	It provides the user with enough help, indications and/or guidance throughout each process
2.5	The meaning of each data input/user selection is clear
2.6	The meaning of each data output is clear
2.7	Visualisation of results is clear and informative
2.8	The user can add further information to the Study through the interface

The overview is shown in Figure 4.25 and Figure 4.26.

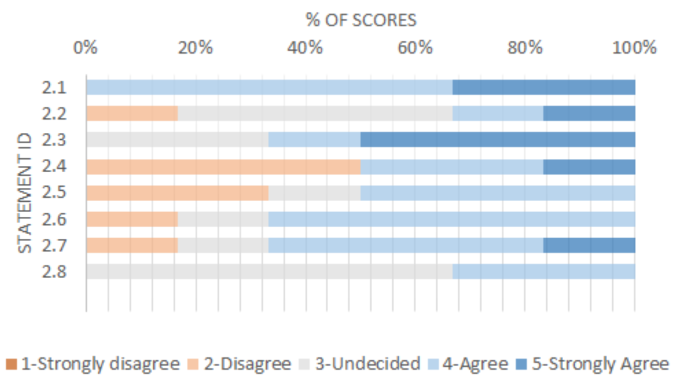

FIGURE 4.25: DISTRIBUTION OF USER SCORES PER VALUE STATEMENT

FIGURE 4.26: MEAN, MAXIMUM AND MINIMUM SCORES PER VALUE STATEMENT

All the users strongly agree or agree that the user interface is simple, easy to navigate and well-organised (ID-2.1).

67% of the users strongly agree or agree that: the tool responds promptly to user actions (inputs, selections, clicks, ...) (ID-2.3), the meaning of each data output is clear (ID-2.6) and Visualisation of results is clear and informative (ID-2.7), while the others do not decide or disagree.

50% of the users agree that: the tool provides the user with enough help, indications and/or guidance throughout each process (ID-2.4) and the meaning of each data input/user selection is clear (ID-2.5), while the others do not decide or disagree.

33.3% of the users agree that: the tool provides the user interface looks professional (ID-2.2) and the user can add further information to the Study through the interface (ID-2.8), while the others do not decide or disagree.

4.3.1.3 PERFORMANCE AND ACCURACY

The following statements have been set as criteria for assessing the RAMS tool in terms of the *Performance and Accuracy*.

TABLE 4.17: ASSESSED PERFORMANCE AND ACCURACY CRITERIA - RAMS

ID	Statement
3.1	Results are robust and not sensitive to small changes of inputs
3.2	Results are credible and trustworthy for the audience
3.3	The accuracy of results is acceptable considering the granularity/complexity of data inputs used
3.4	The accuracy of results corresponds to the user expectation for the stage of technology maturity
3.5	The computational time is adequate for the level of accuracy provided
3.6	The software did not suffer from any sort of data shortage/lack of memory during the test
3.7	The software can handle errors without crashing

The overview is shown in Figure 4.27 and Figure 4.28.

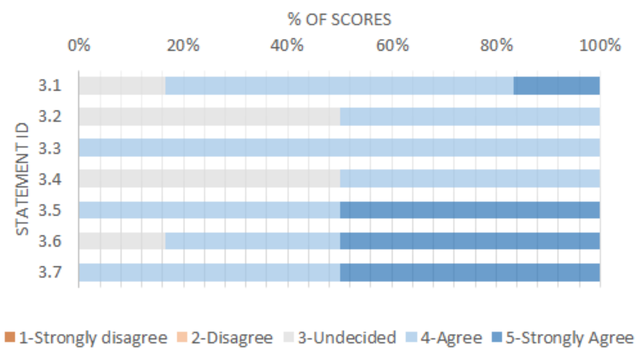

FIGURE 4.27: DISTRIBUTION OF USER SCORES PER VALUE STATEMENT

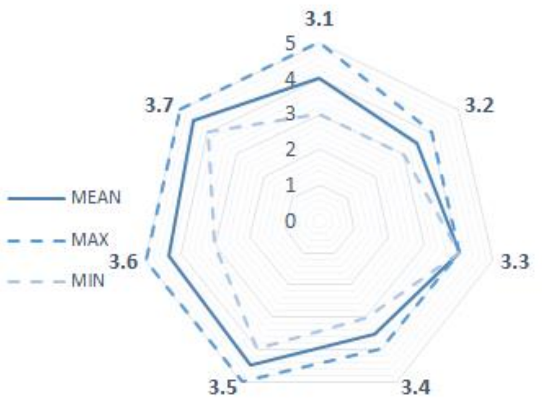

FIGURE 4.28: MEAN, MAXIMUM, AND MINIMUM SCORES PER VALUE STATEMENT

All the users strongly agree or agree that: the accuracy of results is acceptable considering the granularity/complexity of data inputs used (ID-3.3), the computational time is adequate for the level of accuracy provided (ID-3.5) and the software can handle errors without crashing (ID-3.7).

83% of the users strongly agree or agree that: results are robust and not sensitive to small changes of inputs (ID-3.1) and the software did not suffer from any sort of data shortage/lack of memory during the test (ID-3.6), while the others do not decide.

50% of the users agree that: results are credible and trustworthy for the audience (ID-3.2) and the accuracy of results corresponds to the user expectation for the stage of technology maturity (ID-3.4), while the others do not decide.

4.3.1.4 VALUE

The following statements have been set as criteria for assessing the RAMS tool in terms of the *Value*.

TABLE 4.18: ASSESSED VALUE CRITERIA - RAMS

ID	Statement
4.1	The software allows the user full control of the design process
4.2	It produces results that allow easy comparisons
4.3	It provides a large range of alternatives to create/assess technologies
4.4	The user is informed about the internal processing (e.g. remaining time, log) and warned about potential inconsistencies
4.5	The software meets my expectations in terms of results, graphical options, interaction, and functionality
4.6	I would recommend the use of this software

The overview is shown in Figure 4.28 and Figure 4.30.

83% of the users strongly agree or agree that: the user would recommend the use of this software (ID-4.6), while the others do not decide.

50% of the users agree that: the software allows the user full control of the design process (ID-4.1); the tool produces results that allow easy comparisons (ID-4.2); the user is informed about the internal processing (e.g. remaining time, log) and warned about potential inconsistencies (ID-4.4), while the others do not decide or disagree.

33% of the users agree that: the tool provides a large range of alternatives to create/assess technologies (ID-4.3); the software meets my expectations in terms of results, graphical options, interaction, and functionality (ID-4.5), while the others do not decide or disagree.

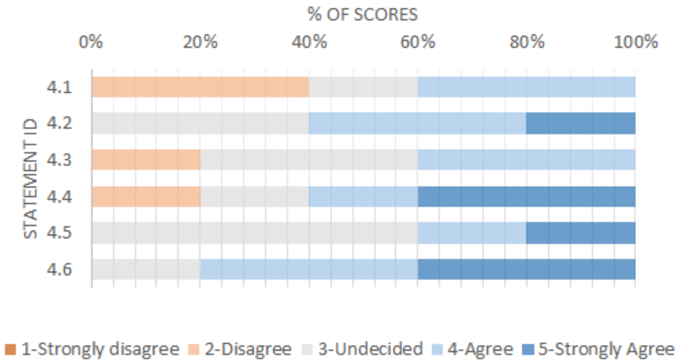

FIGURE 4.29: DISTRIBUTION OF USER SCORES PER VALUE STATEMENT

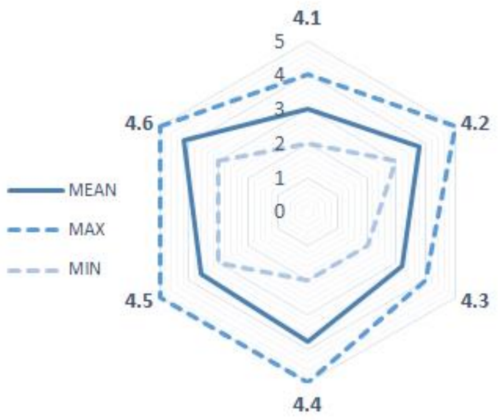

FIGURE 4.30: MEAN, MAXIMUM, AND MINIMUM SCORES PER VALUE STATEMENT

4.3.2 QUALITATIVE ASSESSMENT

4.3.2.1 OVERALL USER EXPERIENCE

Generally, the feedback indicated that the tool is easy to use and straightforward to understand.

The industrial partners have had some comments on improvement of the RAMS tool, with only major comments summarized as follows. See the details of the industrial partners in Annex II.

- Basically, the industrial partners find difficulty in understanding the probabilistic analysis, especially reliability, maintainability, and survivability assessments.
- The hierarchy in json format is difficult for new users to understand; it is suggested to use the excel format instead.
- Details regarding the technical explanation can be added to DTOP-documentation to help the users understand the background.

4.3.2.2 UNINTENDED MODULE PERFORMANCE

Generally, the RAMS module behaves as expected. Few errors related to reliability assessment encountered by one user were caused by misunderstanding of the inputs.

4.3.2.3 PROPOSALS FOR IMPROVEMENT

GENERAL REMARKS

The verifiers have identified the following areas of improvement in terms of general remarks:

- It was not clear what changes from CPX1 to CPX3 in RAMS. Maybe it is suggested to hide the "expert inputs" in the maintainability section of the survivability page, as it will probably be too complex for a simple user in cpx1.
- Is the project duration affecting anything else other than the Maintainability parameter? What happens if the user introduces an input file from LMO with 20 years but when creating a new study, he introduced a different number of years?
- It is expected that there would be far less inputs coming from the user, and more coming from the other tools.

USABILITY

The verifiers have identified the following areas of improvement in terms of usability:

- It would be more intuitive if the input and output displays are distinguished via colour coded or separated panel.
- The functionality to export the study cannot be found.
- In the standalone mode, the json format is really hard to use for a newcomer.
- For the graphical representation of the result, it would be helpful if the unit of time to failure is displayed. Other graphics also need to display the unit.
- For the component reliability, the decimal value can be rounded up to reasonable decimal value.
- Error message when introducing the wrong hierarchy in the wrong place (e.g. ET instead of ED) is a really nice to have.
- Name of device is partially hidden.

USER FRIENDLINESS

The verifiers have identified the following areas of improvement in terms of user friendliness:

- Some descriptive examples of the input data would be better to illustrate what is looked for and required.
- Some indication of how inputs are likely to affect the outputs would also be useful to show how sensitive the outputs are to inputs.
- The user inputs reset between changing tabs, can lead to mistakes.
- Display the current status in the page (waiting inputs, computing step/evolution, finished), the brief popups are easy to miss.
- The plots are nice, but there is no way to visualise and export the numerical results.
- Need more detail in the meaning of the output variables.
- System availability could be presented under another format. It is found that bars are not really informative, as there were only two - identical - values to show.
- Minor changes of formatting, writing words in full etc., will give a professional look.
- Persistent warning message when computations have been calculated is important, especially for tools with long computation times.

PERFORMANCE AND ACCURACY

The verifiers have identified the following areas of improvement in terms of performance and accuracy:

- Given that the user has not tried the simulation with significant number of cycles, at the moment it is not possible to evaluate the accuracy of the simulation, and a real time to compute the results via a Monte-Carlo analysis.

VALUE

The verifiers have identified the following areas of improvement in terms of user friendliness:

- The comparison between studies didn't look direct, the user must collect the results independently and then compare them.
- Indications on how much of the calculation has been done (for reliability in particular, as the status of calculations is not displayed, and the user is still allowed to manipulate inputs, manipulation which may be prevented so that the user keeps control on inputs and avoid wrong manipulations).

4.3.3 IDENTIFYING AND SOLVING INCONSISTENCIES

The industrial partners and the technical verifier have issued comments and recommendations on improving the RAMS module. Some of these comments and recommendations are clearly point out the drawbacks of the RAMS functionalities, which should be addressed/ fixed in the beta version. High priority is given to the actions taken to address/fix these drawbacks summarized in Table 4.19. There are some comments and recommendations which make sense to improve the RAMS functionalities to some extent. However, these comments and recommendations summarized are not related to the critical functionalities. Low priority is given to the actions which would or would not be implemented, depending upon the timeline. Low-priority actions are summarized in Table 4.20. No action will be taken to fix the issues related to the remaining comments and recommendations, as summarized in Table 4.21.

TABLE 4.19: HIGH PRIORITY IMPROVEMENTS TO BE IMPLEMENTED IN THE BETA VERSION OF RAMS

Issue	Resolution
It would be more intuitive if the input and output displays are distinguished via colour coded or separated panel.	The visualization of the outputs will be improved.
For the graphical representation of the result, it would be helpful if the unit of time to failure is displayed. Other graphics also need to display the unit.	The units of the outputs will be added.
For the component reliability, the decimal value can be rounded up to reasonable decimal value.	This will be implemented.
Name of device is partially hidden.	This will be modified.
The user inputs reset between changing tabs, can lead to mistakes.	This will be checked and fixed.
Display the current status in the page (waiting inputs, computing step/evolution, finished), the brief popups are easy to miss.	The pop-up messages will be improved.
Need more detail in the meaning of the output variables	Explanations of the outputs will be added.
System availability could be presented under another format. It is found that bars are not really informative, as there were only two - identical - values to show.	This will be improved.
Minor changes of formatting, writing words in full etc., will give a professional look.	The format will be improved.

TABLE 4.20: LOWER PRIORITY IMPROVEMENTS TO BE IMPLEMENTED IN THE BETA VERSION OF RAMS

Issue	Resolution
The functionality to export the study cannot be found.	This functionality would be implemented, if the time allows.
In the standalone mode, the json format is really hard to use for a new comer.	This functionality of importing excel-formatted hierarchies would be implemented, if the time allows.
Error message when introducing the wrong hierarchy in the wrong place (e.g. ET instead of ED) is a really nice to have.	This functionality would be implemented, if the time allows.
Some indication of how inputs are likely to affect the outputs would also be useful to show how sensitive the outputs are to inputs.	This functionality would be implemented, if the time allows.
The plots are nice, but there is no way to visualise and export the numerical results.	The plots would be improved, if the time allows.

Issue	Resolution
Given that the user has not tried the simulation with significant number of cycles, at the moment it is not possible to evaluate the accuracy of the simulation, and a real time to compute the results via a Monte-Carlo analysis.	Redis queue, a synchronised approach, will be implemented to solve this issue.
Indications on how much of the calculation has been done (for reliability in particular, as the status of calculations is not displayed, and the user is still allowed to manipulate inputs, manipulation which may be prevented so that the user keeps control on inputs and avoid wrong manipulations)	A progress bar might be added to indicate the assessment progress, if the time allows.

TABLE 4.21: ISSUES THAT WILL NOT BE IMPLEMENTED IN THE BETA VERSION OF RAMS

Issue	Resolution and Explanation why it will not be implemented
Persistent warning message when computations have been calculated is important, especially for tools with long computation times.	The current pop-up message box can alert the user to the full extent.
The comparison between studies didn't look direct, the user must collect the results independently and then compare them.	This is the way how RAMS is designed.

4.4 RUNNING THE VERIFICATION CASES: ESA

4.4.1 QUANTITATIVE ASSESSMENT

A total of 5 organisations completed the verification process for the different features of the ESA tool (OMP, Sabella, WES, ESC & EGP) and provided feedback by the Software Evaluation Form. Figure 4.31 shows the average scores across the four categories of evaluation, highlighting an overall satisfaction from using the tool, as all average scores are within the range of 3 to 5.

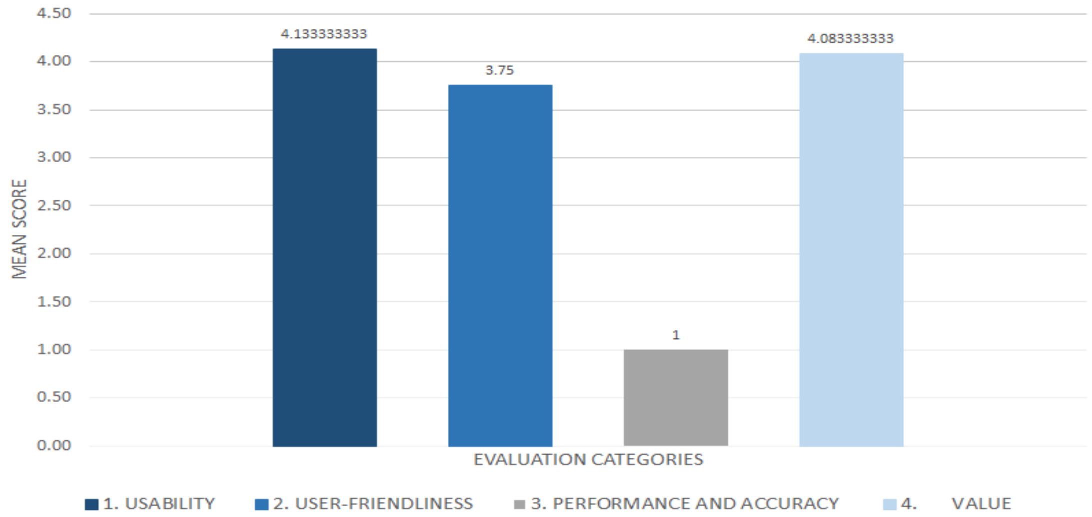

FIGURE 4.31: MEAN RATINGS OF THE EVALUATED CHARACTERISTICS

As can be seen in Figure 4.32 most of the participants of verification (~80%) were satisfied with the usability of the ESA tool. The majority of (56%) the respondents agree or strongly agree that the tool is generally user friendly. More than 90% (in average) of the respondents considered that the tool shows performance and accuracy. More than 70% of the users considered that the tool is valuable. A further analysis on the results is described in the following sections.

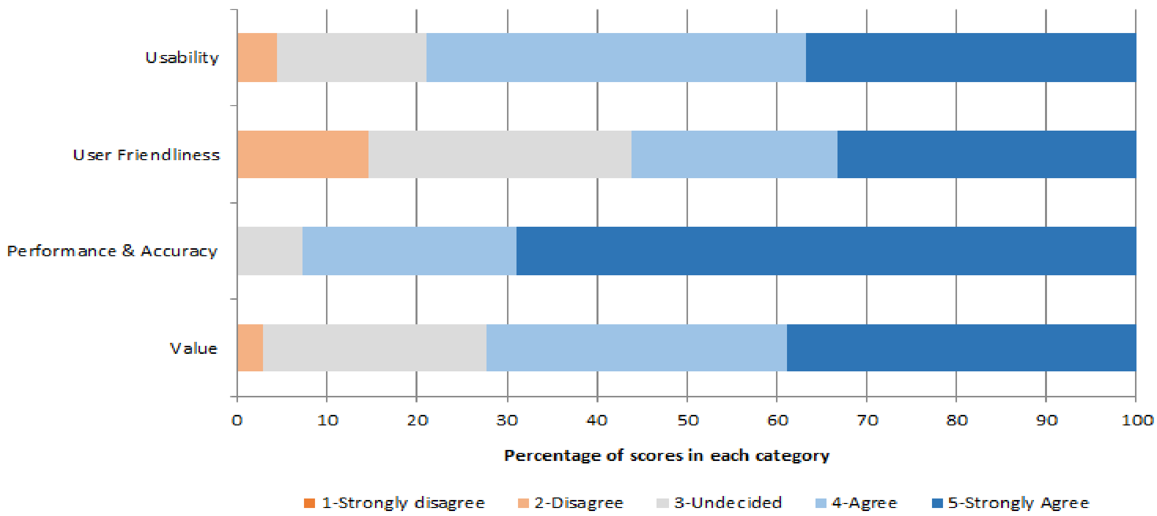

FIGURE 4.32: PERCENTAGE OF SCORES FOR THE FOUR KEY CATEGORIES

4.4.1.1 USABILITY

The following statements have been set as criteria for assessing the ESA tool in terms of the *Usability* category.

TABLE 4.22: ASSESSED USABILITY CRITERIA

ID	Statement
1.1	The software is intuitive and easy to use in general
1.2	It is easy to create and delete a Study
1.3	It is easy to edit, save and export a Study
1.4	The process of inputting data is clear and efficient
1.5	Results are meaningful, easy to interpret and use
1.6	I could complete the process without errors
1.7	I am satisfied with the overall speed of computation
1.8	The software can be run from my computer without any issue
1.9	The training sessions and documentation are useful for learning how to use the software

Figure 4.33 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.34 using a spider chart, to highlight the mean, maximum and minimum values.

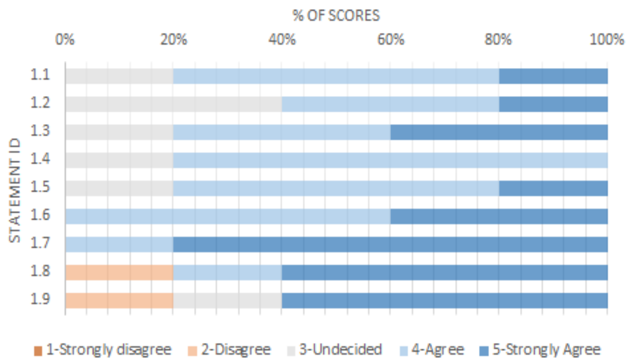

FIGURE 4.33: DISTRIBUTION OF USER SCORES PER USABILITY STATEMENT

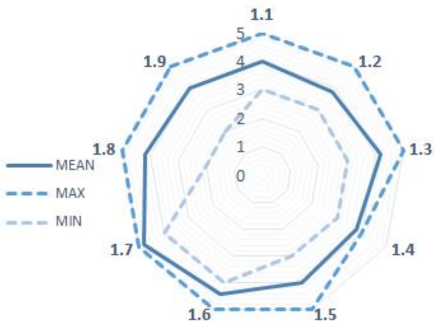

FIGURE 4.34: MEAN, MAXIMUM, AND MINIMUM SCORES PER USABILITY STATEMENT

The results show that users agree unanimously that the tool is easy to use and intuitive (ID-1.1) as users can easily create and delete a study (ID-1.2), are satisfied with the speed of computation (ID-1.7) and are able to run the software without any issue (ID -1.8).

The process of editing, saving and exporting a Study (ID-1.3) is also easy for more than half of the users (80%), and all users were able to run the tool without any problem (ID-1.6). 80% of the users found the process of inputting data (ID-1.4) clear and efficient, and the same number find the results obtained meaningful and easy to interpret and use (ID-1.5).

On average the users find the documentation and the training sessions led by the software developer useful (60%) (ID-1.9).

4.4.1.2 USER FRIENDLINESS

The following statements have been set as criteria for assessing the ESA tool in terms of the *User friendliness* category.

TABLE 4.23: ASSESSED USER FRIENDLINESS CRITERIA

ID	Statement
2.1	The user interface is simple, easy to navigate and well-organised
2.2	The user interface looks professional
2.3	It responds promptly to user actions (inputs, selections, clicks, ...)
2.4	It provides the user with enough help, indications and/or guidance throughout each process
2.5	The meaning of each data input/user selection is clear
2.6	The meaning of each data output is clear
2.7	Visualisation of results is clear and informative
2.8	The user can add further information to the Study through the interface

Figure 4.35 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.36 using a spider chart, to highlight the mean, maximum and minimum values.

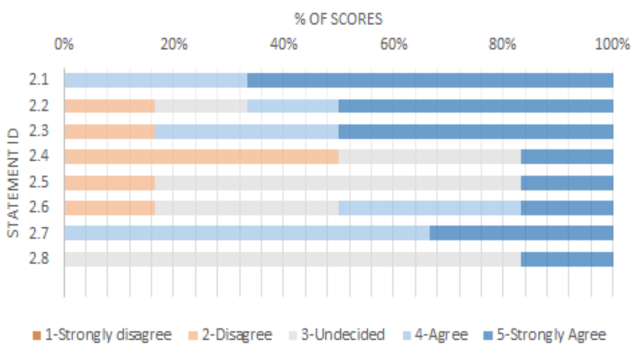

FIGURE 4.35: DISTRIBUTION OF USER SCORES PER USER-FRIENDLINESS STATEMENT

FIGURE 4.36: MEAN, MAXIMUM, AND MINIMUM SCORES PER USER-FRIENDLINESS STATEMENT

All of the respondents either agree or strongly agree that the user interface is simple, easy to navigate and well-organised (ID-2.1). The user interface looks professional for over 60% of the users, with around 16% of users disagreeing with this - statement ID-2.2. For over 80% of the users, the tool responds promptly to user actions, while the remaining disagree (ID-2.3). Around half of the users say that the tool provides the user with enough help, indications and/or guidance throughout each process (ID-2.4), while the remaining disagree, therefore this also can be an improvement area for the next version. Ensuring that the meaning of each data input/user selection and data output is clear for the users can also be an area of improvement, as over 80% of respondents are undecided or disagree with statement ID-2.5 and only 50% agree with ID-2.6. The Visualisation of results is clear and informative according to respondents, with 100% of the respondents agreeing with this statement (ID-2.7). Most of the respondents were undecided regarding statement (ID-2.8) - about the possibility of adding further information to the Study through the interface, signifying that it is not possible or not relevant for this module.

The spider diagram highlights a significant difference between the maximum and minimum scores, especially for statements ID-2.2 to 2.6, which may be due to the different levels of experience with similar tools or datasets by the users from different companies.

4.4.1.3 PERFORMANCE AND ACCURACY

The following statements have been set as criteria for assessing the ESA tool in terms of the *Performance & Accuracy* category.

TABLE 4.24: ASSESSED PERFORMANCE AND ACCURACY CRITERIA

ID	Statement
3.1	Results are robust and not sensitive to small changes of inputs
3.2	Results are credible and trustworthy for the audience
3.3	The accuracy of results is acceptable considering the granularity/complexity of data inputs used
3.4	The accuracy of results corresponds to the user expectation for the stage of technology maturity
3.5	The computational time is adequate for the level of accuracy provided
3.6	The software did not suffer from any sort of data shortage/lack of memory during the test
3.7	The software can handle errors without crashing

Figure 4.37 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.38 using a spider chart, to highlight the mean, maximum and minimum values.

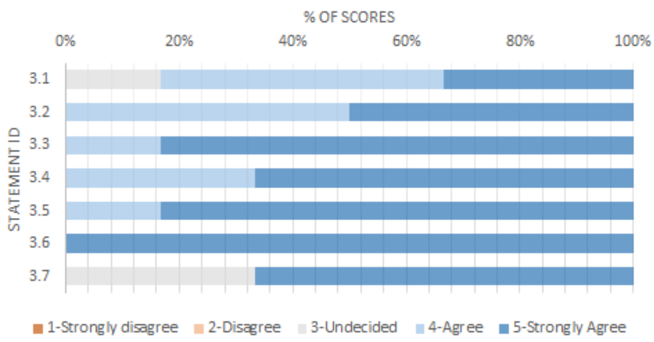

FIGURE 4.37: DISTRIBUTION OF USER SCORES PER PERFORMANCE AND ACCURACY STATEMENT

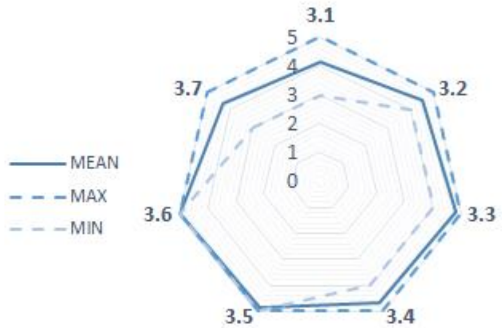

FIGURE 4.38: MEAN, MAXIMUM, AND MINIMUM SCORES PER PERFORMANCE AND ACCURACY STATEMENT

As can be seen from Figure 4.37 and Figure 4.38, the ESA tools shows consistency in performance and accuracy, with no user disagreeing with any of the statements shown in Table 4.24. Over 80% of testers consider that the results are robust and not sensitive to small changes of inputs (ID-3.1). All of the users agree or strongly agree that the results are credible and trustworthy (ID-3.2); the accuracy of results is acceptable considering the quality of data inputs used (ID-3.3); the accuracy of the results corresponds to the user expectation for the stage of the technology maturity (ID-3.4); the computational time is adequate for the level of accuracy provided (ID-3.5) and the software did not suffer from any sort of data shortage/lack of memory during the test (ID-3.6). Around 70% of users strongly agreed that the software can handle errors without crashing (ID3-7), with 30% undecided, highlighted there may have been some problems with the tool crashing during the verification tasks, which should be addressed in the next version. From the spider graph, it is possible to gauge that the mean, maximum and minimum scores are balanced regarding the performance and accuracy of this tool.

4.4.1.4 VALUE

The following statements in Table 4.25 have been set as criteria for assessing the ESA tool in terms of the *Value* category.

TABLE 4.25: ASSESSED VALUE CRITERIA

ID	Statement
4.1	The software allows the user full control of the design process
4.2	It produces results that allow easy comparisons
4.3	It provides a large range of alternatives to create/assess technologies
4.4	The user is informed about the internal processing (e.g. remaining time, log) and warned about potential inconsistencies
4.5	The software meets my expectations in terms of results, graphical options, interaction, and functionality
4.6	I would recommend the use of this software

Figure 4.39 presents in the form of stacked bars the user scores per each statement listed above. The same results are presented in Figure 4.40 using a spider chart, to highlight the mean, maximum and minimum values.

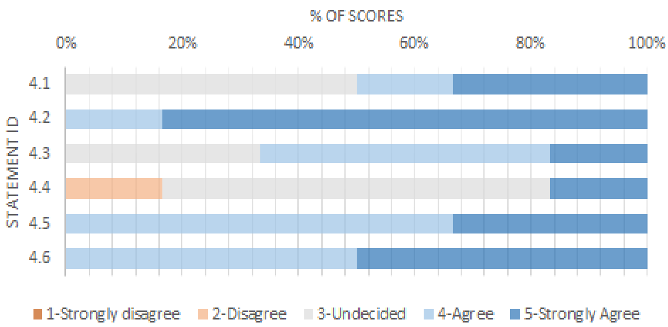

FIGURE 4.39: DISTRIBUTION OF USER SCORES PER VALUE STATEMENT

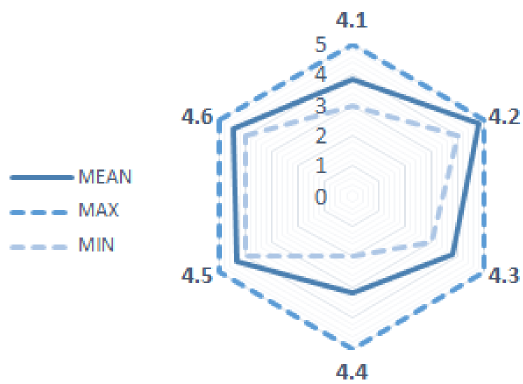

FIGURE 4.40: MEAN, MAXIMUM, AND MINIMUM SCORES PER VALUE STATEMENT

Figure 4.39 shows half the users agree that the software allows the user full control of the design process (ID-4.1), while all users agree or strongly agree that the tool produces results that allow easy comparisons (ID-4.2). For the range of alternatives to create/assess technologies, over 60% of the users agree that the tool provides a large range. (ID-4.3). Only 20% of the users agree that the tool provides information about the internal processing (e.g. remaining time, log) and potential inconsistencies (ID-4.4), therefore, it is a feature to improve in the next version. All the respondents agree that the software meets their expectations in terms of results, graphical options, interaction and functionality (ID-4.5), and would recommend the use of this tool (ID-4.6).

Figure 4.40 shows that there are not significant differences between the minimum (score2) and maximum (score5), except for statement ID4-4, where some users were not able to access easily information on the tool processing time.

4.4.2 QUALITATIVE ASSESSMENT

This section presents feedback from both technical and industrial verifiers, gathered from their Software Evaluation Forms. Comments have been grouped under three main categories: *Overall user experience*, *Unintended module performance*, and *Proposals for improvement*. The aim of this section is to guide the path for improvement of the Environmental and Social Acceptance (ESA) module.

4.4.2.1 OVERALL USER EXPERIENCE

Generally, the feedback indicated that the Environmental and Social Acceptance (ESA) module is straight forward to use and relatively intuitive to fill out. However, the users highlighted that it did not provide enough help, indications and/or guidance throughout each process. According to the comments received, the following can be said about the overall user satisfaction:

- In general, the ESA module is perceived as clear, neat, and professional. It is intuitive and easy to use with meaningful and easy to interpret results. The software can be easily run, and the overall computation speed is satisfactory.
- While the user interface is simple, easy to navigate and well-organized, the users had difficulties to understand some inputs and their meanings and some of the outputs. It was highlighted that the ESA module should give the user more guidance and help throughout each process. This issue will be addressed by adding a help button to each parameter to describe it and a link to a manual will be available for more information.
- Generally, the quality of results is high as judged by all users in terms of accuracy, robustness and performance. For some results, such as "Environmental Impact Assessment" results, users lack guidance for interpretation of the result's values and what actions/suggestions are to implement in relation to the obtained values. More explanation will be added to the EIA outputs page and link to background manual to better understand the results.
- The software produces results allowing easy comparisons between scenarios, but the user is not informed enough about the internal processing and does not have full control of the design process. However, the users highlighted that there is a clear indication of list of input sections and output sections.

Overall, the users felt that the module was useful and easy to use but needed some ameliorations and clarifications. Several suggestions were provided to improve the ESA module's user interface design to be completer and more informative (see section 4.4.2.3).

4.4.2.2 UNINTENDED MODULE PERFORMANCE

In general terms, the tools behaved as expected. However, the following unintended errors in the module's performance were identified by some of the users:

- Some users detected that the **host server was down**, and it prevented them from accessing the module. These issues originated from the host server and not the ESA module itself.
- Problem detected with **resolution** with text that seem to overlap. This occurred when using laptop screen but not when using bigger screen. The module is coded for two sizes of screen and it will be improved.

4.4.2.3 PROPOSALS FOR IMPROVEMENT

GENERAL REMARKS

The verifiers have identified the following areas of improvement in terms of general remarks:

- The welcome page looks clean and professional. It was suggested to remove some double text and an exclamation mark.
- The home page needs to have a contextual description that precises what the tool is about and what should users expect as outputs.
- The exported report could possibly include the inputs of the user such as the Longitude/latitude/ site data, etc.
- Some formatting enhancements were proposed such as limiting the values to 2 decimals after the zero, adding icons where necessary, formatting text size etc.

USABILITY

The verifiers have identified the following areas of improvement in terms of usability:

- The software is intuitive and easy to use in general, but it could be worthwhile adding some help functionality to make the walkthrough easier. Users suggested some enhancements such as letting the user enter the name of the study when they are defining the complexity level and standalone/integrated mode. Also, once the site data have been entered, it is not very intuitive what the user has to do- the next page is the input summary page. This page could use some contextual guidance to let the user know what to do.
- Regarding the process of inputting data, the case VC1 – complexity level 1: it was not as obvious to know if the lat/long were the only data required to run the ESA. It might be worth clarifying this for the user. Also, some more explanation of what the parameters mean in the GUI would be useful.
- When deleting a study, it could be good asking the user for confirmation before deleting a study. When a project is created, there should be a 'Name' option straight away, instead of having to click on 'Save as' to name it which is not intuitive.
- Regarding results, the EIA results are not explained until you click "Detailed Results' which is not an easy button to find – it would be good to have more explanation of the numbers in the actual GUI.
- The training session was good and informative but there was a lack of description in the documentation, it was also formatted such that not very easy to follow. Would have been helpful to have had notes saying that there is no data to input for certain options and explaining the ramifications or what the difference in output would be if no data put in.

USER-FRIENDLINESS

The verifiers have identified the following areas of improvement in terms of user-friendliness:

- In general, the users highlighted that the software is easy to move through. It is very user friendly and the results are well thought out. There could be a bit more information as the user is inputting the data.
- User guidance/ help is missing. Although the tool is clear, it does not give much help or contextual description if required. Although the units are provided as you hover over the cells, it is not sure if this will be obvious to all the users. More guidance and explanations required for the user to understand the language used within the tool.
- The meaning of each data input is not always clear. Some specific explanations were highlighted by the verifiers. Enhancement can also be added for some outputs. For instance, the EIA output scale is probably the best solution to present such qualitative data and compare studies, but the scores are not really easy to understand for someone who did not took time to read training materials and deliverables, and it may require further guidance.
- There is a certain clunkiness to the interface, could do with some better formatting to make look more professional.

PERFORMANCE AND ACCURACY

The verifiers have identified the following areas of improvement in terms of performance and accuracy:

Study Management

- An indication along the top banner which project you're in would be helpful.

Inputs:collection

- Coordinate of the farm: Might be worth adding on top of the Longitude/latitude field the 'title'.
- Some typos and formatting issues (font size) to correct were highlighted by users.
- It is very easy inputting data but they may be some room for adding a small help function or example pop up so a user can understand what they are putting in. For instance, there should be definitions for each parameter e.g. 'Turbidity' – explanation of what these terms mean.

Outputs:collection

- Some typos and formatting issues (font size) to correct were highlighted by users. A glossary for abbreviations could be useful.
- Might be worth adding an explanation if say EIA Scale is -15 or -25 what does that mean?
- Some additional explanations are needed for the outputs. Worth adding contextual guidance to support user.
- For Carbon Footprint outputs, the references are taking a big chunk of the page. They should definitely be moved to a pop-up window or add a help section that can be expanded/collapsed on the Right-hand side of the page. It would also be interesting to find a way to show sensitivity of results to a single parameter (e.g. in the results page for carbon footprint, being allowed to select installation emissions due to fuel consumption, and being given the information that changing the

current value for fuel consumption to a new one will modify total greenhouse emissions for the project by X %)

- For Social Acceptance outputs, a contextual guidance could explain to the user what the results mean. For instance, in VC2-RM3, outputs show zero values. Are these values zero because the inputs were not provided or because this are the correct results of the analysis? Seem strange to have zero cost of consenting and zero number of vessel crew.
- The presence of harmful or toxic substances contained in the WEC such as: lube oil, hydraulic oil or other and relevant risk of leakage or spill. This aspect could be linked to FMEA and evaluated environmental risk.

VALUE

The verifiers have identified the following areas of improvement in terms of value:

- The software should have more contextual description and help/ glossary.
- The user is not informed about the internal processing however, there is a clear indication of list of input sections and output sections.
- Regarding resource used and associated environmental impact, it would be appreciated to be given the possibility to add materials, and their characteristics, or edit current characteristics, in case it can provide more accurate values for the specific material/process.

4.4.3 IDENTIFYING AND SOLVING INCONSISTENCIES

TABLE 4.26: HIGH PRIORITY IMPROVEMENTS TO BE IMPLEMENTED IN THE BETA VERSION OF ESA

Issue	Resolution
Remove the text and exclamation mark in the picture in the welcome page	This will be implemented
Add a contextual description of the tool in the module home page	This will be implemented
Let the user enter the name of the project when he defines cmpl and mode	A box to name the project will be added when complexity and mode are defined
Add some guidance to the user on the type of data necessary for each cmp	Description on what each complexity level refers to and the required inputs will be added to guide the user
Ask confirmation when user wants to delete a project	This will be implemented
Add a previous page button	This will be implemented
Add a go back button when in the summary input page or propose a button for each incomplete page	This will be implemented
Indication along the top banner which project you are in would be helpful	The name of the project will be displayed at the top of each page
Add explanation info on each parameter in the GUI	Help button will be added to each parameter with small description and link to a manual for more information

Issue	Resolution
Labelling the boxes with permanent labels would work better than the hover over	Will add units label next to input boxes instead of hover over
Use the same cell size for title head and column width	This will be implemented
Score could be rounded	Results will be rounded to 2 decimals
Format could be reduced to fit in 1 line in EIA results	This will be implemented
Suppress the hover option on run module since there is just an empty space	This will be implemented
Add brackets to defined abbreviations	This will be implemented
Typos	Typos will be corrected
Better have another colour for the message that appears to highlight that everything is fine (Use success variable in bootstrap)	This will be implemented
For EIA, more explanation is necessary to better understand scoring system	More explanation will be added to the EIA section results and links to manuals
Correct columns in EIA results, which are redundant	EIA results tab will be reviewed
No information if materials not implemented	Precision will be added when no data are provided in the materials section
"actual project" is a confusing label, use the name of the project would be better	The name of the project will be used in the CFP graphs
In CFP section, change name other techno/eneries to other energy sources/technologies	This will be implemented
Add explanations on what LCA stands for and the ISO standards, assumptions of DTOceanPlus	Will add a short description on LCA and link to background manual for more information
In social acceptance section, not clear if '0' mean no data or that '0' is the result	"no data" will be displayed in the case of no data
Put the references in CFP results to a pop-up windows or in a help section	References will be hidden; user will have the possibility to have access to them if needed
Add glossary for abbreviations	A short description of the features will be added to each results page with definition of abbreviations

TABLE 4.27: LOW PRIORITY IMPROVEMENTS TO BE IMPLEMENTED IN THE BETA VERSION OF ESA

Issue	Resolution
Add section breaks to ensure title and section are on the same page of the report	This will be implemented in the export file
Add the DTOcean+ logo in the header of the report	This will be implemented in the export file
Adapt the titles of EIA results sections for more specific ones	Changes in names in EIA section will be changed if there is enough time
No commentary box available	This will be implemented if there is enough time
Include the inputs in the export report	This will be implemented in the export file if there is enough time
Adapt size, font to screen size	The module is coded for two sizes of screen and it will be improved if there is enough time
Add glossary for abbreviations	An independent glossary of all abbreviations of the module will be available to the user and accessible from any page of the module if time allows

TABLE 4.28: ISSUES THAT WILL NOT BE IMPLEMENTED IN THE BETA VERSION OF ESA

Issue	Resolution and Explanation why it will not be implemented
No information on toxic substances contained in the WEC (lube oil, hydraulic oil)	This will not be included in the beta version due to a lack of time but will be considered in future development of the tool
Would be good to be given the possibility to add materials and characteristics to materials	This will not be included in the beta version due to a lack of time but will be considered in future development of the tool
Social acceptance is not detailed as the other pages	This feature will be extended in future development
Visual impact could be an important matter in social acceptance	This will not be included in the beta version due to a lack of time but will be considered in future development of the tool

5. CONCLUSIONS

The objective of Task 6.7 was to carry out the testing of the Assessment Design tools in order to verify that it meets all the previously defined requirements (in WP2 [3] and T6.1 [1]). The verification task has shown that each of the Assessment Design Tools:

- responds correctly to a varied set of inputs,
- performs its functions in an acceptable time and reasonable use of computational resource,
- is adequate in terms of usability, and,
- is verified against control data.

The following actions were completed as part of the verification and were described throughout this report.

- Definition of the Verification Cases and evaluation criteria.
- Organisation of training sessions (for technical and industrial partners).
- Collection of data for each Verification Case.
- Running the Verification Cases (by technical and industrial partners).
- Analysis of the results based on quantitative and qualitative assessments.
- Creation of a task list of changes that could improve the tools to improve performance.

A stable beta version of each of the Assessment Design Tools is now available. Additionally, a first draft of the technical and user manuals that will be delivered alongside the final version of the tools has been written and are included as Annex I to this report.

According to the quantitative results, the end-users involved in evaluating the tools were, in general, satisfied with the usability, user-friendliness, performance, and value of the software. The qualitative assessment feedback highlighted several improvements that should be made to the tools. From this, some of the improvements have been categorised as high priority tasks, that will be implemented in the final release of the DTOceanPlus suite of design tools.

The next steps in the development of the Assessment tools will focus on the implementation of the suggested improvements as discussed above alongside the full integration of the modules with the other DTOceanPlus tools.

Further validation of the Assessment tools will be obtained as part of the work planned in WP7, which aims to validate the suite of tools using real-world demonstration scenarios.

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7. ANNEX I: USER MANUAL

This annex provides an overview of the user manual that is being developed alongside the tools, firstly outlining how this will be produced, and secondly providing an early draft of the documentation content.

7.1 DOCUMENTATION FORMAT

As with the overall suite of tools, there will be an overarching main documentation, with a separate set of documentation for each module. The main documentation will cover areas including installing and running the tools; use cases and user journeys, including linkages between the various parts of the suite; and how to manage projects and studies.

To provide a dynamic and useful documentation system for the DTOceanPlus suite of tools, it is proposed that this will be developed with a linked hierarchical structure that can be viewed in a browser or exported as a document format as required. The documentation will follow an established system[15], split into four main areas preceded by a brief overview of the functionalities and workflow:

- **Tutorials** to give step-by-step instructions on using the tool for new users.
- **How-to guides** that show how to achieve specific outcomes using the tool.
- An **explanation of features and calculation methods** gives technical background on how the tool works, to give confidence in the tools.
- The **API reference section** documents the code of modules, classes, API, and GUI.

The documentation will be produced using the Sphinx Python Documentation Generator[16].

The contents of the documentation will build on the work done to date within the project and will continue to be updated alongside the code. The tutorials will build on those produced to train the partners for the verification activities described in the main report. The explanation of features and calculation methods will be based on the comprehensive details outlined in the alpha-version deliverables. Finally, the API reference section will document the code of the modules, based on the code docstrings written alongside the module code.

The results of the verification activities will be used to improve the documentation, for example the tutorials and/or how-to guides could be added or improved to address any shortcomings identified or feedback received.

For reasons of brevity, the content from the alpha version deliverables and code docstrings will not be included in this annex but will be published alongside the final software at the end of the project.

[15] The Documentation System, https://documentation.divio.com/
[16] Sphinx Python Documentation Generator https://www.sphinx-doc.org/en/master/

7.2 SYSTEM PERFORMANCE AND ENERGY YIELD (SPEY)

The System Performance and Energy Yield (SPEY) module will compute a set of dimensionless and dimensional parameters for assessing the behaviour of the ocean energy system (wave or tidal energy farm, device, or subsystem) for energy production, power quality, alternative metrics, and efficiency.

7.2.1 OVERVIEW OF SPEY FUNCTIONALITIES

The System Performance and Energy Yield (SPEY) module will:

- Compute several dimensionless (**Efficiency**) and dimensional (**Alternative Metrics**) parameters, given the technical design of the ocean energy plant and the power production of the different subsystems, at different level of aggregation (array and device level) and facilitate the visualisation of these outputs to the user.
- Estimate the **Energy Production** at different level of aggregation (array and device level) accounting for the probabilistic distribution of the downtime throughout the life of the project, within different timescales (lifetime of the plant, annual and monthly energy production) and facilitate the visualisation of these outputs to the user.
- Show results in terms of **Power Quality** (Reactive vs Active power to the grid and as outputs per device) obtained by technical modules.

7.2.2 WORKFLOW FOR USING THE SPEY MODULE

The workflow for using the System Performance and energy Yield Module can be summarised as 1) create a study, 2) provide inputs, 2) run the assessment, and 3) view the results, as shown next.

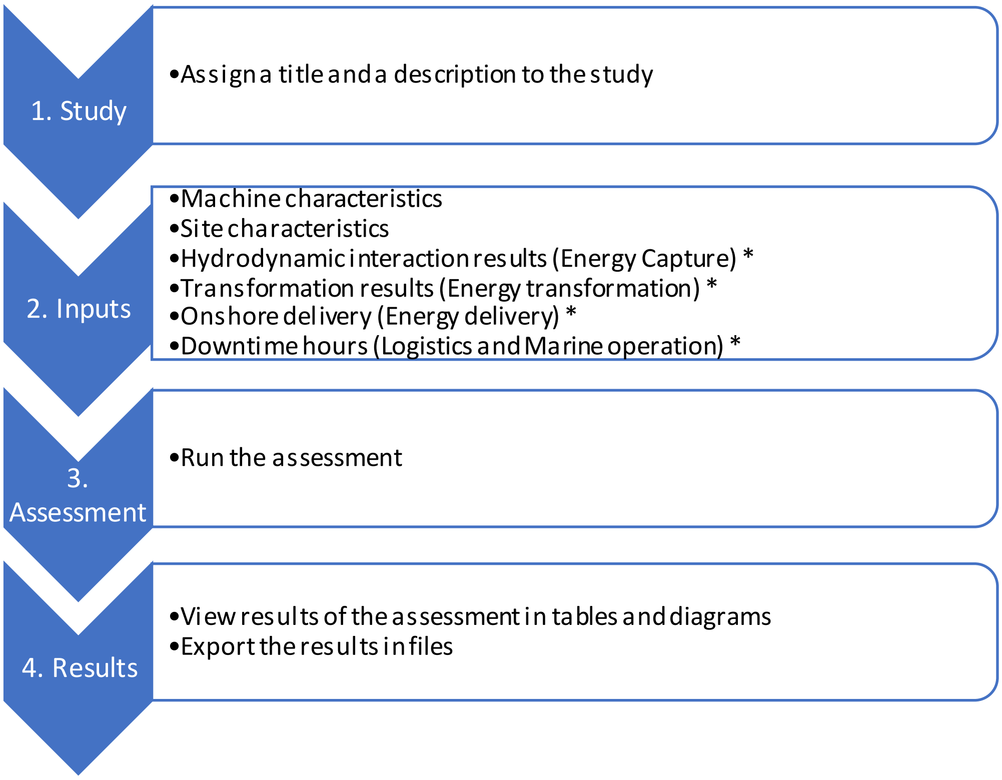


FIGURE 7.1: WORKFLOW OF SPEY IN STANDALONE MODE

7.2.3 OVERVIEW OF SPEY DATA REQUIREMENTS

This section summarises the types of input data required to run the System Performance and Energy Yield module. Full details and data specifications are given in the how to guide on preparing data.

The required and optional inputs to run the module are summarised in the tables below. Note that in integrated mode, all the required inputs will all come from other modules. The inputs have been grouped as for the modules they should come from in integrated mode. Of course, in standalone mode, they all come from the user. A summary of the required inputs is in Table 7.1.

TABLE 7.1: SUMMARY OF INPUTS

Group of Inputs	Parameter
Machine characterisation	▫ Technology: ▫ Rated Power ▫ Mass ▫ Wet area ▫ Characteristic Length
Site Characterisation	▫ Annual Average Energy Flux Tidal [(for tidal energy devices) ▫ Annual Average Energy Flux Wave (for wave energy devices) ▫ Lease area extension. ▫ Monthly Wave Scatter Diagram (for wave energy devices) ▫ Current Monthly Scenario (for tidal energy devices)

Group of Inputs	Parameter
Energy Capture	▫ Number of devices ▫ Array Annual Captured Energy Production ▫ Array q-factor ▫ Device Annual Captured Energy Production ▫ Device q-factor
Energy Transformation	▫ Array Annual Transformed Energy Production ▫ Device Annual Transformed Energy Production ▫ Device Active Transformed Power ▫ Device Reactive Transformed Power
Energy Delivery	▫ Array Annual Delivered Energy Production ▫ Total Length of Cables ▫ Export Cable Length ▫ Onshore active Power per sea state ▫ Onshore reactive Power per sea state
Logistics and Marine Operation	▫ Project Life ▫ Downtime hours per device, per month, per year

7.2.4 SPEY TUTORIALS

7.2.4.1 CREATING A NEW SPEY STUDY IN STANDALONE MODE

Once logged into the server, the next step is to create a new study within the SPEY module. Since multiple users across multiple organisations may be simultaneously accessing the module on the server, **please add your organisation's name in the name of the study you create**. This is to ensure that all users work on independent studies and are not editing the same study at the same time.

1. In the left menu, select 'SPEY Studies' and click 'Create SPEY study'.
2. Fill in an appropriate name and description to identify your study (see Figure 7.2).

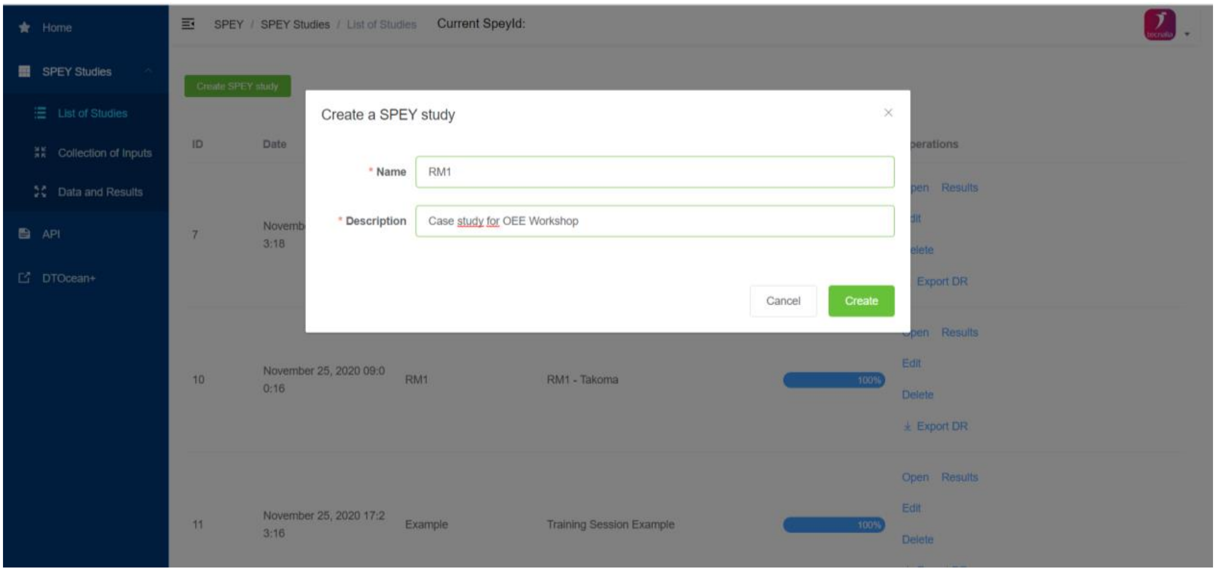


FIGURE 7.2: HOW TO CREATE A SPEY STUDY

3. Click 'create' to save these inputs and return to the list of studies.
4. From the list of studies, click 'Open' to start working on a study by redirecting the user to inputs page, 'Edit' to change the name or description, or 'Delete' to permanently remove a study. If the status of a study is 100% (which means that the assessments where calculated and finalised), two other buttons are active: 'Results', which leads directly to the outputs pages and 'Export DR', in order to export a json file with the SPEY contribution to the Digital Representation of the project.

The user can also click on 'Open' for a study that has been already completed and fully calculated. The user will be redirected to the inputs page, also in this case, in case he/she wants to change some oif the inputs.

[*Note that this tutorial will be updated once studies are centrally managed, but this reflects the current version of the tool.*]

7.2.4.2 INSERTING INPUTS AND RUN A SPEY STUDY

The inputs view is like the one in Figure 7.3.

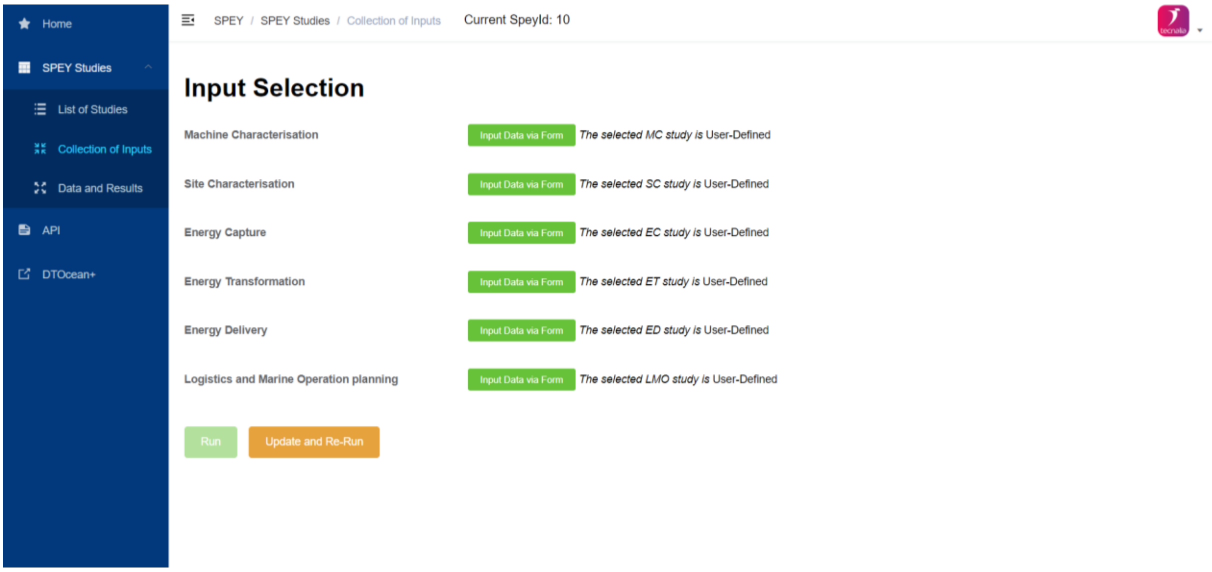


FIGURE 7.3: INPUTS VIEW OF THE SPEY MODULE.

The inputs, in the standalone mode, have been categorised in 6 groups, namely reproducing the modules that the user should have been running if he/she was working in integrated mode: Machine characterisation, Site Characterisation, Energy capture, Energy Transformation, Energy Delivery, Logistics and Marine Operation planning. The only two sets of data that are mandatory are those pertinent to Machine Characterisation and Site Characterisation (in this ord er). All the other sets of data are optional. All these sets of data are optional; however, if the user must input all the data required for a specific set.

By clicking to the green buttons, a form will appear to the user (see for example Figure 7.4). For the description of the data requirements for each set, see the How-to-guide at Section 7.2.5.1.

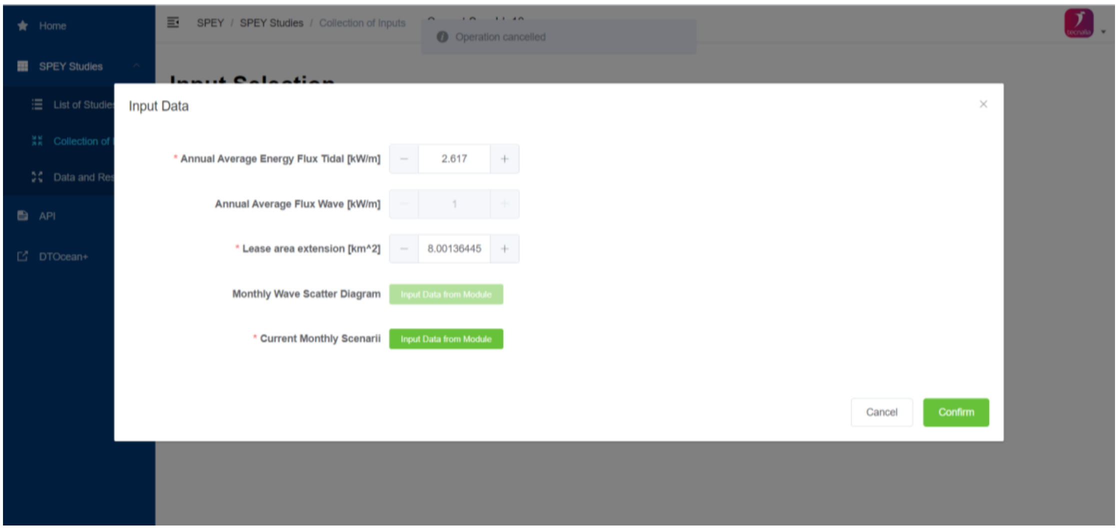


FIGURE 7.4: EXAMPLE OF INPUT FORM (E.G. SITE CHARACTERISATION DATA)

Once that the user has filled the data required to calculate the assessments, he/she can click on the button Run if the study was not run anytime before; if this is not the case, the green button Run will be deactivated and the user can click on Update and Re-Run orange button.

7.2.4.3 EXPLORING THE RESULTS

If SPEY has run successfully, the user can visualise and export the results.

The results are presented in a view as the one in Figure 7.5.

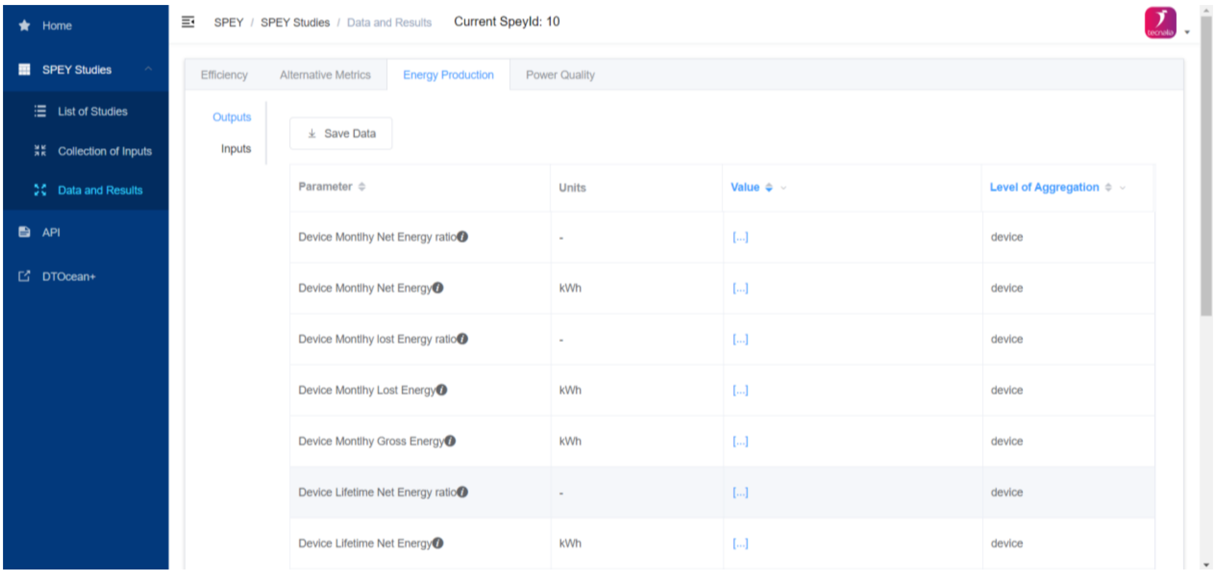


FIGURE 7.5: EXAMPLE OF OUTPUTS VIEW IN SPEY MODULE.

The user can visualise the outputs of one specific assessment by clicking on the dedicated tab (Efficiency, Alternative Metrics, Energy Production and Power Quality). The user can therefore visualise the outputs as well as the inputs required for a specific assessment by clicking on Outputs/Inputs tab. A friendly description of each parameter can be shown by approaching the cursor to the icon next to the parameter name. The different columns will show:

(1) Parameter: the parameter name
(2) Units: the units of the parameter
(3) Value: the actual value of that parameter.

Additionally, all the Outputs have the following:

(4) Level of Aggregation: it could be array or device, if the metrics has been calculated at array or device level.

Finally, the outputs of Power quality, Alternative metrics and Efficiency have also the column:

(5) View: to view a diagram of parameter with respect to the device number or the sea state number.

For each assessment, the inputs and the outputs could be exported in JSON format by clicking on the 'Save data' button.

The fields Parameter and Level of Aggregation are sortable when present. The fields Level of Aggregation and Value are filterable: the former, with respect to 'array' or 'device'; the latter, based if an assessment has been calculated or not. By default, only the calculated assessments are visible.

7.2.5 SPEY HOW-TO GUIDES

7.2.5.1 HOW TO PREPARE DATA FOR USING THE SYSTEM PERFORMANCE AND ENERGY YIELD MODULE

This guide summarises the data requirements and specifications for running the System Performance and Energy Yield in standalone mode.

MACHINE CHARACTERISATION DATA (MANDATORY)

All the data needed for the Machine Characterisation data must be input via the GUI (see Figure 7.6)

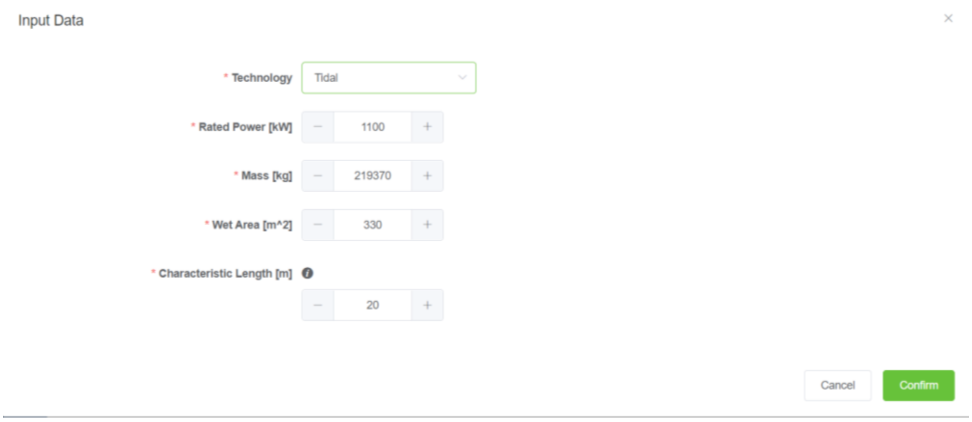


FIGURE 7.6: MACHINE CHARACTERISATION INPUTS FOR THE SPEY MODULE.

- Technology: is a dropdown menu, the user can choose between Wave and Tidal
- Rated Power [kW]: the user can type the rated power of the prime mover
- Mass [kg]: the user can type the mass of the prime mover
- Wet area [m^2]: the user can type the wet area of the prime mover
- Characteristic Length [m]: the user can type the characteristic length of the prime mover. In case of tidal turbine, this is represented by the rotor diameter.

SITE CHARACTERISATION DATA (MANDATORY)

All the data needed for the Site Characterisation data must be input partially directly via the GUI and by uploading a support file (see Figure 7.4).

The data consist in:

- Annual Average Energy Flux Tidal [kW/m^2]: activated only in case of tidal energy devices, the user can type the annual average flux of the site.
- Annual Average Energy Flux Wave [kW/m2]: activated on in case of tidal energy devices, the user can type the annual average flux of the site.
- Lease area extension [km^2]: the user can type the value of the extension of the lease area of the site.
- Monthly Wave Scatter Diagram (for wave energy devices) and Current Monthly Scenario (for tidal energy devices): the user is asked to upload an excel file. The structure of such a file is the same both for tidal and wave cases, as shown in Figure 7.7.

	A	B	C
1	id	1	2
2	January	0.270	0.040
3	February	0.270	0.040
4	March	0.270	0.040
5	April	0.270	0.040
6	May	0.270	0.040
7	June	0.270	0.040
8	July	0.270	0.040
9	August	0.270	0.040
10	September	0.270	0.040
11	October	0.270	0.040
12	November	0.270	0.040
13	December	0.270	0.040
14			

FIGURE 7.7: STRUCTURE OF THE FILE FOR UPLOADING THE MONTHLY WAVE SCATTER DIAGRAM (WAVE ENERGY DEVICES) AND THE CURRENT SCENARII MATRIX (FOR TIDAL ENERGY DEVICES)

The name of the rows are fixed: 'id', 'January', 'February', 'March', 'April', 'May', 'June', 'July', 'August', 'September', 'October', 'November', 'December'. The user should add as many columns as the number of sea (wave or tidal) conditions he/she wants to examine. Each sea state is identified by an incremental integer. The values in the remaining cells corresponds to the monthly occurrence of each sea state.

ENERGY CAPTURE DATA (OPTIONAL)

The data required in terms of Energy capture are optional. However, as mentioned in Section 7.2.4, if the user decides to include the set of data corresponding to Energy capture, the full stack of data is required (no partial input is permitted). Data must be input via the GUI and via file (see Figure 7.8)

FIGURE 7.8: ENERGY CAPTURE INPUTS FOR THE SPEY MODULE.

The data consist in

- Number of devices: the user can type the number of devices in the array.
- Array Annual Captured Energy Production [kWh]: the user can type the value of the annual total energy production in the array.
- Array q-factor: the user can type the q-factor of the whole array.
- Device Captured Energy: the user can upload an Excel file. The structure for this file is shown in Figure 7.9.

	A	B	C
1	id	Annual Captured Energy [kWh]	q-factor
2	1	3930570.80	1
3	2	3918916.51	1
4	3	3659166.76	1
5	4	3042552.03	1
6	5	1749501.41	1
7	6	950385.76	1
8	7	2200704.71	1
9	8	3994573.72	1
10	9	4465244.96	1
11	10	4593879.71	1
12			

FIGURE 7.9: STRUCTURE OF THE FILE FOR UPLOADING THE DEVICE CAPTURED ENERGY

In this case, the names of the Columns are fixed: 'id', 'Annual Captured energy [kWh]' and 'q-factor'. The user must include as many rows as the number of devices, identifying each of them by an increasing integer an adding the corresponding value for the energy production of the device and the q-factor.

ENERGY TRANSFORMATION DATA

The data required in terms of Energy transformation are optional. However, as mentioned in Section 7.2.4, if the user decides to include the set of data corresponding to Energy transformation, the full stack of data is required (no partial input is permitted). Data must be input via the GUI and via file (see Figure 7.10)

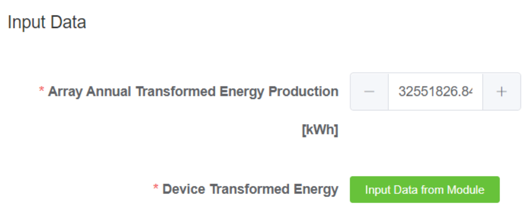


FIGURE 7.10: ENERGY TRANSFORMATION INPUTS FOR THE SPEY MODULE.

The data consist in

- Array Annual Transformed Energy Production [kWh]: the user can type the value of the annual total energy production in the array.
- Device transformed Energy: the user can upload an Excel file. The structure for this file is shown in Figure 7.11.

	A	B	C	D
1	id	Annual Transformed Energy [kWh]	Active Power per Sea State [kW]	Reactive Power per Sea State [kW]
2	1	3927196.006	[19.5266272189349,114,0,587.0:	[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0]
3	2	3935597.923	[19.5266272189349,114,0,121.8:	[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0]
4	3	3619125.719	[19.5266272189349,180,0,0,328.	[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0]
5	4	3029591.214	[22.7810650887574,114,0,265.8:	[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0]
6	5	1800110.703	[29.8816568047337,114,434.782	[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0]
7	6	1042537.859	[54.1420118343195,114,27.1739	[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0]
8	7	2210404.313	[22.7810650887574,0,172.10144	[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0]
9	8	3953802.077	[22.7810650887574,0,172.10144	[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0]
10	9	4436912.3	[19.5266272189349,0,271.73913	[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0]
11	10	4596548.722	[19.5266272189349,0,172.10144	[0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0]

FIGURE 7.11: STRUCTURE OF THE FILE FOR UPLOADING THE DEVICE CAPTURED ENERGY

In this case, the names of the Columns are fixed: 'id', 'Annual transformed energy [kWh]', 'Active power per Sea State [kW]' and 'Reactive power per Sea State [kW]'. The user must include as many rows as the number of devices, identifying each of them by an increasing integer an adding the corresponding value for the energy production of the device, and a list of the active/reactive power per sea state. The length of these lists is the same of the number of sea states considered.

ENERGY DELIVERY DATA

The data required in terms of Energy delivery are optional. However, as mentioned in Section 7.2.4, if the user decides to include the set of data corresponding to Energy delivery, the full stack of data is required (no partial input is permitted). Data must be input via the GUI and via file (see Figure 7.12).

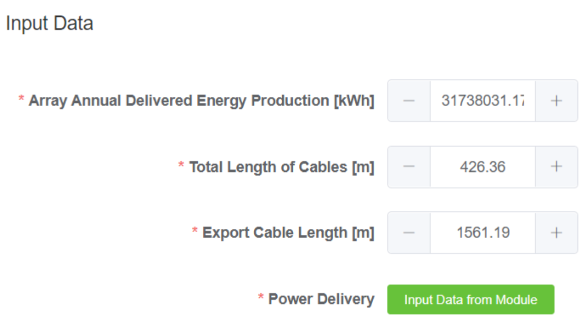


FIGURE 7.12: ENERGY DELIVERY INPUTS FOR THE SPEY MODULE.

The data consist in:

- Array Annual Delivered Energy Production [kWh] : the user can type the value of the annual total energy production in the array.
- Total Length of Cables [m]: the user can type the total length of cables
- Export Cable Length [m]: the user can type the length of the export cable(s).
- Power Delivery: the user can upload an Excel file. The structure for this file is shown in Figure 7.13.

	A	B	C
1	id	1	2
2	Active Power per Condition [kW]	238.1322	715.7475
3	Reactive Power per Condition [kVar]	54.27091	163.1206
4			

FIGURE 7.13: STRUCTURE OF THE FILE FOR UPLOADING THE POWER DELIVERY

The name of the rows are fixed: 'id', 'Active Power per Condition [kW]', 'Reactive Power per Condition [kVar]'. The user should add as many columns as the number of sea (wave or tidal) conditions input in Site condition data. Each sea state is identified by an incremental integer (first row). The values in the remaining cells corresponds to the values of active/reactive power per sea state.

LOGISTICS AND MARINE OPERATION DATA

The data required in terms of Logistics and Marine operation planning are optional. However, as mentioned in Section 7.2.4, if the user decides to include the set of data corresponding to Energy Logistics and marine operation planning, the full stack of data is required (no partial input is permitted). Data must be input via the GUI and via file (see Figure 7.14)

FIGURE 7.14: LOGISTICS AND MARINE OPERATION INPUTS FOR THE SPEY MODULE.

The data consist in

- Project Life [years]: the user can type the value of the project life.
- Downtime per device per year per month: the user can upload a JSON file.

The JSON file should contain a list (introduced by '[', concluded by a ']', and the elements are separated by a ',') of objects (an object for each device is required), introduced by a '{' and concluded by a '}', and the different fields are separated by a ','. Each field consists of a label, between quotation marks, followed by a colon and the value corresponding to this label.

The following fields should be included in the JSON file:

- "device_id" – the value should be a string (identified by quotation marks)
- "downtime_table" – is an object (identified by '{}') whose fields are:
  - "year" – a sequential list from 0 to project life-1
  - "jan", "feb", "mar", "apr", "may", "jun", "jul", "aug", "sep", "oct", "nov", "dec" – they are lists containing the number of dowintime hours for each year of the project life. The length of these lists is the same of the field "year". An example is shown in Figure 7.15.

```
[
    {
      "device_id": "device_1",
      "downtime_table": {"year": [0, 1],
        "jan": [0.0, 10.0],
        "feb": [8.0,1.0],
        "mar": [8.0,0.0],
        "apr": [10.0,0.0],
        "may": [10.0,10.0],
        "jun": [10.0,10.0],
        "jul": [0.0,10.0],
        "aug": [1.0,1.0],
        "sep": [10.0,10.0],
        "oct": [0.0,0.0],
        "nov": [7.0,1.0],
        "dec": [5.0,5.0]
      }
    },
    {
        "device_id": "device_2",
        "downtime_table": {"year": [0, 1],
          "jan": [0.0, 10.0],
          "feb": [8.0,1.0],
          "mar": [8.0,0.0],
          "apr": [10.0,0.0],
          "may": [10.0,10.0],
          "jun": [10.0,10.0],
          "jul": [0.0,10.0],
          "aug": [1.0,1.0],
          "sep": [10.0,10.0],
          "oct": [0.0,0.0],
          "nov": [7.0,1.0],
          "dec": [5.0,5.0]
        }
      }
]
```


FIGURE 7.15: EXAMPLE OF THE JSON FILE FOR UPLOADING THE DOWNTIME PER DEVICE PER YEAR PER MONTH

7.3 System Lifetime Costs (SLC)

The present section is the user manual of the System Lifetime Costs module within the DTOceanPlus design suite of tools.

- For new users, the tutorials give step-by-step instructions on using the tool.
    - List of key tutorials to be added here.
- The how-to guides show how to achieve specific outcomes using the tool.
    - List of main guides?
- The explanation of features and calculation methods gives technical background on how the tool works.
- The API reference section documents the code of modules, classes, API, and GUI.

The System Lifetime Costs module is used to assess the economic performance and financial attractiveness of a given ocean energy project, benchmarking against reference projects. As one of the Assessment Design Tools, the SLC module runs after the selected Deployment Design Tools, and after the System Performance and Energy Yield Assessment Tool, as described in Section 1.2.

7.3.1 OVERVIEW OF SLC FUNCTIONALITIES

The main purpose of the System Lifetime Costs module is to assess the economic performance and financial attractiveness of a given ocean energy project, benchmarking against reference projects. SLC's functionalities include:

- **Compile Bill of Materials (BOM)**: it compiles an inventory of materials, assemblies, and components, including the quantities of each, as well as the installation operations required to construct a given ocean energy farm.
- **Financial assessment**: it evaluates the financial attractiveness of the project from the perspective of the investor, assessing project profitability.
- **Economic assessment**: it performs a techno-economic assessment, estimating the LCOE of the farm, or using other alternative metrics for early-stage technologies.
- **Benchmark analysis**: it compares the economic and financial results of the project against reference values from wave and tidal projects.

All assessments produced by the System Lifetime Costs module are carried out based on the design outputs of the Deployment design tools but also project characteristics introduced by the user and a catalogue of reference cost-breakdowns of ocean energy projects at different development stages.

7.3.2 WORKFLOW FOR USING THE SLC MODULE

The workflow for using the System Lifetime Costs module can be summarised as 1) provide inputs, 2) perform a design, and 3) view the results, as shown in Figure 7.16.

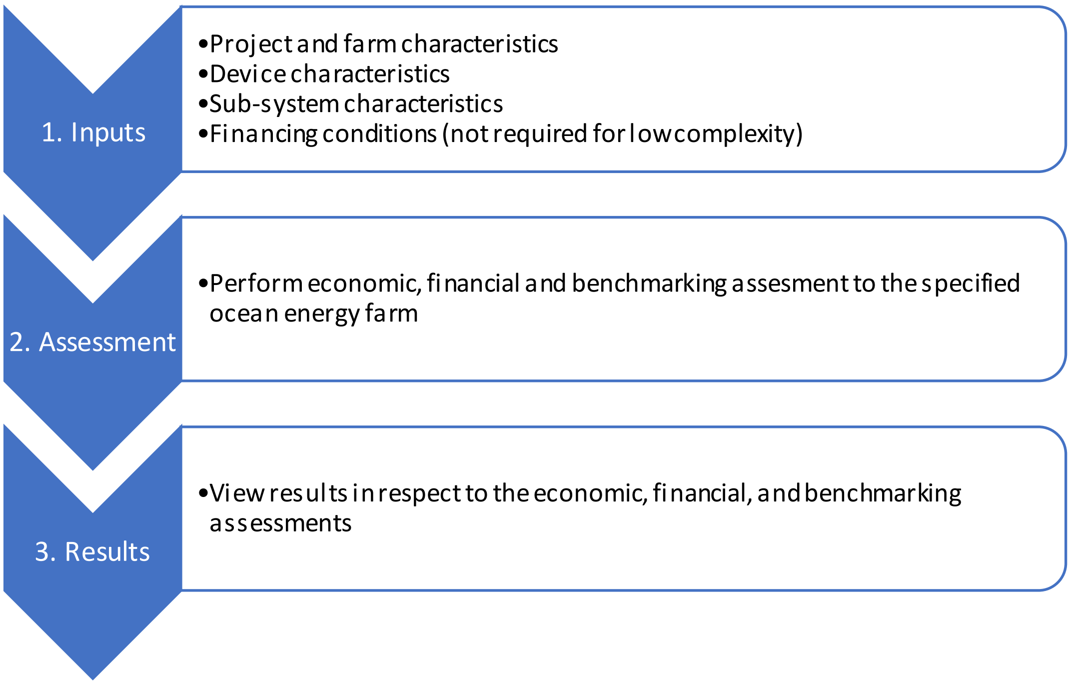


FIGURE 7.16: WORKFLOW OF SLC MODULE

7.3.3 OVERVIEW OF SLC DATA REQUIREMENTS

This section summarises the types of input data required to run the System Lifetime Costs module. Full details and data specifications are given in the how to guide Section 7.3.5, on preparing data.

The required and optional inputs to run the module are summarised in the tables below Table 7.2 and Table 7.3. Note that in integrated mode, the required inputs will come from three different sources:

- External modules (EC, ET, SK, ED, LMO, SPEY)
- User inputs from the GUI
- Component Database (Catalogue)

TABLE 7.2: SUMMARY OF REQUIRED INPUTS

Input Page	Complexity 1	Complexity 2	Complexity 3
General inputs	▫ Device type ▫ Device topology ▫ Device rated power ▫ Device unit structural cost ▫ Project lifetime ▫ Number of devices	▫ Device type ▫ Device topology ▫ Device rated power ▫ Device unit structural cost ▫ Project lifetime ▫ Discount rate ▫ Number of devices	▫ Device type ▫ Device topology ▫ Device rated power ▫ Device unit structural cost ▫ Project lifetime ▫ Discount rate ▫ Number of devices
Financial inputs	–	▫ Electricity market price	▫ Electricity market price
ACE inputs	–		
External inputs	▫ Bill of Materials from ET ▫ Bill of Materials from ED ▫ Bill of Materials from SK ▫ Bill of Materials from LMO ▫ Annual Energy Production ▫ Maintenance solution		

TABLE 7.3: SUMMARY OF OPTIONAL INPUTS

Input Page	Complexity 1	Complexity 2	Complexity 3
General inputs	▫ Development and other CAPEX costs	▫ Development and other CAPEX costs	▫ Development and other CAPEX costs
Financial inputs	–	▫ Grant value ▫ Feed-in tariff price ▫ Years of feed-in tariff	▫ Grant value ▫ Feed-in tariff price ▫ Years of feed-in tariff
ACE inputs	▫ Average Climate Capture Width ▫ Surface area ▫ Surface thickness ▫ Material density ▫ Cost of manufacture		
External inputs	–		

7.3.3.1 USER INPUTS FROM THE GUI

The user will set basic information about the SLC study and provide the main project inputs, device and subsystem characteristics, as well as financing inputs and preferences, depending on the complexity level and technology.

- **Study**: Name, description and standalone mode (yes/no).
- **General inputs**: Device type (Wave/Tidal), device rated power, device structural costs, project lifetime, discount rate, number of devices, other development costs.

- **ACE inputs**: Optional metrics to calculate the ACE metric, a proxy metric for LCOE in low maturity technologies.
- **Financial metrics**: Electricity market price, awarded grant values, feed-in tariff schemas, duration of feed-in tariffs.

7.3.3.2 INPUTS FROM EXTERNAL MODULES

In order to run the System Lifetime Costs module, different inputs will be needed.

- The Bill of Materials from the Energy Transformation module
- The Bill of Materials from the Energy Delivery module
- The Bill of Materials from the Station Keeping module
- The Bill of Materials from the Logistics and Marine Operations module
- The Annual Energy Production from the SPEY module
- The Maintenance solution by the Logistics and Marine Operations module.

While the Bills of Materials from each module are not strictly required for the module to be able to run, the respective cost figures will not be considered in the economic and financial assessments.

In standalone mode, these inputs will be uploaded to the SLC study through six independent json files. All external modules input studies must have the same complexity level.

7.3.3.3 CATALOGUE INPUTS

Apart from external inputs, and user inputs, the System Lifetime Costs module uses default data stored in a catalogue, in order to benchmark the project outputs against reference projects. These parameters may be changed by directly modifying the catalogue.

TABLE 7.4: SLC BENCHMARK CATALOGUE

Project stage	0,1,2,3	4	5	0,1,2,3	4	5
Technology	Tidal	Tidal	Tidal	Wave	Wave	Wave
Description	1st array	2nd array	Commercial	1st array	2nd array	Commercial
CAPEX (€/kW)	9500	7000	4500	10500	9800	4500
OPEX (€/kW/yr)	600	370	270	700	350	300
LCOE (€/kWh)	0.57	0.35	0.22	0.7	0.5	0.41
Station Keeping (%LCOE)	8	8	8	10	10	10
Electrical costs (%LCOE)	8	8	8	5	5	5
Device costs (%LCOE)	28	28	28	43	43	43
Installation costs (%LCOE)	12	12	12	9	9	9
Other Costs (%LCOE)	5	5	5	3	3	3
OPEX (%LCOE)	39	39	39	30	30	30

7.3.4 SLC TUTORIALS

7.3.4.1 CREATING A NEW SYSTEM LIFETIME COSTS STUDY IN STANDALONE MODE

Once logged into the server, the next step is to create a new study within the System Lifetime Costs module. Since multiple users across multiple organisations may be simultaneously accessing the module on the server, **we ask that you add your organisation's name in the name of the study you create** (e.g. "wavec_vc01"). This will ensure that all users work on independent studies and are not editing the same study at the same time.

1. In the left menu, select 'Create project'.
2. Fill in an appropriate title and description to identify your study, then select the appropriate complexity level link to main module complexity levels section. Complexity level 1 can be used to get a quick estimate with minimal inputs. Complexity levels 2 & 3 have the same functionalities although inputs are expected to have different uncertainties.
3. Click 'create' to save these inputs and return to the list of studies.
4. From the list of studies, click 'Open' to start working on a study, 'Edit' to change the name or description, or 'Delete' to permanently remove a study. The status progress bar denotes the percentage of inputs that have already been filled in order to run the module.

[*Note that this tutorial will be updated once studies are centrally managed, but this reflects the current version of the tool.*]

7.3.4.2 USING SYSTEM LIFETIME COSTS AT LOW COMPLEXITY IN STANDALONE MODE

Complexity CPX1 was designed to provide simplified assessments, requiring minimum inputs from the user and other design modules. Inputs are grouped into three input categories: i) "General inputs", which includes fundamental project parameters, ii) "ACE inputs", which consists of optional inputs that are only required in order to calculate the ACE metric (as a proxy to the LCOE), and iii) "External inputs", which groups all the inputs from other upstream modules that are required to run SLC. In this complexity, financial assessments are not available due to limited data availability.

1) If required, create a new complexity level 1 study, as described in the tutorial of Section 7.3.4.1.
2) From the list of studies, click 'Open' to start working on the complexity level 1 study.
3) Click on the General inputs tab and:
   a) Select from the dropdown the device type [*required*].
   b) Select from the dropdown the device topology [*required*].
   c) Introduce the device rated power (kW) [*required*].
   d) Introduce the device unitary structural costs (€), which does not include the costs of the PTO [*required*].
   e) Introduce the project lifetime[17] (in years) [*required*]

[17] The project lifetime must be consistent with the annual energy production (AEP) input file introduced in the external outputs section.

f) Introduce the number of devices[18] [*required*].
g) Introduce Development and other CAPEX costs (€) [*optional*].
h) Click "Validate".
i) If successful, you will get a message "General inputs added" and redirect the user to the inputs page. Otherwise, an error message will pop-up.

4) In case the ACE metric is to be calculated, the inputs in the ACE input tab must be <u>all</u> filled. However, since calculating the ACE metric is optional, the following inputs are described as optional as well:
   a) Specify the Average Climate Capture Width[19] (m) *[optional]*
   b) Surface Area (m2) *[optional]*
   c) Surface Thickness (m) *[optional]*
   d) Density [20](kg/m3) *[optional]*
   e) Cost of manufacture (€/kg) *[optional]*
   f) Click "Validate".
   g) If successful, you will get a message "ACE inputs added" and redirect the user to the inputs page. Otherwise, an error message will pop-up.
5) In order to provide meaningful assessments, the components of the farm, featured in the bill of materials produced by each design module, must be introduced in order to be considered in the economic and financial assessments. However, the SLC module does not strictly require all of the BOMs to be able to run, being therefore optional.
   a) Upload the Bill of Materials of the Energy Transformation module (json file) [*optional*]
   b) Upload the Bill of Materials of the Energy Delivery module (json file) [*optional*]
   c) Upload the Bill of Materials of the Station Keeping module (json file) [*optional*]
   d) Upload the Bill of Materials of the Logistics and Marine Operations module (json file) [*optional*]
   e) Upload the Bill of Materials of the Station Keeping module (json file) [*optional*]
   f) Upload the Annual Energy Production of the farm, for each year (json file) [*required*]
   g) Upload the maintenance solution, outputted by the Logistics and Marine Operations module, including the maintenance activities and costs for different years (json file) [*required*].
   h) In order to remove any file, press the "x" button close to the filename.
   i) Click "Validate".
   j) If successful, you will get a message "External inputs added" and redirect the user to the inputs page. Otherwise, an error message will pop-up.
6) In order to view, modify or delete inputs, the input pages may be revisited.
7) Once all the desired inputs have been filled, click "Compute SLC Assessment" to run the tool

[18] The number of devices must be consistent with the annual energy production (AEP) input file introduced in the external outputs section. Otherwise, changing the number of devices will increase the total costs of the devices but not the total energy production.
[19] The Average Climate Capture Width (ACCW) is a measure of the effectiveness of a WEC at absorbing power from the incident wave energy field, expressed in m.
ACCW [m] = P_{avg} [kW] / $P_{resource}$ [Kw/m]
[20] The surface area, thickness and density are used to estimate the total material mass that is required, in order to calculate the Characteristic Capital Expenditure (CCE).

a) If successful, a message will be shown to the user: "System Lifetime Costs assessment was successfully computed". Otherwise, an error message will be presented to the user, describing what went wrong.

8) After pressing the button to run the SLC assessment, the user is directed to the results page, where the three main result categories are presented.

7.3.4.3 USING SYSTEM LIFETIME COSTS AT MEDIUM/HIGH COMPLEXITY IN STANDALONE MODE

In case of higher data availability, the System Lifetime Costs module can be run at a higher complexity level (CPX2 or CPX3), to provide more detailed assessments. In these complexities, the financial assessment functionality is available. In this case, inputs are grouped into <u>four</u> input categories: i) "General inputs", which includes fundamental project parameters, ii) Financial inputs, which include financial parameters that are required to evaluate cashflows and financial performance, iii) "ACE inputs", which consists of optional inputs that are only required in order to calculate the ACE metric (as a proxy to the LCOE), iv) "External inputs", which groups all the inputs from other upstream modules that are required to run SLC.

1) If required, create a new complexity level 3 study, as described in the tutorial of Section 7.3.4.1.
2) From the list of studies, click 'Open' to start working on the complexity level 3 study
3) Click on the General inputs tab and:
   a) Select from the dropdown the device type [*required*].
   b) Select from the dropdown the device topology [*required*].
   c) Introduce the device rated power (kW) [*required*].
   d) Introduce the device unitary structural costs (€), which does not include the costs of the PTO [*required*].
   e) Introduce the project lifetime[21] (in years) [*required*]
   f) Introduce the number of devices[22] [*required*].
   g) Introduce Development and other CAPEX costs (€) [*optional*].
   h) Click "Validate".
   i) If successful, you will get a message "General inputs added" and redirect the user to the inputs page. Otherwise an error message will pop-up.
4) Click on the Financial inputs tab and:
   a) Introduce market price (€/kWh) [*required*].

   The market price specified in a) consists of the electricity selling price. However, in case a feed-in tariff is in place, especially if it does not cover the entire project lifetime, the user is allowed to specify a feed-in-tariff and the number of years, after which, the energy price reverts to the market priced specified in a).

   b) Grant value (€) [*optional*], featuring possible grants that were awarded to the project.

[21] The project lifetime must be consistent with the annual energy production (AEP) files introduced in the external outputs section.
[22] Changing the number of devices will increase the total costs of the devices but not the AEP.

   c) Feed-in Tariff (FIT) price (€/kWh) [*optional*].
   d) Years of FIT (years) [*optional*].
5) Click on the ACE inputs tab and:
   a) Specify the Average Climate Capture Width[23] (m) [optional]
   b) Surface Area (m2)
   c) Surface Thickness (m)
   d) Density[24] (kg/m3)
   e) Cost of manufacture (€/kg)
   f) Click "Validate".
   g) If successful, you will get a message "ACE inputs added" and redirect the user to the inputs page. Otherwise, an error message will pop-up.
6) In order to provide meaningful assessments, the components of the farm, featured in the bill of materials produced by each design module, must be introduced in order to be considered in the economic and financial assessments. However, the SLC module does not strictly require all of the BOMs to be able to run, being therefore optional.
   a) Upload the Bill of Materials of the Energy Transformation module (json file) [*optional*]
   b) Upload the Bill of Materials of the Energy Delivery module (json file) [*optional*]
   c) Upload the Bill of Materials of the Station Keeping module (json file) [*optional*]
   d) Upload the Bill of Materials of the Logistics and Marine Operations module (json file) [*optional*]
   e) Upload the Bill of Materials of the Station Keeping module (json file) [*optional*]
   f) Upload the Annual Energy Production of the farm, for each year (json file) [*required*]
   g) Upload the maintenance solution, outputted by the Logistics and Marine Operations module, including the maintenance activities and costs for different years (json file) [*required*].
   h) In order to remove any file, press the "x" button close to the filename.
   i) Click "Validate".
   j) If successful, you will get a message "External inputs added" and redirect the user to the inputs page. Otherwise an error message will pop-up.
7) In order to view, modify or delete inputs, the input pages may be revisited.
8) Click "Compute SLC Assessment" to run the tool
   a) If successful, a message will be shown to the user: "System Lifetime Costs assessment was successfully computed". Otherwise, an error message will be presented to the user, describing what went wrong.
9) After pressing the button to run the SLC assessment, the user is directed to the results page, where the four main result categories are presented.

---

[23] The Average Climate Capture Width (ACCW) is a measure of the effectiveness of a WEC at absorbing power from the incident wave energy field, expressed in m.
ACCW [m] = Pavg [kW] / Presource [Kw/m]

[24] The surface area, thickness and density are used to estimate the total material mass that is required, in order to calculate the Characteristic Capital Expenditure (CCE).

7.3.5 SLC HOW-TO GUIDES

7.3.5.1 HOW TO PREPARE DATA FOR USING THE SYSTEM LIFETIME COSTS MODULE

This guide summarises the data requirements and specifications for running the System Lifetime Costs module in full complexity standalone mode (introduced in the "External inputs" tab), but notes which parameters are not required at low complexity and which come from other modules in integrated mode.

FORMAT THE BILL OF MATERIALS OF THE ENERGY TRANSFORMATION, ENERGY DELIVERY, STATION KEEPING, AND LOGISTIC AND MARINE OPERATIONS

The bill of materials produced by each design module is stored in a json format, with the specific data structures described below. Although all the information stored in the individual BOMs are compiled into the final Bill of Materials produced by the System Lifetime Costs module, only the total costs values of each subsystem are considered for the economic and financial computations.

Regardless of the module source, the bill of materials files follows the same data structure, a *json* file comprised of six lists of the same size:

i) *id* is the component/system identifier,
ii) *name* corresponds to the name of the component/system,
iii) *qnt* refers to the quantities of each component/system,
iv) *uom* refers to the unity of measurement (e.g. m, kg, ...),
v) *unit_cost* corresponds to the unitary cost of each item, and,
vi) *total_cost*, which corresponds to the total cost (in Euros) associated with each item.

The SLC module is responsible for compiling the bill of materials of each module, although it only uses the values in the *total_cost* variable, attributable to items with a "Tot_" *id*, to carry out internal calculations.

A dummy bill of materials for the components of the Energy Transformation module was generated, as presented in Table 7.5. Even though the entire list of attributes will be presented in the final bill of materials compiled by SLC, only the *total_cost* value attributable:

- The total costs of the ET system (*id* = "*Tot_ET*", *total_cost* = 300,000€) will be considered.

TABLE 7.5: EXAMPLE BILL OF MATERIALS OF THE ENERGY TRANSFORMATION MODULE


```
{
 "id":["CAT_turbine", "CAT_gen", "CAT_b2b", "Tot_ET"],
 "name":["Air turbine", "Generator", "Back to back converter", "Total ET system"],
 "qnt":["1", "1", "1", "-"],
 "uom":["-", "-", "-", "-"],
 "unit_cost":["100000", "100000", "100000", "-"],
 "total_cost":[100000, 100000, 100000, 300000]
}
```

A dummy bill of materials for the components of the Energy Delivery module was generated, as presented in Table 7.6. Even though the entire list of attributes will be presented in the final bill of materials compiled by SLC, only the total cost values (stored in the *total_cost* list) attributable to:

- Total onshore infrastructure costs (*id* = "*tot_onshoreinf*", *total_cost* =45,000€)
- Total transmission network costs (*id* = "*Tot_transm*", *total_cost* = 2,000,000€)
- Total array network costs (*id* = "*Tot_network*", *total_cost* = 1,000,000€)
- Total collection point costs (*id* = "*Tot_colpoint*", *total_cost* = 500,000€)

TABLE 7.6: EXAMPLE BILL OF MATERIALS OF THE ENERGY DELIVERY MODULE

{
 "**id**": ["CAT_Cable001", "CAT_Cable062", "CAT_colpoint", "CAT_con001", "**Tot_onshoreinf**",
 "**Tot_transm**", "**Tot_network**", "**Tot_colpoint**"],
 "**name**": ["Cable xyz", "Cable xyz239", "Subsea hub", "Connector wet-mate", "Total onshore
 infrastructure", "Total Transmission network", "Total Array network", "Total
 Collection point"],
 "**qnt**": ["3000", "9000", "2", "3", "-", "-", "-", "-"],
 "**uom**": ["m", "m", "-", "-", "-", "-", "-", "-"],
 "**unit_cost**": ["2300", "1100", "1000000", "1000000", "-", "-", "-", "-"],
 "**total_cost**": [100, 200, 300, 400, **45000, 2000000, 1000000, 500000**]
}

For the Station Keeping components, a dummy bill of materials was compiled in Table 7.7. Even though the entire list of attributes will be presented in the final bill of materials compiled by SLC, only the total cost values (stored in the *total_cost* list) attributable to:

- The total cost of the station keeping system (*id* = "*Tot_SK*", *total_cost* = 4,590,000€)

TABLE 7.7: EXAMPLE BILL OF MATERIALS OF THE STATION KEEPING MODULE

{
 "**id**": ["CAT_Anchor001", "CAT_ML001", "**Tot_SK**"],
 "**name**": ["Anchor ", "Mooring line", "Total costs of SK system"],
 "**qnt**": ["3", "1500", "-"],
 "**uom**": ["-", "m", "-"],
 "**unit_cost**": ["20000", "3000", "-"],
 "**total_cost**": [90000, 4500000, **4590000**]
}

The costs of the installation operations to be considered are compiled in the bill of materials typically produced by LMO, as presented in Table 7.8. The SLC module will include every installation operation featured in the LMO BOM file, as long as its *id* starts with "Tot_".

In case a given operation is not to be considered, it can be ignored and not included in the file. This is the case of the mooring and collection point installation costs, which did not take place in this example. In this case, only total costs are compiled and considered, even though the operations are not in order:

- The total cost of installing devices (*id* = "*Tot_Inst_Dev*", *total_cost* = 872,215€)
- The total cost of installing anchors and foundations[25] (*id* = "*Tot_Inst_Anc*", *total_cost* = 6,128,696€)
- The total mooring installation costs[26] (*id* = "*Tot_Inst_Moor*", *total_cost* = 1628674€)
- The total cable installation costs[27] (*id* = "*Tot_Inst_Cable*", *total_cost* = xxxx€ - not included)
- The collection point installation costs[28] (*id* = "*Tot_Inst_Col*", *total_cost* = xxxx€ - not included)

TABLE 7.8: EXAMPLE BILL OF MATERIALS OF THE LOGISTICS AND MARINE OPERATIONS MODULE


```
{
  "id": ["Tot_Inst_Dev", "Tot_Inst_Anc", "Tot_Inst_Cable"],
  "name": ["Total cost of installation of devices", "Total cost of installation of Anchors", "Total cost
            of installation of cables"],
  "qnt": ["-", "-", "-"],
  "uom": ["-", "-", "-"],
  "unit_cost": ["-", "-", "-"],
  "total_cost": [872215, 6128696, 1628674]
}
```


FORMAT THE ANNUAL ENERGY PRODUCTION PRODUCED BY SPEY

The AEP file contains the net annual energy production <u>of the array</u>, in kW, for each year of the project (in the example in Table 7.9, 20 years are considered). In the integrated mode, this input is produced by SPEY and already takes into consideration the downtime due to component failure and O&M, as calculated by the LMO module.

It must be noted that changing the number of years (e.g. from 20 to 30 years) or the number of devices (e.g. from 5 to 1), without changing the AEP file will create an inconsistency and no effect on the calculations will take place. The AEP file must be also modified to reflect these changes[29].

[25] These installation costs refer to piles (pile anchors and pile foundations) as well as other considered foundations.
[26] Generally, the mooring installation costs include the costs of installing anchors, unless they are pile anchors (which are assumed to be installed separately). In this case, the mooring costs are not considered.
[27] Including array and export cables
[28] Depending on the collection point characteristics, it may require an individual installation operation.
[29] Note that the last item of the AEP file does not end with a comma ",".

TABLE 7.9: EXAMPLE BILL OF MATERIALS OF THE SYSTEM PERFORMANCE AND ENERGY YIELD MODULE


```
{
 "array_annual_net_energy_pd": {
  "Aggregation-Level": "array",
  "value": {
   "1": 2727000,
   "2": 2727000,
   "3": 2727000,
   "4": 2727000,
   "5": 2727000,
   "6": 2727000,
   "7": 2727000,
   "8": 2727000,
   "9": 2727000,
   "10": 2727000,
   "11": 2727000,
   "12": 2727000,
   "13": 2727000,
   "14": 2727000,
   "15": 2727000,
   "16": 2727000,
   "17": 2727000,
   "18": 2727000,
   "19": 2727000,
   "20": 2727000
  }
 }
}
```


FORMAT THE MAINTENANCE SOLUTION FILE

In the integrated mode, the maintenance solution is produced by the Logistics and Marine Operations planning tools. In this example, one maintenance operation per year is assumed (with an average OPEX cost per year on the "operation_cost" parameter), to simplify the data inputting process. An example of the maintenance solution input is shown in Table 7.10.

TABLE 7.10: EXAMPLE MAINTENANCE SOLUTION INPUT


```
{
 "operation_id": [
  "OP13_0",
  "OP13_0",
  "OP13_0",
  "OP13_0",
  "OP13_0",
  "OP13_0",
  "OP13_0",
  "OP12_0",
  "OP13_1",
  "OP12_1",
  "OP13_2",
  "OP12_2",
  "OP13_3",
  "OP12_3",
  "OP12_4",
  "OP13_4",
  "OP12_5",
  "OP12_6",
  "OP13_5",
  "OP12_7"
 ],
 "proj_year": [
  1,
  2,
  3,
  4,
  5,
  6,
  7,
  8,
  9,
  10,
…
…
  11,
  12,
  13,
  14,
  15,
  16,
  17,
  18,
  19,
  20
 ],
 "operation_cost": [
        1599527,
        1599527,
        1599527,
        1599527,
        1599527,
        1599527,
        1599527,
        1599527,
        1599527,
        1599527,
        1599527,
        1599527,
        1599527,
        1599527,
        1599527,
        1599527,
        1599527,
        1599527,
        1599527,
        1599527
        ],
}
```

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

This is the user manual for the RAMS module within the DTOceanPlus suite of tools.

- For new users the tutorials give step-by-step instructions on using the tool.
  - Accessing the module on the Open cascade server
  - Creating a new study in standalone mode
  - Using the module at low complexity in standalone mode
- The how-to guides show how to achieve specific outcomes using the tool.
- The explanation of features and calculation methods gives technical background on how the tool works.
- The API reference section documents the code of modules, classes, API, and GUI.

The Reliability, Availability, Maintainability and Survivability (RAMS) module assesses the following metrics:

- Reliability - the ability of a structure or structural member to fulfil the specified requirements, during the working life, for which it has been designed.
- Availability - the probability that a system or component is performing its required function at a given point in time or over a stated period of time when operated and maintained in a prescribed manner. In engineering applications, the availability of a device is the ratio of the uptime to the sum of uptime and downtime during the design lifetime. The availability of the array is the arithmetic average of that of all devices in the array.
- Maintainability - the ability of a system to be repaired and restored to service when maintenance is conducted by personnel using specified skill levels and prescribed procedures and resources.
- Survivability - the probability that the critical structural and mechanical components can survive the ultimate and fatigue loads during the design lifetime.

7.4.1 OVERVIEW OF FUNCTIONALITIES

- Reliability assessment
  - Estimating the maximum, mean and standard deviation of time to failure (TTF) of basic components in Energy Delivery (ED), Energy Transformation (ET) and Station Keeping (SK) subsystems.
  - Estimating the maximum, mean and standard deviation of TTF of the ED, ET, SK subsystems and the array.
  - Calculating the maximum annual probabilities of failure (PoFs) of the ED, ET, SK subsystems and the array.
- Availability assessment
  - Calculating the availability of all the devices and the average availability of the array.
- Maintainability assessment
  - Calculating the probability that the damaged components can be successfully repaired or replaced in a period of time, given the equipment and the resources.

- Survivability assessment
    - Calculating the probability that the critical structural and mechanical components can survive the ultimate loads/stresses during the design lifetime.
    - Calculating the probability that the critical structural and mechanical components can survive the ultimate loads/stresses during the design lifetime.

7.4.2 WORKFLOW FOR USING THE TOOL

The four features, namely reliability, availability, maintainability and survivability, are assessed separately in the RAMS module. The generic workflows are the same, which includes collection of inputs, check the inputs, perform assessment and view the results, as shown in Figure 7.17 to Figure 7.20.

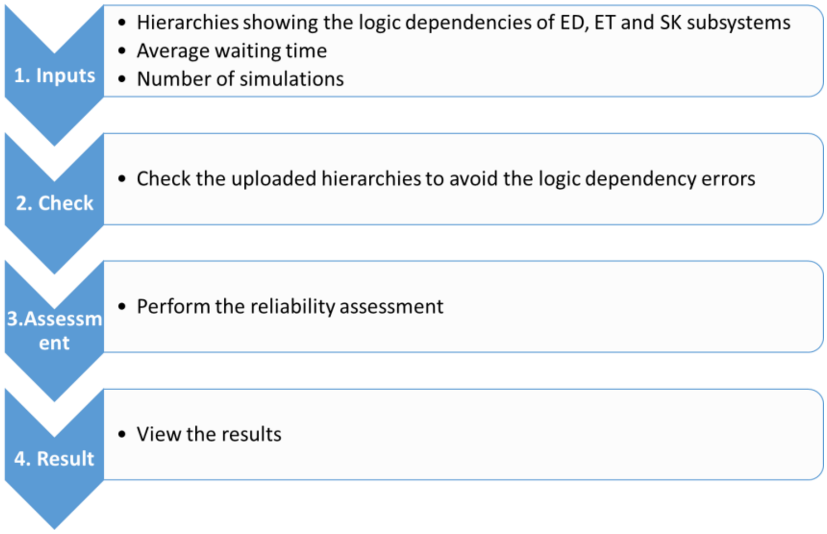


FIGURE 7.17: WORKFLOW OF RAMS MODULE (A) RELIABILITY ASSESSMENT

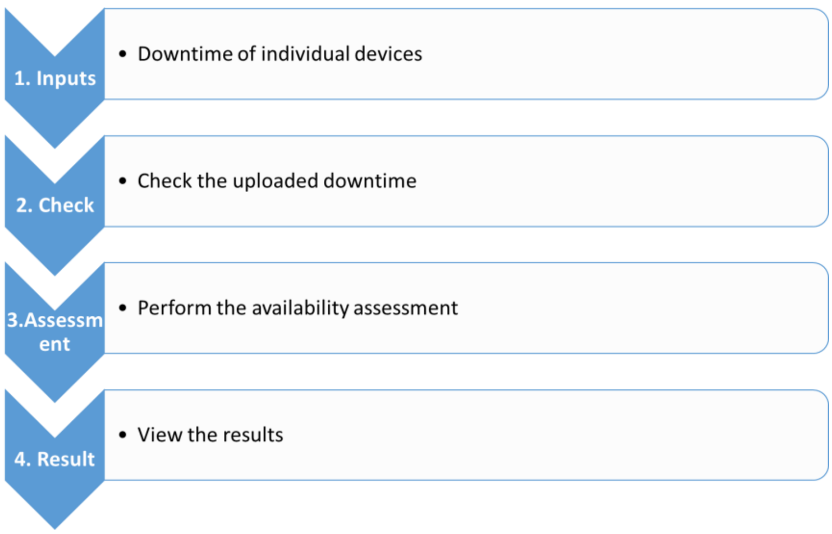


FIGURE 7.18: WORKFLOW OF RAMS MODULE (B) AVAILABILITY ASSESSMENT

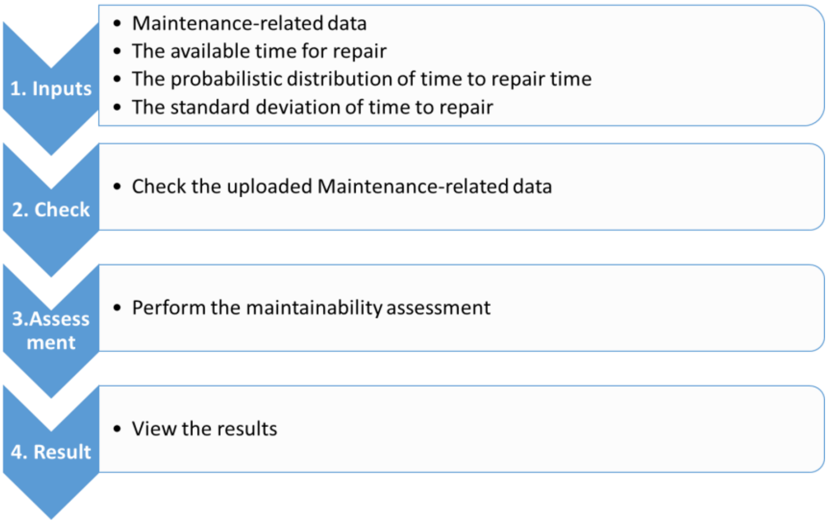


FIGURE 7.19: WORKFLOW OF RAMS MODULE (C) MAINTAINABILITY ASSESSMENT

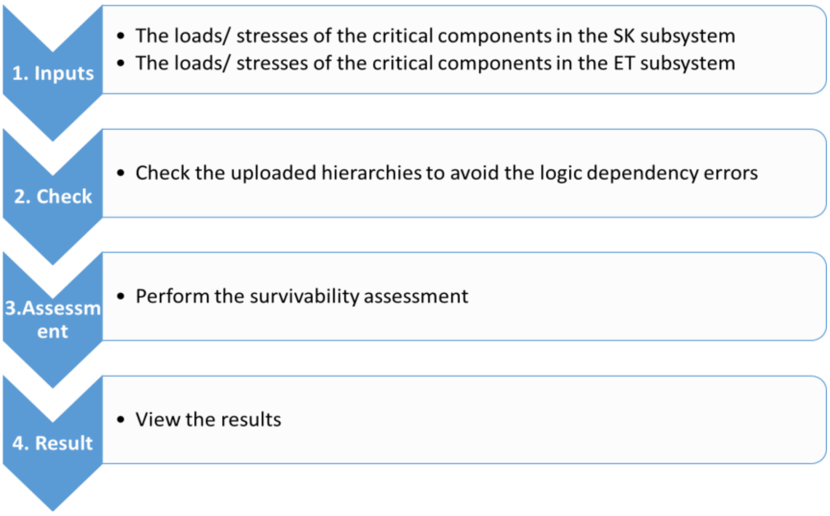


FIGURE 7.20: WORKFLOW OF RAMS MODULE (D) SURVIVABILITY ASSESSMENT

7.4.3 OVERVIEW OF DATA REQUIREMENTS

This section summarises the types of input data required to run the RAMS module. Please check Section 3 for more details.

DATA REQUIREMENT FOR RELIABILITY ASSESSMENT

Reliability assessment requires the hierarchies of the ED, ET and SK subsystems, the number of simulations and the waiting time, as summarized in Table 7.11.

TABLE 7.11: SUMMARY OF INPUTS FOR RELIABILITY ASSESSMENT

External module inputs	Default	Data origin	Units
ED hierarchy	Required	ED or user-defined	-
ET hierarchy	Required	ET or user-defined	-
SK hierarchy	Required	SK or user-defined	-
Number of simulations	Required	User-defined	-
Waiting time	Required	User-defined	hour

DATA REQUIREMENT FOR AVAILABILITY ASSESSMENT

Availability assessment requires the downtime of all the devices in an array, as summarized in Table 7.12.

TABLE 7.12: SUMMARY OF INPUTS FOR AVAILABILITY ASSESSMENT

External module inputs	Default	Data origin	Units
Downtime	Required	LMO or user-defined	-

DATA REQUIREMENT FOR MAINTAINABILITY ASSESSMENT

Maintainability assessment requires the downtime of all the devices in an array, as summarized in Table 7.13.

TABLE 7.13: SUMMARY OF INPUTS FOR MAINTAINABILITY ASSESSMENT

External module inputs	Default	Data origin	Units
Available time	Required	User-defined	hour
Probability distribution of repair time	Required	User-defined	-
Standard deviation of repair time	Required	User-defined	hour
Mttr	Required	LMO or user-defined	hour
Technologies	Required	LMO or user-defined	-

DATA REQUIREMENT FOR SURVIVABILITY ASSESSMENT

Survivability assessment requires many inputs, as summarized in Table 7.14. "Other parameters" are elaborated on in
Table 7.15.

TABLE 7.14: SUMMARY OF INPUTS FOR SURVIVABILITY ASSESSMENT

External module inputs	Default	Data origin	Units
Stress_sk.json	Required	SK or User-defined	-
Stress_et.json	Required	ET or User-defined	-
Other parameters	Required	Default or User-defined	-

TABLE 7.15: EXPLANATION OF OTHER PARAMETERS FOR SURVIVABILITY ASSESSMENT

Parameters	Format	Explanation
cov_a	float	The coefficient of variance of the S-N curve parameter a
cov_l	float	The coefficient of variance of the extreme/ultimate load
cov_q	float	The coefficient of variance of the scale parameter of the 2-parameter Weibull distribution (assumed that the long-term stress ranges follow the 2-parameter Weibull distribution)
cov_r	float	The coefficient of variance of the resistance (maximum breaking load, MBL) of the mooring lines
cov_ufl	float	The coefficient of variance of the uncertainty factor associated with the load
cov_ufr	float	The coefficient of variance of the uncertainty factor associated with the resistance
mu_ufl	float	The mean value of the uncertainty factor associated with the load
mu_ufr	float	The mean value of the uncertainty factor associated with the resistance
n_sim_fls	integer	The number of simulations for the survivability assessment (fatigue limit state, FLS)

Parameters	Format	Explanation
n_sim_uls	integer	The number of simulations for the survivability assessment (ultimate limit state, ULS)
option_fls	string	The method used for assessing the survivability (FLS), option 1 – 'Monte Carlo' (for complexity 1, 2 & 3); option 2 – 'FORM' (for complexity 2 & 3)
option_uls	string	The method used for assessing the survivability (ULS), option 1 – 'Monte Carlo' (for complexity 1, 2 & 3); option 2 – 'FORM' (for complexity 2 & 3)
pd_a	string	The probability distribution of the S-N curve parameter a
pd_h	string	The probability distribution of the shape parameter of the 2-parameter Weibull distribution (assumed that the long-term stress ranges follow the 2-parameter Weibull distribution)
pd_l	string	The probability distribution of the load
pd_m	string	The probability distribution of the S-N curve parameter m
pd_n	string	The probability distribution of the number of stress range cycles
pd_q	string	The probability distribution of the scale parameter of the 2-parameter Weibull distribution (assumed that the long-term stress ranges follow the 2-parameter Weibull distribution)
pd_r	string	The probability distribution of the resistance
pd_ufl	string	The probability distribution of the uncertainty factor associated with the load
pd_ufr	string	The probability distribution of the uncertainty factor associated with the resistance

It should be noted that: if Log-normal is chosen for a stochastic variable, the mean and standard deviation should be those of logged variable. For example, suppose a stochastic variable X following the Log-normal distribution. $\mu_{\ln(X)}$ and $\sigma_{\ln(X)}$ should be the inputs. The relationship of mean and standard deviation between X and log(X) can be given as follows:

With μ_X and σ_X known, $\mu_{\ln(X)}$ and $\sigma_{\ln(X)}$ are expressed as:

$$\sigma_{\ln(X)} = \sqrt{\ln\left[1 + \left(\frac{\sigma_X}{\mu_X}\right)^2\right]}$$

$$\mu_{\ln(X)} = \ln(\mu_X) - \frac{1}{2}\sigma_{\ln(X)}^2$$

The data structure of stress_sk.json and stress_et.json are described as follows:

- stress_sk.json: It is a json file, which contains the following data relevant for survivability assessment in Table 7.16.

TABLE 7.16: EXPLANATION OF THE DATA IN STRESS_SK.JSON

Data	Key Name in stress_sk.json
The ultimate loads on the mooring lines	devices[i]["uls_results"]["mooring_tension"]
The maximum breaking loads (MBL) of the mooring lines	devices[i]["uls_results"]["mbl_uls"]
The stress ranges on the mooring lines	devices[i]["fls_results"]["cdf_stress_range"]
The cumulative distribution functions (CDFs) of the stress ranges	devices[i]["fls_results"]["cdf"]
The S-N curve parameter a	devices[i]["fls_results"]["ad"]
The S-N curve parameter m	devices[i]["fls_results"]["m"]
The number of stress range cycles	devices[i]["fls_results"][" n_cycles_lifetime"]

- stress_et.json: It is a json file, which contains the following data relevant for survivability assessment in Table 7.17.

TABLE 7.17: EXPLANATION OF THE DATA IN STRESS_ET.JSON

Data	Key Name in stress_et.json
The label of the critical device	"device_id"
The mean of the S-N curve parameter a	"mu_a"
The standard deviation of the S-N curve parameter a	"std_a"
The S-N curve parameter m	"m"
The shape parameter of the 2-p Weibull distribution for the long-term stress ranges	"h"
The mean scale parameter of the 2-p Weibull distribution for the long-term stress ranges	"mu_q"
The standard deviation of scale parameter of the 2-p Weibull distribution for the long-term stress ranges	"mu_q"
The mean of the ultimate load	"mu_l"
The standard deviation of the ultimate load	"std_l"
The number of cycles of stress ranges	"n"

As mentioned in Section 3.3.4.4, the updated stress_et.json file contains the data as summarized in Table 7.18.

TABLE 7.18: EXPLANATION OF THE DATA IN UPDATED STRESS_ET.JSON

Data	Key Name in stress_et.json
The S-N curve	"S_N"
The ultimate stresses	"ultimate_stress"
The fatigue stresses and probability	" fatigue_stress_probability"
The number of cycles of stress ranges	"number_cycles"

7.4.4 TUTORIALS

7.4.4.1 CREATING A RAMS STUDY

Once logged into the server, the next step is to create a new study within the RAMS module. Since multiple users across multiple organisations may be simultaneously accessing the module on the server, **please add your organisation's name in the name of the study you create**. This is to ensure that all users work on independent studies and are not editing the same study at the same time.

1) In the home page, select 'Environmental and Social Acceptance Studies' and click 'Create new project'.
2) Choose "Standalone" running mode, then select the appropriate complexity level.
3) Click 'confirm' to enter list of inputs required in the chosen complexity level.
4) From any page of inputs, click on "save" or "save as" to name and save the project.

[*Note that this tutorial will be updated once studies are centrally managed, but this reflects the current version of the tool.*]

7.4.4.2 RELIABILITY ASSESSMENT

Given an array composed of three major subsystems (ED, ET and SK), the user would like to know: how long it will take before basic components fail (namely mean TTF) and the uncertainties of TTF; to know how long it will take before these subsystems fail (namely mean TTF) and the uncertainties of TTF. The uncertainties refer to the standard deviation of TTF. Reliability assessment is performed at both the component and system levels.

The user can walk through the following steps to perform reliability assessment:

- Upload the inputs
  - Navigate to Reliability by clicking "R.A.M.S. Studies" in the navigation pane on the left-hand side of the RAMS GUI.
  - Upload the hierarchies of the ED, ET and SK subsystems by clicking the " SK hierarchy", "ED hierarchy " and " ET hierarchy " buttons on the top of the RAMS GUI. A panel pops up, after clicking either of these buttons. Click the "Browse" button to find and upload the input file. Two messages, namely "JSON file decoded successfully" and "JSON file saved to DB successfully", pop up to indicate that the inputs are successfully uploaded.
- Set the user-defined parameters in GUI
  - Define the average waiting time by typing a value or adjusting the symbol button labelled "+/-" in the "Average Waiting Time".
  - Define the simulation numbers by typing a value or adjusting the symbol button labelled "+/-" in the "Number of simulations".
- Check the input summary
  - The user can check the inputs to confirm, by clicking "Input Summary".
- Perform the assessment.

  - Click the button labelled "Calculate". The system-level reliability assessment takes a long time, if a high number of simulations is applied.
- View the assessment results
  - Click on "Component Reliability" to obtain the component-level reliability assessment results. The results in "Component Reliability" is a form including four columns. The first column contains the IDs of basic components. The second column contains the mean time to failure (MTTF) of these basic components. The third column contains the maximum TTF of these basic components. The last column contains the standard deviation of TTF of basic components.
  - Click on "System Reliability" to obtain the component-level reliability assessment results. The results in "System Reliability" contain two parts. Part 1, a bar plot, contains the maximum PoFs the subsystems (ED, ET, SK) and the array. Part 2, a bar plot, contains the MTTF, maximum TTF and standard deviation of the subsystems (ED, ET, SK) and the array.

7.4.4.3 AVAILABILITY ASSESSMENT

Given an array composed of *N* devices. The user would like to know how many hours each device can work normally and the average normal working hours of an array.

The user can walk through the following steps to perform availability assessment:

- Upload the inputs
  - Navigate to Availability by clicking "R.A.M.S. Studies" in the navigation pane on the left-hand side of the RAMS GUI.
  - Upload the downtime of the individual devices by clicking the "Downtime" button on the top of the RAMS GUI. A panel pops up, after clicking the " Downtime " button. Click the "Browse" button to find and upload the input file. Two messages, namely "JSON file decoded successfully" and "JSON file saved to DB successfully", pop up to indicate that the inputs are successfully uploaded.
- Check the input summary
  - The user can check the inputs to confirm, by clicking "Input Summary".
- Perform the assessment
  - Click the "Calculate" button to start the calculation.
- View the assessment results
  - Click "System availability" to see the availability of the devices and the average availability of the array which are shown in a bar plot. The horizontal axis represents the availability in percentage. The vertical represents different items, for example, devices, array.

7.4.4.4 MAINTAINABILITY ASSESSMENT

There is such a scenario in which a basic component fails. Suppose it is a critical component, the mean time to repair (TTR) is μ_{repair} (assumed to be in a begin weather) and the available time window for repairing it is t_{ava} hour. Based upon the engineering experience, the time to repair (TTR) follows the

Gaussian distribution. The technician is expected to repair it in a begin weather and is given all the necessary spare parts and tools. The user would like to know the probability that the technician can successfully repair it within t_{ava}.

The user can walk through the following steps to perform maintainability assessment:

- Upload the inputs
  - Navigate to Maintainability by clicking "R.A.M.S. Studies" in the navigation pane on the left-hand side of the RAMS GUI.
  - Upload the downtime of the individual devices by clicking the "Maintenance" button on the top of the RAMS GUI. A panel pops up, after clicking the "Maintenance " button. Click the "Browse" button to find and upload the input file. Two messages, namely "JSON file decoded successfully" and "JSON file saved to DB successfully", pop up to indicate that the inputs are successfully uploaded.
- Check the input summary
  - The user can check the inputs to confirm, by clicking "Input Summary".
- Set the user-defined parameters in GUI
  - Set up the "Available Time" and the "Standard Deviation" by clicking either plus or minus icons. Choose the "Probability Distribution".
- Perform the assessment
  - Click the "Calculate" button to start the calculation.
- View the assessment results
  - Click "System maintainability" to see the probability that the damaged components can be repaired within a specific period of time.

7.4.4.5 SURVIVABILITY ASSESSMENT

Suppose that the user only cares about the structural integrity of the array, e.g. mooring lines, PTOs;

The user has performed dynamic response analyses to obtain the ultimate loads or stresses and the fatigue stress ranges of critical components. The user would like to know the probabilities that these critical components can survive the ultimate loads or stresses and the fatigue stress ranges during the design lifetime.

The user can walk through the following steps to perform maintainability assessment:

- Upload the inputs
  - Navigate to Survivability by clicking "R.A.M.S. Studies" in the navigation pane on the left-hand side of the RAMS GUI.
  - Upload the stress of the ET subsystem by clicking the "Stress ET" button on the top of the RAMS GUI. A panel pops up, after clicking the "Stress ET" button. Click the "Browse" button to find and upload the input file. Two messages, namely "JSON file decoded successfully" and "JSON file saved to DB successfully", pop up to indicate that the inputs are successfully uploaded.

- Upload the stress of the SK subsystem by clicking the "Stress SK" button on the top of the RAMS GUI. A panel pops up, after clicking the " Stress SK" button. Click the "Browse" button to find and upload the input file. Two messages, namely "JSON file decoded successfully" and "JSON file saved to DB successfully", pop up to indicate that the inputs are successfully uploaded.

- Check the input summary
  - The user can check the inputs to confirm, by clicking "Input Summary".
- Set the user-defined parameters in GUI
  - Refer to the explanation of variables in Section 3.3.4.4 to set up the user-defined parameters.
- Perform the assessment
  - Click the "Calculate" button to start the calculation.
- View the assessment results
  - Click "System survivability ULS" to see the probability that the critical structural/mechanical components can survive the ultimate loads/stresses during the design lifetime.
  - Click "System survivability FLS" to see the probability that the critical structural/mechanical components can survive the fatigue stress ranges during the design lifetime.

7.4.5 RAMS HOW-TO GUIDES

7.4.5.1 HOW TO PREPARE DATA FOR USING THE RAMS MODULE

This guide summarises the data requirements and specifications for running the Reliability Availability Maintainability Survivability module.

INPUTS FOR RELIABILITY ASSESSMENT

As mentioned in the main text of the report, hierarchies, the number of simulations, and the average waiting time are required to run reliability assessment. The number of simulations, and the average waiting time are scalar inputs, which are easily understood. Hierarchy is a complicated data structure which will be elaborated on in the following part of this subsection.

A hierarchy is a 2-D table array storing the information on the working philosophy and the interrelationship of the units at different levels reflected in a fault tree. See the template below.

System	Name of Node	Design Id	Node Type	Node Subtype	Category	Parent	Child	Gate Type	Failure Rate Repair [1/hour]	Failure Rate Replacement [1/hour]

The first column gives the subsystem or system to be analysed. All failure events are considered nodes in the hierarchy. The second column, 'Name of Node', gives the names of these failure events. The third column, 'Design Id', gives the identification labels of the basic components and other units. The column, 'Node Type', defines the levels of a hierarchy. The column, 'Node SubType', defines the additional information the design modules use to identify the corresponding node. The column, 'Category', defines which levels the nodes in the 'Name of Node' column belong to in the fault tree. The columns 'Parent' and 'Child' define the dependencies of units at various levels. Each entry in 'Parent' defines the label of the higher-level unit which the current unit in the column 'Name of Node' belongs to. Each entry in 'Child' defines the labels of lower-level units which belong to the current unit. Based upon the aforementioned descriptions, the units in the column 'Child' are connected through a specific logic gate to the higher-level unit. The logic gates are given in the column 'Gate Type'. The logic gate in each entry of this column is used to connect the unit in the column 'Name of Node' and the units in the column 'Child'. The last two columns give the failure rates of basic components for two failure modes. Please refer to Section 3.3.4.1 for more details.

INPUTS FOR AVAILABILITY ASSESSMENT

As mentioned in the main text of the report, the downtime of individual devices is required to run the availability assessment. Prepare the inputs according to data format detailed in Section 3.3.4.2.

INPUTS FOR MAINTAINABILITY ASSESSMENT

As mentioned in the main text of the report, maintenance-related data, the probabilistic distribution, and the standard deviation of time to repair are required run the maintainability assessment. Prepare the inputs according to data format detailed in Section 3.3.4.3.

INPUTS FOR SURVIVABILITY ASSESSMENT

As mentioned in the main text of the report, there are many input data used to run the survivability assessment. Prepare the inputs according to data format detailed in Section 3.3.4.4.

HOW TO VISUALIZE THE RESULTS IN THE RAMS MODULE

This guide summarises the data requirements and specifications for running the Reliability Availability Maintainability Survivability module.

7.5 ENVIRONMENTAL AND SOCIAL ACCEPTANCE (ESA)

This is the user manual for the Environmental and Social Acceptance module within the DTOceanPlus suite of tools.

- For new users the tutorials give step-by-step instructions on using the tool.
  - Accessing the module on the Open cascade server
  - Creating a new study in standalone mode
  - Using the module at low complexity in standalone
  - Using the module at medium/high complexity in standalone mode
- The how-to guides show how to achieve specific outcomes using the too
- The explanation of features and calculation methods gives technical background on how the tool works
- The API reference section documents the code of modules, classes, API, and GUI

The Environmental and Social Acceptance module (ESA) aims to assess the environmental and social impacts generated by the various technology choices and array configurations of wave or tidal devices. It is one of the Assessment Tools, run after the Deployment Design tools. Link to main manual section on the suite of tools.

7.5.1 OVERVIEW OF FUNCTIONALITIES

ESA tools will provide the user with four main features described in the following sections.

The module has different complexity levels that reflect the level of information needed for the assessment. This is not a different process of data but an addition of functionalities depend ing on the stage of development the user is in:

At the early complexity level, the level of information is not enough developed in the various DTOceanPlus modules to be able to achieve a full ESA assessment. At this stage, only the "Endangered species" main function can be run as this function requires only the site location in order to run and to inform about the presence or not of endangered species.

At the mid complexity level, the four main functions (i.e. Endangered species; Environmental impacts; Carbon FootPrint and Social Acceptance) can be partially run to produce an incomplete ESA assessment.

At the late complexity level, the ESA assessment is complete and includes all functions developed under the four main functions.

7.5.1.1 ENDANGERED SPECIES

Considering the coordinates of chosen site of the project, this feature will:

- Identify the potential presence of very sensitive species in the lease area (Table 7.19) selected based on their IUCN red list status and presence in European directives and international conventions.
- Identify aspects of the design that can be considered as a risk for the present endangered species.
- Identify possible improvements to work on to minimise the impacts on the endangered species.
- Provide recommendations for design processes based on the main risks associated and provide global recommendations including monitoring survey protocols that are relevant to monitor the species in the array area.

TABLE 7.19: LIST OF THE 26 ENDANGERED SPECIES CONSIDERED IN ESA MODULE

Latin name	Commun name	IUCN status (years)	Berne	Bonn	Directive habitats	Directive oiseaux	Ospar	Helcom	Barcelone
Balaenoptera borealis	Sei whale	EN (2018)	√	√	√	-	-	-	√
Balaenoptera musculus	Blue whale	EN (2018)	√	√	√	-	√	-	-
Balaenoptera physalus	Fin whale	VU (2018)	√	√	√	-	-	-	√
Eubalaena glacialis	NA right whale	EN (2017)	√	√	√	-	√	-	√
Phocoena phocoena	Harbour porpoise	LC (2008)	√	√	√	-	√	√	√
Physeter macrocephalus	Sperm whale	VU (2006	√	√	√	-	-	-	√
Monachus monachus	Mediterranean Monk seal	EN (2015)	√	√	√	-	-	-	√
Acipenser sturio	Sturgeon	CR 2009)	√	√	√	-	√	-	√
Anguilla anguilla	European Eel	CR (2008)	-	-	-	-	√	√	√
Thunnus thynnus	Atlantic blue tuna	EN (2011)	-	-	-	-	√	-	√
Carcharodon carcharias	Great white shark	VU (2005)	√	√	-	-	√	-	√
Lamna nasus	Porbeagle	VU (2006)	√	-	-	-	√	√	√
Cetorhinus maximus	Basking Shark	VU (2005)	√	-	-	-	√	-	√
Dipturus batis	Common skate	CR (2006)	-	-	-	-	√	√	-
Rostroraja alba	White skate	EN (2006)	-	-	-	-	√	-	-
Squatina squatina	Angelshark	CR (2017)	√	-	-	-	√	-	√
Branta ruficollis	Red breasted goose	VU (2016)	√	√	√	√	-	-	-
Polysticta stelleri	Steller's eider	VU (2018)	√	√	√	√	√	√	-
Numenius tenuirostris	Slender-billed Curlew	CR (2018)	√	√	√	√	-	-	√
Puffinus mauretanicus	Balearic Shearwater	CR (2018)	√	-	√	√	√	-	-
Puffinus yelkouan	Yelkouan Shearwater	VU (2018)	√	-	√	√	-	-	√
Eretmochelys imbricata	Hawkskill turtle	CR (2008)	√	√	√	-	-	-	√
Lepidochelys kempii	Kemp's ridley	CR (2019)	√	√	√	-	-	-	√
Dermochelys coriacea	Leatherback	VU (2013)	√	√	√	-	√	-	√
Caretta caretta	Loggerhead turtle	VU (2015)	√	√	√	-	√	-	√
Chelonia mydas	Green sea turtle	EN (2004)	√	√	√	-	-	-	-

7.5.1.2 ENVIRONMENTAL IMPACT ASSESSMENT

Considering the different design choices, this feature will quantify the potential pressures generated by the device array on the maritime environment.

TABLE 7.20: LIST OF THE PRESSURES CONSIDERED IN ESA MODULE

Function's name		Brief description
Footprint		Evaluation of the footprint impact of the array components
Collision risk		Evaluation of collision risks between fauna (marine mammals, fish and birds) and devices
Energy modification		Evaluation of impact of the energy modification due to the array
Noise (underwater)		Evaluation of the impact of underwater noise produced by the array
Electromagnetic fields		Evaluation of the electromagnetic fields from the electrical components
Chemical pollution		Evaluation of potential chemical pollution due to devices or facilities in the array (eg oil leaks, antifouling leaks…)
Turbidity		Evaluation of the intensity of the modification of the turbidity in the water column due to the array
Temperature modification		Evaluation of the impact of the water temperature modifications around electrical components
Reef effect		Evaluation of new habitats created from device's parts (mainly foundations)
Reserve effect		Evaluation the reserve effect (safe area) due to array area where no fishing activity is allowed
Resting place		Evaluation of the impact of emerged parts of the devices as resting place for pinnipeds and birds.

7.5.1.3 CARBON FOOTPRINT

This feature performed a Life Cycle Assessment (LCA) structured by two main standards which are ISO 14040 and ISO 14044 in order to:

- translate the preliminary flows (e.g. bills of material required for the production of devices, fuel required for transportation during installation) of an MRE conceptual array into midpoint informative indicators (I.e. Global Warming Potential (gCO2-eq/kWh), Cumulative Energy Demand (MJ/kWh) and Energy Payback Period (Years))
- make it possible to situate a concept among its alternative concepts and to judge, in the first degree, of its relevance.

7.5.1.4 SOCIAL ACCEPTANCE

This feature provides insight on social acceptance of the project in terms of cost of consenting (€/kWh) and jobs creation.

7.5.2 WORKFLOW FOR USING THE TOOL

The workflow for using the Environmental and Social Acceptance module can be summarised as 1) provide inputs, 2) perform an assessment depending on the complexity level, and 3) view the results, as shown in Figure 7.21.

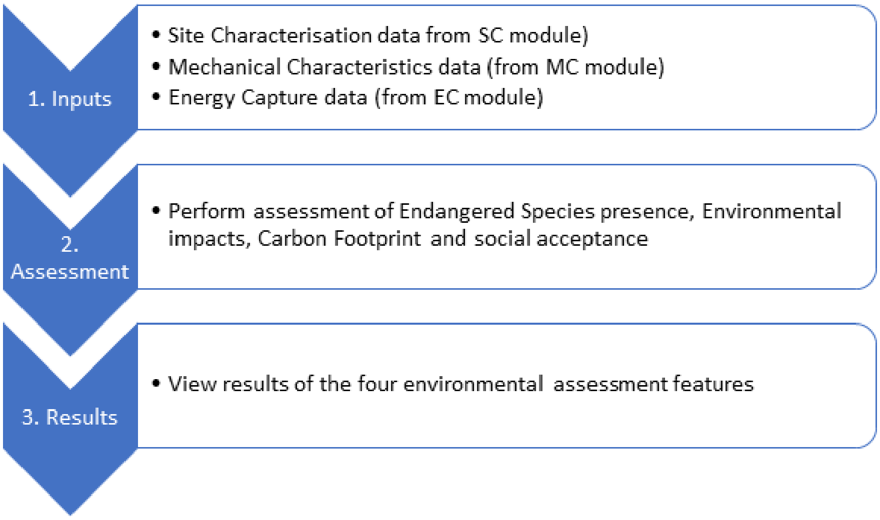


FIGURE 7.21: WORKFLOW OF ESA MODULE

7.5.3 OVERVIEW OF DATA REQUIREMENTS

This section summarises the types of input data required to run the Environmental and Social Acceptance module. Full details and data specifications are given in Section 3.4.4.

The required inputs to run the module are summarised at Table 7.21. Note that in integrated mode, these will all come from other modules except for environmental measurements and optional inputs (Table 7.22).

TABLE 7.21: SUMMARY OF REQUIRED INPUTS

Section	Complexity 1	Complexity 2	Complexity 3
Farm inputs	Coordinates of the farm	Global area description, fishing regulation	Global area description, fishing regulation Initial environmental state
Devices inputs		General information, dimensions, resources, fishing restriction, foundations information	General information, dimensions, resources, fishing restriction, foundations information Measurements of environmental parameters
Electrical inputs		General information, installation information, fishing restriction, resources	General information, installation information, fishing restriction, resources Measurements of environmental parameters
Logistics inputs		Characteristics of the boats in each phase, fuel consumption	Characteristics of the boat in each phase, fuel consumption Measurements of environmental parameters

TABLE 7.22: SUMMARY OF OPTIONAL INPUTS

Section	Sub category
Farm inputs	▫ Protected species on site ▫ Receptors presence on site and seasonal information

7.5.4 TUTORIALS

7.5.4.1 CREATING A NEW ENVIRONMENTAL AND SOCIAL ACCEPTANCE STUDY IN STANDALONE MODE

Once logged into the server, the next step is to create a new study within the Environmental and Social Acceptance module. Since multiple users across multiple organisations may be simultaneously accessing the module on the server, **please add your organisation's name in the name of the study you create**. This is to ensure that all users work on independent studies and are not editing the same study at the same time.

1. In the home page, select 'Environmental and Social Acceptance Studies' and click 'Create new project'.

2. Choose "Standalone" running mode, then select the appropriate complexity level.
3. Click 'confirm' to enter list of inputs required in the chosen complexity level.
4. From any page of inputs, click on "save" or "save as" to name and save the project.

[*Note that this tutorial will be updated once studies are centrally managed, but this reflects the current version of the tool.*]

7.5.4.2 USING ENVIRONMENTAL AND SOCIAL ACCEPTANCE AT LOW COMPLEXITY IN STANDALONE MODE

To get information on the potential presence of endangered species and get recommendations on mitigation measures to lower the main risks associated with the implementation. Use the low complexity (level 1) version of the Environmental and Social Acceptance module. This assumes the user has information only on the coordinates of implementation.

1. If required, create a new complexity level 1 study, as described in tutorial 2.
2. Fill the "Farm info" inputs page
    a. Enter Coordinates of the farm [*required*]
    b. Add information about protected species present in the area [*optional*]
    c. Click "Next page"
3. If successful, "inputs summary" page will appear and inform you if farm info is "complete"
    a. Click "Run module"
    b. Enter a name for your project in the "Save your inputs before running" pop up
4. If the run calculation is successful, results page of Endangered species will appear and detail by the five classes of species:
    a. Taxonomic information
    b. Main associated risks
    c. Recommendations on mitigation measures and surveys

7.5.4.3 USING ENVIRONMENTAL AND SOCIAL ACCEPTANCE AT MEDIUM/HIGH COMPLEXITY IN STANDALONE MODE

To perform a more detailed assessment of a project environmental impacts use the full complexity (level 2 or 3) version of the Environmental and Social Acceptance module. Difference between level 2 and 3, is the measurements of environmental parameters before and after implementation of the farm. If the user has no information or if the project is not implemented yet, it is suggested to use complexity level 2.

1. If required, create a new complexity level 2 or 3 study, as described in tutorial 2.
2. Enter "Farm info" required inputs:
    a. In the "farm general info" section:
        i. Enter the coordinates of the farm (degree decimal),
        ii. project lifetime (years),
        iii. Levelized cost of Energy (€/kWh)

   b. In the "Area description" section:
      i. Select zone type,
      ii. Enter Water depth (m),
      iii. Enter Current main direction (degree),
      iv. Select soil type
      v. In the "Initial state" section, enter initial measurements of turbidity, underwater noise, electrical field, magnetic field and temperature
   c. Select the fishing regulation applied in the farm
   d. Inform on presence of endangered species in the "protected species" section
   e. Select the type of receptors global and seasonal presence in "receptors" section
   f. Click "Next page"
3. Enter "device info" required inputs:
   a. In the "device general" info section:
      i. Select the type of device,
      ii. Precise if the device(s) are floating or not
      iii. Enter the number of device(s)
      iv. Enter device locations (UTM)
   b. In "Device dimensions" section:
      i. Enter height, width, length of the device (m)
      ii. Enter wet area surface of the device (m^2)
      iii. Enter dry area surface of the device (m^2)
   c. In the "Resources" section:
      i. Enter the resource reduction (%)
      ii. Select used materials for device and precise quantity used and quantity to recycle
   d. In the "Environmental measurements" section:
      i. Enter measured noise of the device (dB re 1 u Pa)
      ii. Enter measured turbidity due to device installation (mg/L)
   e. In the "Fishing restriction" section, enter total surface of fishing restriction around devices (m^2)
   f. In "Foundation" section:
      i. Select used materials for foundation and precise quantity used and quantity to recycle
      ii. Enter footprint surface of foundation
      iii. Enter colonisable surface of foundation
      iv. Enter measured noise of foundation
   g. Click "Next page"
4. Enter "Electrical info" required inputs:
   a. In the "electrical general info":
      i. Enter annual energy produced (kWh)
      ii. Enter colonisable surface of electrical components (m^2)
      iii. Enter footprint of electrical installation (m^2)
   b. In the "Installation info" section:

            i. Precise if there is a collection point
                1. If yes, Enter collection point coordinates (UTM)
                2. Enter collection points dimensions (height, width, length) (m)
                3. Enter collection point wet area (m^2)
                4. Enter collection point dry area (m^2)
            ii. Precise if there is a substation
            iii. Precise if cables are buried
    c. In the "Fishing restriction" section, enter total surface of fishing restriction around cables (m^2)
    d. In the "Environmental measurements" section:
        i. Enter measured noise of the device (dB re 1 u Pa)
        ii. Enter measured electrical field (V/m)
        iii. Enter measured magnetic field (uT)
        iv. Enter measured temperature around cables (°C)
    e. Click "Next page"
5. For each phase of the life cycle of the farm (Installation, exploitation, decommissioning), enter "Logistic info" required inputs:
    a. Enter number of vessels
    b. Enter mean size of vessels (mean lao) (m)
    c. Enter number of passengers on boats
    d. Enter measured noise of the vessels (dB re 1 u Pa)
    e. Enter measured turbidity due to marine operations (mg/L
    f. Select type of chemical pollutant if any during marine operation
    g. Enter total fuel consumption during the phase (kg)
    h. Click "Next page"
6. In the "Inputs summary" page, check that all categories are "complete", if not go back to fill the required inputs
7. Click "Run module", name your project and save your inputs and click "save"

8. ANNEX II: SOFTWARE EVALUATION FORM – STANDALONE VERSIONS

8.1 SYSTEM PERFORMANCE AND ENERGY YIELD (SPEY)

Tool – Module: Assessment Design Tool - System Performance and Energy Yield

Name (user)	
Company	
Date	Pick a delivery date

Instructions

Numeric assessment

Please rate each field in the tables using a scale from 1 to 5, where 1 represents the most negative assessment and 5 the most positive one.

Strongly disagree	Disagree	Undecided	Agree	Strongly Agree
(1)	(2)	(3)	(4)	(5)

Qualitative assessment

Please use the box in each section to add comments, overall experience, or other points that may be useful to record.

1. USABILITY

This section aims to assess the high-level software experience. A Study is a design case of an ocean energy technology that can be independently managed in DTOceanPlus.

ID	Statement	Rating
1.1	The software is intuitive and easy to use in general	[Select]
1.2	It is easy to create and delete a Study	[Select]
1.3	It is easy to edit, save and export a Study	[Select]
1.4	The process of inputting data is clear and efficient	[Select]
1.5	Results are meaningful, easy to interpret and use	[Select]
1.6	I could complete the process without errors	[Select]
1.7	I am satisfied with the overall speed of computation	[Select]
1.8	The software can be run from my computer without any issue	[Select]
1.9	The training sessions and documentation are useful for learning how to use the software	[Select]

Comments

[Please add other key points and comments]

2. USER-FRIENDLINESS

This section aims to assess the user interface of the software.

ID	Statement	Rating
2.1	The user interface is simple, easy to navigate and well-organised	[Select]
2.2	The user interface looks professional	[Select]
2.3	It responds promptly to user actions (inputs, selections, clicks, ...)	[Select]
2.4	It provides the user with enough help, indications and/or guidance throughout each process	[Select]
2.5	The meaning of each data input/user selection is clear	[Select]
2.6	The meaning of each data output is clear	[Select]
2.7	Visualisation of results is clear and informative	[Select]
2.8	The user can add further information to the Study through the interface	[Select]

Comments

[Please add other key points and comments]

3. PERFORMANCE AND ACCURACY

This section aims to assess the quality of results in terms of accuracy, robustness, and performance. A Feature is a main functionality of the software that adds value to the user.

ID	Statement	Rating
3.a.1	Results are robust and not sensitive to small changes of inputs	[Select]
3.a.2	Results are credible and trustworthy for the audience	[Select]
3.a.3	The accuracy of results is acceptable considering the granularity/complexity of data inputs used	[Select]
3.a.4	The accuracy of results corresponds to the user expectation for the stage of technology maturity	[Select]
3.a.5	The computational time is adequate for the level of accuracy provided	[Select]
3.a.6	The software did not suffer from any sort of data shortage/lack of memory during the test	[Select]
3.a.7	The software can handle errors without crashing	[Select]

Comments about Study Management

[Please add other key points and comments]

Comments about Inputs Collection

[Please add other key points and comments]

Comments about Outputs: Efficiency

[Please add other key points and comments]

Comments about Outputs: Alternative Metrics

[Please add other key points and comments]

Comments about Outputs: Power Quality

[Please add other key points and comments]

Comments about Energy Production

[Please add other key points and comments]

4. VALUE

This section aims to assess the perceived value to the user.

ID	Statement	Rating
4.1	The software allows the user full control of the design process	[Select]
4.2	It produces results that allow easy comparisons	[Select]
4.3	It provides a large range of alternatives to create/assess technologies	[Select]
4.4	The user is informed about the internal processing (e.g. remaining time, log) and warned about potential inconsistencies	[Select]
4.5	The software meets my expectations in terms of results, graphical options, interaction, and functionality	[Select]
4.6	I would recommend the use of this software	[Select]

Comments

[Please add other key points and comments]

5. GENERAL REMARKS

This section aims to record other qualitative aspects not mentioned above.

[Please add any final remarks]

8.2 SYSTEM LIFETIME COSTS (SLC)

Tool – Module: Assessment Design Tool - System Lifetime Costs

Name (user)	
Company	
Date	Pick a delivery date

Instructions

Numeric assessment

Please rate each field in the tables using a scale from 1 to 5, where 1 represents the most negative assessment and 5 the most positive one.

Strongly disagree	Disagree	Undecided	Agree	Strongly Agree
(1)	(2)	(3)	(4)	(5)

Qualitative assessment

Please use the box in each section to add comments, overall experience, or other points that may be useful to record.

1. USABILITY

This section aims to assess the high-level software experience. A Study is a design case of an ocean energy technology that can be independently managed in DTOceanPlus.

ID	Statement	Rating
1.1	The software is intuitive and easy to use in general	[Select]
1.2	It is easy to create and delete a Study	[Select]
1.3	It is easy to edit, save and export a Study	[Select]
1.4	The process of inputting data is clear and efficient	[Select]
1.5	Results are meaningful, easy to interpret and use	[Select]
1.6	I could complete the process without errors	[Select]
1.7	I am satisfied with the overall speed of computation	[Select]
1.8	The software can be run from my computer without any issue	[Select]
1.9	The training sessions and documentation are useful for learning how to use the software	[Select]

Comments

[Please add other key points and comments]

2. USER-FRIENDLINESS

This section aims to assess the user interface of the software.

ID	Statement	Rating
2.1	The user interface is simple, easy to navigate and well-organised	[Select]

2.2	The user interface looks professional	[Select]
2.3	It responds promptly to user actions (inputs, selections, clicks, …)	[Select]
2.4	It provides the user with enough help, indications and/or guidance throughout each process	[Select]
2.5	The meaning of each data input/user selection is clear	[Select]
2.6	The meaning of each data output is clear	[Select]
2.7	Visualisation of results is clear and informative	[Select]
2.8	The user can add further information to the Study through the interface	[Select]

Comments

[Please add other key points and comments]

3. PERFORMANCE AND ACCURACY

This section aims to assess the quality of results in terms of accuracy, robustness, and performance. A Feature is a main functionality of the software that adds value to the user.

ID	Statement	Rating
3.a.1	Results are robust and not sensitive to small changes of inputs	[Select]
3.a.2	Results are credible and trustworthy for the audience	[Select]
3.a.3	The accuracy of results is acceptable considering the granularity/complexity of data inputs used	[Select]
3.a.4	The accuracy of results corresponds to the user expectation for the stage of technology maturity	[Select]
3.a.5	The computational time is adequate for the level of accuracy provided	[Select]
3.a.6	The software did not suffer from any sort of data shortage/lack of memory during the test	[Select]
3.a.7	The software can handle errors without crashing	[Select]

Comments about Study Management

[Please add other key points and comments]

Comments about Inputs Collection

[Please add other key points and comments]

Comments about Outputs: Bill of Materials tables

[Please add other key points and comments]

Comments about Outputs: Economic metrics (LCOE, …)

[Please add other key points and comments]

Comments about Outputs: Alternative Metrics (ACE)

[Please add other key points and comments]

Comments about Outputs: Financial metrics (IRR, NPV, …)

[Please add other key points and comments]

Comments about Benchmarking metrics (CAPEX/KW, LCOE Breakdowns)

[Please add other key points and comments]

4. VALUE

This section aims to assess the perceived value to the user.

ID	Statement	Rating
4.1	The software allows the user full control of the design process	[Select]
4.2	It produces results that allow easy comparisons	[Select]
4.3	It provides a large range of alternatives to create/assess technologies	[Select]
4.4	The user is informed about the internal processing (e.g. remaining time, log) and warned about potential inconsistencies	[Select]
4.5	The software meets my expectations in terms of results, graphical options, interaction, and functionality	[Select]
4.6	I would recommend the use of this software	[Select]

Comments

[Please add other key points and comments]

5. GENERAL REMARKS

This section aims to record other qualitative aspects not mentioned above.

[Please add any final remarks]

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

Tool – Module: Assessment Design Tool - Reliability, Availability, Mantainability, Survivability

Name (user)	
Company	
Date	Pick a delivery date

Instructions

Numeric assessment

Please rate each field in the tables using a scale from 1 to 5, where 1 represents the most negative assessment and 5 the most positive one.

Strongly disagree	Disagree	Undecided	Agree	Strongly Agree
(1)	(2)	(3)	(4)	(5)

Qualitative assessment

Please use the box in each section to add comments, overall experience, or other points that may be useful to record.

1. USABILITY

This section aims to assess the high-level software experience. A Study is a design case of an ocean energy technology that can be independently managed in DTOceanPlus.

ID	Statement	Rating
1.1	The software is intuitive and easy to use in general	[Select]
1.2	It is easy to create and delete a Study	[Select]
1.3	It is easy to edit, save and export a Study	[Select]
1.4	The process of inputting data is clear and efficient	[Select]
1.5	Results are meaningful, easy to interpret and use	[Select]
1.6	I could complete the process without errors	[Select]
1.7	I am satisfied with the overall speed of computation	[Select]
1.8	The software can be run from my computer without any issue	[Select]
1.9	The training sessions and documentation are useful for learning how to use the software	[Select]

Comments

[Please add other key points and comments]

2. USER-FRIENDLINESS

This section aims to assess the user interface of the software.

ID	Statement	Rating
2.1	The user interface is simple, easy to navigate and well-organised	[Select]
2.2	The user interface looks professional	[Select]

2.3	It responds promptly to user actions (inputs, selections, clicks, …)	[Select]
2.4	It provides the user with enough help, indications and/or guidance throughout each process	[Select]
2.5	The meaning of each data input/user selection is clear	[Select]
2.6	The meaning of each data output is clear	[Select]
2.7	Visualisation of results is clear and informative	[Select]
2.8	The user can add further information to the Study through the interface	[Select]

Comments

[Please add other key points and comments]

3. PERFORMANCE AND ACCURACY

This section aims to assess the quality of results in terms of accuracy, robustness, and performance. A Feature is a main functionality of the software that adds value to the user.

ID	Statement	Rating
3.a.1	Results are robust and not sensitive to small changes of inputs	[Select]
3.a.2	Results are credible and trustworthy for the audience	[Select]
3.a.3	The accuracy of results is acceptable considering the granularity/complexity of data inputs used	[Select]
3.a.4	The accuracy of results corresponds to the user expectation for the stage of technology maturity	[Select]
3.a.5	The computational time is adequate for the level of accuracy provided	[Select]
3.a.6	The software did not suffer from any sort of data shortage/lack of memory during the test	[Select]
3.a.7	The software can handle errors without crashing	[Select]

Comments about Reliability assessment

[Please add other key points and comments]

Comments about Availability assessment

[Please add other key points and comments]

Comments about Maintainability assessment

[Please add other key points and comments]

Comments about Survivability assessment

[Please add other key points and comments]

Comments about Outputs: Reliability

[Please add other key points and comments]

Comments about Outputs: Availability

[Please add other key points and comments]

Comments about Outputs: Maintainability

[Please add other key points and comments]

Comments about Outputs: Survivability

[Please add other key points and comments]

4. VALUE

This section aims to assess the perceived value to the user.

ID	Statement	Rating
4.1	The software allows the user full control of the design process	[Select]
4.2	It produces results that allow easy comparisons	[Select]
4.3	It provides a large range of alternatives to create/assess technologies	[Select]
4.4	The user is informed about the internal processing (e.g. remaining time, log) and warned about potential inconsistencies	[Select]
4.5	The software meets my expectations in terms of results, graphical options, interaction, and functionality	[Select]
4.6	I would recommend the use of this software	[Select]

Comments

[Please add other key points and comments]

5. GENERAL REMARKS

This section aims to record other qualitative aspects not mentioned above.

[Please add any final remarks]

8.4 ENVIRONMENTAL AND SOCIAL ACCEPTANCE (ESA)

Tool – Module: Assessment Design Tool - Environmental and Social Acceptance

Name (user)	
Company	
Date	Pick a delivery date

Instructions

Numeric assessment

Please rate each field in the tables using a scale from 1 to 5, where 1 represents the most negative assessment and 5 the most positive one.

Strongly disagree	Disagree	Undecided	Agree	Strongly Agree
(1)	(2)	(3)	(4)	(5)

Qualitative assessment

Please use the box in each section to add comments, overall experience, or other points that may be useful to record.

1. USABILITY

This section aims to assess the high-level software experience. A Study is a design case of an ocean energy technology that can be independently managed in DTOceanPlus.

ID	Statement	Rating
1.1	The software is intuitive and easy to use in general	[Select]
1.2	It is easy to create and delete a Study	[Select]
1.3	It is easy to edit, save and export a Study	[Select]
1.4	The process of inputting data is clear and efficient	[Select]
1.5	Results are meaningful, easy to interpret and use	[Select]
1.6	I could complete the process without errors	[Select]
1.7	I am satisfied with the overall speed of computation	[Select]
1.8	The software can be run from my computer without any issue	[Select]
1.9	The training sessions and documentation are useful for learning how to use the software	[Select]

Comments

[Please add other key points and comments]

2. USER-FRIENDLINESS

This section aims to assess the user interface of the software.

ID	Statement	Rating
2.1	The user interface is simple, easy to navigate and well-organised	[Select]
2.2	The user interface looks professional	[Select]
2.3	It responds promptly to user actions (inputs, selections, clicks, ...)	[Select]

2.4	It provides the user with enough help, indications and/or guidance throughout each process	[Select]
2.5	The meaning of each data input/user selection is clear	[Select]
2.6	The meaning of each data output is clear	[Select]
2.7	Visualisation of results is clear and informative	[Select]
2.8	The user can add further information to the Study through the interface	[Select]

Comments

[Please add other key points and comments]

3. PERFORMANCE AND ACCURACY

This section aims to assess the quality of results in terms of accuracy, robustness, and performance. A Feature is a main functionality of the software that adds value to the user.

ID	Statement	Rating
3.a.1	Results are robust and not sensitive to small changes of inputs	[Select]
3.a.2	Results are credible and trustworthy for the audience	[Select]
3.a.3	The accuracy of results is acceptable considering the granularity/complexity of data inputs used	[Select]
3.a.4	The accuracy of results corresponds to the user expectation for the stage of technology maturity	[Select]
3.a.5	The computational time is adequate for the level of accuracy provided	[Select]
3.a.6	The software did not suffer from any sort of data shortage/lack of memory during the test	[Select]
3.a.7	The software can handle errors without crashing	[Select]

Comments about Study Management

[Please add other key points and comments]

Comments about Inputs Collection

[Please add other key points and comments]

Comments about Outputs: Endangered species

[Please add other key points and comments]

Comments about Outputs: Environmental Impact Assessment

[Please add other key points and comments]

Comments about Outputs: Carbon Footprint

[Please add other key points and comments]

Comments about Outputs: Social Acceptance

[Please add other key points and comments]

4. VALUE

This section aims to assess the perceived value to the user.

ID	Statement	Rating
4.1	The software allows the user full control of the design process	[Select]
4.2	It produces results that allow easy comparisons	[Select]
4.3	It provides a large range of alternatives to create/assess technologies	[Select]
4.4	The user is informed about the internal processing (e.g. remaining time, log) and warned about potential inconsistencies	[Select]
4.5	The software meets my expectations in terms of results, graphical options, interaction, and functionality	[Select]
4.6	I would recommend the use of this software	[Select]

Comments

[Please add other key points and comments]

5. GENERAL REMARKS

This section aims to record other qualitative aspects not mentioned above.

[Please add any final remarks]

9. ANNEX III: ANONYMOUS FEEDBACK

9.1 SYSTEM PERFORMANCE AND ENERGY YIELD (SPEY)

SCORES

TABLE 9.1: USABILITY OF SPEY

ID	Statement	Response 1	Response 2	Response 3	Response 4	Response 5
1.1	The software is intuitive and easy to use in general	5	4	5	4	4
1.2	It is easy to create and delete a Study	5	4	5	5	5
1.3	It is easy to edit, save and export a Study	5	4	5	4	3
1.4	The process of inputting data is clear and efficient	4	4	5	3	3
1.5	Results are meaningful, easy to interpret and use	3	4	4	4	3
1.6	I could complete the process without errors	4	3	5	5	4
1.7	I am satisfied with the overall speed of computation	5	5	5	5	5
1.8	The software can be run from my computer without any issue	5	4	5	5	5
1.9	The training sessions and documentation are useful for learning how to use the software	5	5	5	5	3

TABLE 9.2: USER-FRIENDLINESS OF SPEY

ID	Statement	Response 1	Response 2	Response 3	Response 4	Response 5
2.1	The user interface is simple, easy to navigate and well-organised	4	4	5	3	4
2.2	The user interface looks professional	2	5	3	4	2
2.3	It responds promptly to user actions (inputs, selections, clicks, ...)	5	5	5	5	3
2.4	It provides the user with enough help, indications and/or guidance throughout each process	3	4	4	3	3
2.5	The meaning of each data input/user selection is clear	4	4	5	3	2
2.6	The meaning of each data output is clear	4	4	5	4	2
2.7	Visualisation of results is clear and informative	2	4	5	4	2
2.8	The user can add further information to the Study through the interface	5	3	4	5	4

TABLE 9.3: PERFORMANCE AND ACCURACY OF SPEY

ID	Statement	Response 1	Response 2	Response 3	Response 4	Response 5
3.1	Results are robust and not sensitive to small changes of inputs	5	4	5	5	4
3.2	Results are credible and trustworthy for the audience	5	2	5	5	3
3.3	The accuracy of results is acceptable considering the granularity/complexity of data inputs used	5	4	5	5	4
3.4	The accuracy of results corresponds to the user expectation for the stage of technology maturity	5	3	5	3	3
3.5	The computational time is adequate for the level of accuracy provided	5	5	5	5	5
3.6	The software did not suffer from any sort of data shortage/lack of memory during the test	5	5	5	5	5
3.7	The software can handle errors without crashing	5	5	5	5	4

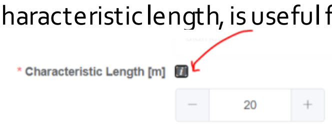
Fully aggregated results have been analysed without differentiating scores between VSs and functionalities. In all cases the average value per statement has been considered.

TABLE 9.4: VALUE OF SPEY

ID	Statement	Response 1	Response 2	Response 3	Response 4	Response 5
4.1	The software allows the user full control of the design process	4	4	5	5	4
4.2	It produces results that allow easy comparisons	2	4	5	5	3
4.3	It provides a large range of alternatives to create/assess technologies	4	4	4	5	4
4.4	The user is informed about the internal processing (e.g. remaining time, log) and warned about potential inconsistencies	3	3	3	5	2
4.5	The software meets my expectations in terms of results, graphical options, interaction, and functionality	4	4	4	4	3
4.6	I would recommend the use of this software	4	4	5	5	3

COMMENTS

TABLE 9.5: COMMENTS FOR SPEY

ID	Section	Feature	Comments
1	Usability	-	After clicking on 'Run', it would be more user friendly to automatically go to results, rather than go back to the menu to view the study results.
2	User-friendliness	-	Very quick and simple to use, input data and navigate each result, however better visualisation of the results would improve the tool. Easy to upload data and export results.
3	Performance & Accuracy	Study Management	Simple, clear, straightforward.
4	Performance & Accuracy	Inputs:Collection	Could be useful to have short description of inputs on the GUI, so the user doesn't need to sift through user manuals /documentation. Like this for characteristic length, is useful for other inputs too: 
5	Performance & Accuracy	Inputs:Collection	The GUI says that a json is required, when I tried to input, it asks for excel. (except for lmo)
6	Performance & Accuracy	Output: Efficiency	No names on the axes of graphs - same for other results with the option to visualise on a graph.
7	Value	-	The results can't be compared with other studies (or reference results), from what I could tell. 4.4 – user is not informed about remaining time etc, but the tool is very fast
8	General remarks	-	The running of the tool was very smooth. With a good understanding of the inputs required, it should be easy to use, and generate meaningful results which can be saved easily. Visualisation could be improved, to enhance user friendliness.
9	Usability	-	You need to finish all input data to save (which is difficult if you don't have json files)
10	Usability	-	There's a small bug, when you delete a project (that is in memory) it brings you with white data when you ask input data or results (keeps id even if it's deleted)
11	User-friendliness	-	On results it would be great having some idea before clicking… (information pop-up Like total amount, mean value or something similar)
12	Performance & Accuracy	Inputs:Collection	Put label on each input data sheet (Machine, site,…)
13	Performance & Accuracy	Inputs:Collection	Allow to save incomplete, especially for json files.

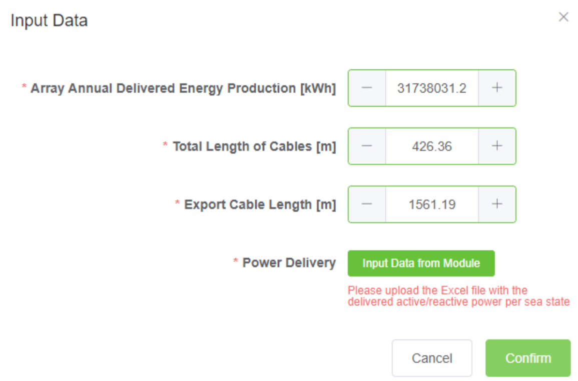
ID	Section	Feature	Comments
14	Performance & Accuracy	Output: Efficiency	Some results regarding efficiency values looks formally not correct: values higher than unity has been obtained in tidal RM1 case "device_rel_transf_eff","value": [0.9991413989213692, 1.0042566395245125, 0.9890573340347277, 0.9957401501444791, 1.0289278396501071, 1.0969628313891415, 1.0044074989254852, 0.9897932418080151, 0.9936548483055834, 1.0005809936453296]
15	Performance & Accuracy	Output: Power quality	From a Grid point of view a power quality parameter could be the array irregularity of produced power (e.g. power variance) and its comparison with single device power irregularity. The reduced power irregularity is beneficial to the energy storage system too.
16	General remarks	-	The overall tool is great. Maybe improving the aspect of the website to make it more professional.
17	Usability	-	The usability is globally very good. Maybe the one small thing that could be quickly improve is to automatically replace "," by "." when writing a number (for example 2,617 to 2.617 directly)
18	Usability	-	Generally, it is very usable, especially the clear lists of results split up into 'Efficiency', 'Alternative Metrics', 'Energy Production' and 'Power Quality' – this was really nice to go between these results and see everything so clearly.
19	Usability	-	Not full marks as there as an option for a study to "Export DR", this is essentially exporting a study, but maybe this is not clear to new users.
20	Usability	-	Additionally, a clearer name for the "Edit" button would probably be better (similar to feedback received for SG module). This is a button for simply editing name and description, and some might think it was edit inputs or something like that.
21	Usability	-	This scored a 3 as there was some duplication of values in the files to be uploaded and values to be typed in by the user. We know the amount of data input required is due to the tool being in Standalone mode and when it's in Integrated mode this would not be as lengthy a process. Relative to other modules, the input requirements are quite low.
22	Usability	-	I think the results are easy to interpret because of the pop-up information buttons which are very helpful. Without these, I think the tool would be very hard to understand.

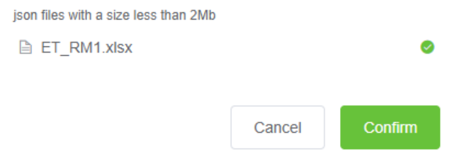
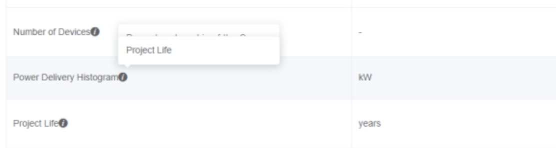
ID	Section	Feature	Comments
23	Usability	-	It would be good to add temporary loading screens while the back-end is finishing calling the routes. Particularly useful for some of the results pages that can take a small bit longer to load. Loading/computation speeds are very good, but often the 'skeleton' of the GUI page is shown and then, soon after, it "refreshes" with the actual data. Loading screens could be used to solve this easily. https://element.eleme.io/#/en-US/component/loading
24	Usability	-	The training was very good and set me up well to run the verification, in particular the demonstrations of the tool
25	User-friendliness	-	I found it very well organised, but I would say some more informative 'Introduction' to the tool would be useful e.g. A summary of the tool, what it aims to achieve and why the results are useful.
26	User-friendliness	-	As with comments on 2.1, more guidance and help bars would be welcome. For example, an introductory section on would be beneficial, as would a pop-up screen for each page of the GUI just advising the user where to start or what each page is concerned with
27	User-friendliness	-	The meaning of the data was clear but I think this is because I have seen a demonstration of the tool twice before. I don't know if it would be as intuitive to someone for the first time, but this could be addressed by the comment above – by having a clearer Introduction to the tool.
28	User-friendliness	-	Yes, with the pop-up Information buttons being critical to this
29	User-friendliness	-	Visualisation is mostly good. A couple of minor bugs (see section 3) and the formatting and labels of axes in graphs could be tidied up. Lots of unlabelled figures at the moment, e.g. monthly x-axis plots that have numbers as ticks representing months.
30	Performance & Accuracy	Study Management	Tested sensitivity of efficiency metrics to minor changes in the inputs and the accuracy was as expected

ID	Section	Feature	Comments
31	Performance & Accuracy	Study Management	Since there was no option to select a Complexity Level, it would be better if it is clear to the user that the tool can run without all of the inputs. For example, the Station Keeping module has kept the complexity levels, but for the lower levels some of the inputs are hidden since the tool can run without them. We know SPEY never intended to have complexity levels, but it needs to be clear that the tool can run with different amounts of inputs. If even two complexity levels were available then this would keep consistency with the other modules – for example: Cpx_1: Module just asks for SC and MC inputs CPx_2: All inputs are required Alternatively, make sure 'Optional' and 'Required' are labelled next to each of the inputs and the user can provide as much or as little as they like to the SPEY module. It is not absolutely essential for SPEY to have a complexity level dropdown, but if Deployment modules all use complexity level 1 as the inputs to SPEY, then it should be clear that it is 'complexity 1' for SPEY that is being run (If this is the case).
32	Performance & Accuracy	Inputs:Collection	Typo in error message "you must complete at <u>lest</u> MC and SC à at <u>least</u>"
33	Performance & Accuracy	Inputs:Collection	The explanatory text column on the Input Selection screen could be clearer. To me, the options are a) provide user defined inputs or b) use a module study in integrated mode. So if you are doing the User Defined routes, there should not be a reference to another module study. As such, I suggest changing wording from "Not defined MC study" to "MC inputs have not been defined". Also change "*The selected MC study is* User-Defined" to "The MC inputs are user-defined". For the integrated case, you can use something like "The MC inputs from Study X have been selected".
34	Performance & Accuracy	Inputs:Collection	The header of the input dialog boxes should be specific to the tab. I.e. if you are inputting the MC inputs, the dialog box header should be "Machine Characterisation inputs", not "Input data".
35	Performance & Accuracy	Inputs:Collection	[already implemented] Improve labelling of "Run" and "Update" buttons. Was expecting to have to click "Update" to update the inputs and then click "Run" to run the analysis again. But this is not the case. Suggest updating the button labels to clarify.
36	Performance & Accuracy	Output: Efficiency	Most columns have an empty View column – I wondered if these would always be empty or if there are plans to fill this in? Either way I think it's OK – perhaps in the empty ones it could say "No charts available for this metric" so the user doesn't think there is something wrong or missing.

ID	Section	Feature	Comments
37	Performance & Accuracy	Output: Efficiency	For the graphs that are available, labelled axes (with units included where applicable) would be better
38	Performance & Accuracy	Outputs: Alternative Metrics	These are great! Very useful for the user. Same comment applies on labelled axes as not all of them had labels, especially the x axis.
39	Performance & Accuracy	Outputs: Alternative Metrics	Being able to switch between 'array' and 'device' level is very useful – great feature!
40	Performance & Accuracy	Outputs: Power Quality	I think the table could be clearer – for example I think I'm looking at the years as the columns but this could be labelled more clearly
41	Performance & Accuracy	Outputs: Power Quality	Typo: Power Quality tab >>> Device Transfomerd energy phase >>> should be transformed
42	Performance & Accuracy	Outputs: Power Quality	The Device Transformed energy phase graph is really nice, but should have better labels. E.g. use "Device 1, Device 2" (or whatever it is) rather than "Element 1, Element 2" in the legend.
43	Performance & Accuracy	Energy Production	Too many decimal places on the energy values e.g. 6951735.568265123
44	Performance & Accuracy	Energy Production	Years are labelled clearly here which is good.
45	Performance & Accuracy	Energy Production	In 'Device Monthly Net Energy Ratio' (all device monthly parameters, in fact); there is a bug when opening any of the nested results. Weird "isRootInsert", "elm" and/or "undefined" added to table
46	Value	-	We gave this a 5 since SPEY does not restrict the user in their design, and is open enough to accept a range of technologies, therefore the user has control over their design.
47	Value	-	Absolutely. For instance, the alternative metrics go above and beyond the expected range of outputs.
48	Value	-	I didn't witness any information on processing time, but perhaps this wasn't necessary
49	Value	-	Once the graphs are formatted correctly, the tabular and graphical results will be excellent. Right now, they just need some tidying up. This is my reason for scoring a 4 and not a 5
50	General remarks	-	The tool looks great and is fairly intuitive to use. The GUI is nicely presented, especially the opening page.
51	General remarks	-	As mentioned in the comments, I'd like to see either different complexity levels in the tool with less inputs for a lower level of complexity OR it's very clear which inputs are 'Optional' and which are 'Required'

ID	Section	Feature	Comments
52	General remarks	-	Formatting of numbers; use thousand separators in number inputs (eg. 219,370 rather than 219370) and round to appropriate significant figures. At the moment, far too many significant figures in most numeric results
53	General remarks	-	Formatting; on all results pages, for the parameters... include a space between name of parameter and information button
54	General remarks	-	Excellent error checking and validation; this is really good. For instance, making sure number of devices input by the user lines up with values specified in Excel or input JSON files. Or, not being able to run the tool unless MC and SC are completed. All this input validation is really beneficial, with good feedback to the user as to why actions cannot be performed.
55	General remarks	-	[already implemented] On the results page, the "Inputs" tab should be below the "Outputs" tab and the default tab that is shown when results page is loaded should be the outputs. Clearer to the user. Inputs are additional information, outputs are what the user really wants to see when clicking "outputs".
56	Usability	-	I expected the Edit button not to allow to edit only the study name, but the study itself, while the "Open" button allow to edit the study. Maybe this could be adjusted.
57	Usability	-	The json format is not something I am familiar with, thus the option to save results with this format was not of particular interest for me
58	Usability	-	Maybe manipulating a slider could be better than the +/- buttons, adding 1 unit per click. Adapting the steps to the expected values/range of values could be good (1000 unit steps when the input magnitude is expected to be around 50000 for exemple)
59	Usability	-	It could be useful to provide the user with a preprocessing tool to help formatting inputs into a json format, or the Excel file format which is required for the inputs provided by the other modules when in a standalone use, with more guidance for each subtable of the Excel files (in case this standalone use should really be used by end-users in some cases).
60	Usability	-	I hope training material such as the ones we had for Stage Gate and Structured Innovation tools would be available to public, it helped me save a lot of time, though the training session was helpful.
61	User-friendliness	-	I didn't find useful to display the Current SpeyId.
62	User-friendliness	-	The error message when providing a file which is not an XLSX file is "File must be XSLX format!".

ID	Section	Feature	Comments
63	User-friendliness	-	I found a lot a typo errors (probably due to lack of time to fix it.
64	User-friendliness	-	Maybe the information sign ('i' in a black circle) could be displayed somewhere else in the results section, I did not find this really aesthetical to have it following the parameter name.
65	User-friendliness	-	I filled the inputs, confirmed, then removed the values and confirmed again, came back to this window (the inputs where there), but I could not confirm (the button did not work) and quit this ED windows, I had to cancel (which had the same effect as values were kept in memory). Maybe this is a bug. Note in the illustration below that the Excel file had been kept in memory, thus the error message is weird. I could not change the Excel file, as it accepted the file in the drop box, but I could not confirm in the ED window. 
66	User-friendliness	-	In a general manner, I would appreciate way more description of what is intended as inputs for Excel tables required by the tool (maybe this is not really important as the SPEY tool is not really intended to be used in a standalone version?).
67	User-friendliness	-	When clicking on the button which opens the windows where user provides inputs, there is no indication of the module being filled, and maybe it could be more user-friendly to have something like 'Input Data : Energy Delivery' at the top of this window. It could be flagged in this window to the user that a xlsx file has been read and accepted by the tool.
68	User-friendliness	-	The red asterisks could be supplemented with an explanation that the section to be filled is mandatory (even if an error message prevent from clicking on the "Confirm" button).

ID	Section	Feature	Comments
69	User-friendliness	-	I could launch the study without providing all the elements, but I would appreciate to be aware of what inputs I provided and what I didn't (for example I launched the study without filling the Excel file for the EC module – well, I think-, but it was never explained to me if it would change or not the results, and no message came to indicate that such input was missing). Maybe it was kept in memory, but just not displayed in the window in the way it is below (because I was pretty sure to have previously dropped the file in the box, and maybe I ran a study before witnessing there were no file displayed under the box, maybe it changes this information): 
70	User-friendliness	-	Maybe a progression bar with the fraction of information provided by the user over what is expected by the tool, for each section (MC, SC, EC,…) could be useful, as well as guidance regarding the risks of running the tool with incomplete information for these sections. Nonetheless, the inputs are summarized in the Results section, which helps to identify what is missing.
71	User-friendliness	-	I had this bug when passing with my cursor on the help for Power Delivery Histogram: 
72	User-friendliness	-	InputSelection/Machine characterisation: I found input definition too much oriented towards wave energy. Once telling I will do a tidal study, I would find more interesting to only input rotor diameter instead of wet area and characteristic length (I can't understand if wet area is used for tidal device ?). Why is wet area different from 400 m^2 ?

ID	Section	Feature	Comments
73	User-friendliness	-	InputSelection/Site characterization: Unit for the first input is kW/m^2, the square has been forgotten. Maybe removing Annual Average Flux Wave and Monthly Wave Scatter Diagram could be better than shading it. Indication 'json files with a size less than 2Mb' under the file drop box may be misleading, as people may think only this file format is accepted. This section does not emit any warning or error message if the user puts into it more than one file, or if the format cannot be processed. When running without filling ED and LMO section, I had the weird message 'November'.
74	User-friendliness	-	Maybe a lot of work could be done on data visualization, because the current proposition is not really professional (e.g. some dropdown menus could be added to make it more user-friendly, instead of the [...], splitting the big array in multiple subarrays sorted by parameter categories, ...)
75	User-friendliness	-	Some tables are really hard to read, a cut in the decimal part could help, and in some case, the "View" column is empty
76	User-friendliness	-	In every table we access from the previous one clicking on [...], we get the following ones, with the two last lines with weird outputs: 13 254951.176916933 14 254951.176916933 15 254951.176916933 16 254951.176916933 17 248097.6506557251 18 254951.176916933 19 254951.176916933 20 254951.176916933 isRootInsert elm undefined
77	User-friendliness	-	Maybe it could be useful to adapt the tools that can be used to visualize the plot (ex : zoom, lasso selection...) to the data to be plotted (e.g. all the zoom options for data relative to monthly data are not really useful)
78	User-friendliness	-	Adding axis legends would help a lot
79	Performance & Accuracy	Output: Efficiency	It is hard to assess the meaning trustworthiness of results, because a number of inputs were not totally clear to me, in the way they were defined in the Excel files

9.2 SYSTEM LIFETIME COSTS (SLC)

SCORES

TABLE 9.6: USABILITY OF SLC

ID	Statement	Response 1	Response 2	Response 3	Response 4	Response 5	Response 6
1.1	The software is intuitive and easy to use in general	4	4	4	4	5	4
1.2	It is easy to create and delete a Study	4	5	5	4	5	5
1.3	It is easy to edit, save and export a Study	4	3	3	3	4	4
1.4	The process of inputting data is clear and efficient	3	3	4	4	3	5
1.5	Results are meaningful, easy to interpret and use	3	3	3	3	4	5
1.6	I could complete the process without errors	3	5	5	3	5	5
1.7	I am satisfied with the overall speed of computation	4	5	5	4	5	5
1.8	The software can be run from my computer without any issue	3	5	5	4	5	5
1.9	The training sessions and documentation are useful for learning how to use the software	4	3	4	3	4	5

TABLE 9.7: USER-FRIENDLINESS OF SLC

ID	Statement	Response 1	Response 2	Response 3	Response 4	Response 5	Response 6
2.1	The user interface is simple, easy to navigate and well-organised	4	3	4	4	4	5
2.2	The user interface looks professional	3	2	5	3	4	5
2.3	It responds promptly to user actions (inputs, selections, clicks, ...)	3	5	3	2	2	5
2.4	It provides the user with enough help, indications and/or guidance throughout each process	3	2	3	2	3	4
2.5	The meaning of each data input/user selection is clear	4	2	4	3	4	5
2.6	The meaning of each data output is clear	3	4	4	3	2	5
2.7	Visualisation of results is clear and informative	3	3	4	1	3	4
2.8	The user can add further information to the Study through the interface	3	1	3	3	4	4

TABLE 9.8: PERFORMANCE AND ACCURACY OF SLC

ID	Statement	Response 1	Response 2	Response 3	Response 4	Response 5	Response 6
3.1	Results are robust and not sensitive to small changes of inputs	4	5	5	3	4	5
3.2	Results are credible and trustworthy for the audience	4	3	5	3	5	5
3.3	The accuracy of results is acceptable considering the granularity/complexity of data inputs used	4	4	5	3	4	4
3.4	The accuracy of results corresponds to the user expectation for the stage of technology maturity	4	5	5	3	4	5
3.5	The computational time is adequate for the level of accuracy provided	5	5	5	3	5	5
3.6	The software did not suffer from any sort of data shortage/lack of memory during the test	4	2	5	3	5	5
3.7	The software can handle errors without crashing	4	3	4	3	5	5

Fully aggregated results have been analysed without differentiating scores between VSs and functionalities. In all cases the average value per statement has been considered.

TABLE 9.9: VALUE OF SLC

ID	Statement	Response 1	Response 2	Response 3	Response 4	Response 5	Response 6
4.1	The software allows the user full control of the design process	-	5	4	3	4	5
4.2	It produces results that allow easy comparisons	4	2	3	4	4	5
4.3	It provides a large range of alternatives to create/assess technologies	4	-	2	3	4	5
4.4	The user is informed about the internal processing (e.g. remaining time, log) and warned about potential inconsistencies	2	1	1	3	3	2
4.5	The software meets my expectations in terms of results, graphical options, interaction, and functionality	3	3	4	3	4	4
4.6	I would recommend the use of this software	4	5	5	4	4	5

COMMENTS

TABLE 9.10: COMMENTS FOR SLC

ID	Feature	Subject	Comments
1	General comments	Left Panel	Left-hand panel is not intuitive. What does the Projects tab meant to do?
2	General comments	Initial page	Change title "Please Enter Details below to start SLC Project"
3	General comments	Initial page	Change levels of complexity from low/medium/high to 1/2/3
4	General comments	Initial page	Open/Edit study terminologies is confusing. Change (maybe use the one from ED or SG)
5	General comments	All pages	All numerical values should have 1000 separators (results and inputs)
6	General comments	All pages	Sometimes unresponsive "view" buttons, which sometimes needs clicking multiple times
7	General comments	All pages	Review capitalisation of the heading is a bit mixed
8	Usability	-	Implement progress bar (which would follow in every page, not just the first)
9	Usability	-	Create feedback messages after pressing validate button to warn user that everything went ok or not
10	Usability	-	If is any problem with the inputs a generic 'problem computing results' message appears briefly, but there is not explanation of the error or steps to fix it, which is a serious flaw
11	Usability	-	Warning messages to warn user in case of missing data (which inputs are missing)
12	Usability	-	Create less generic/more personalized error messages when introducing wrong input files (instead of just problem computing result)
13	Usability	-	Had issues as mentioned above with clicks registering
14	Performance & Accuracy	Functionalities	Currently, not easy to compare against other studies/projects. Add the option to do this?
15	Performance & Accuracy	Functionalities	Having an option to export the study (Excel/CSV) and generate a pdf report will add value to the tool. According to verifiers, excel is better than json
16	Performance & Accuracy	Functionalities	Implement export study option
17	Performance & Accuracy	Functionalities	Implement export DR option
18	Performance & Accuracy	Input page	Change button name from "Validate"
19	Performance & Accuracy	Input page	Change buttons in input page to "view/edit"
20	Performance & Accuracy	All inputs	It would also be nice to have the scope to add in a contingecy on top of the other cost elements to deal with optimism bias etc.
21	Performance & Accuracy	All inputs	Maybe manipulating a slider could be better than the +/- buttons, adding 1 unit per click.
22	Performance & Accuracy	All inputs	Adapting the steps to the expected values/range of values could be good (100 unit steps when the input magnitude is expected to be around 1000 for exemple).

ID	Feature	Subject	Comments
23	Performance & Accuracy	All inputs	Create pop-up button with further information about each input (e.g. FIT, FIT years, typical ranges of discount rate). Would be good to describe how it will probably affect the results
24	Performance & Accuracy	All inputs	The option to add further information ot the study through the interface is not available (e.g. commentary box with source of data)
25	Performance & Accuracy	All inputs	Show filled inputs in red or green depending whether they have been filled or not (or other type of indication)
26	Performance & Accuracy	All inputs	Adding more devices: If I change VS1VC1 to have 5 devices, the LCOE goes up rather than down. I presume this is because the total capex gets increased slightly from the extra devices, but the AEP and other inputs from files don't change, but this is not clear
27	Performance & Accuracy	General inputs	Introduce other "annual costs".
28	Performance & Accuracy	Financial inputs	Financial metrics: If I add a 100M€ grant to VS1VC1, it gives a Pay-back Period: -1.0 years. I'm not sure negative years make sense
29	Performance & Accuracy	Financial inputs	Difficulty in introducing decimal values "0.05" in the FIT and market price and surface thickness entry boxes.
30	Performance & Accuracy	Financial inputs	FIT moves in €1 and it should be lower (increments of 0.1/0.01)
31	Performance & Accuracy	Financial inputs	FIT /market price inputs are not clear to non-expert people
32	Performance & Accuracy	Financial inputs	When entering grant value, would be nice if it could be formatted to show thousands (as it is easy to add wrong number of zeros in 100M€)
33	Performance & Accuracy	Financial inputs	I cannot change the financial inputs to remove a FIT (by setting it to zero), tried this when adding a grant
34	Performance & Accuracy	ACE inputs	Change surface thickness increments to 0.01m
35	Performance & Accuracy	ACE inputs	Not clear how this is valuable for Tidal developers
36	Performance & Accuracy	Economic inputs	Describe what device structural costs include (pto?...)
37	Performance & Accuracy	Economic inputs	Reformat grant value to show thousands (it's easy to add the wrong number of zeros)
38	Performance & Accuracy	Economic inputs	Plant lifetime (20 years) cannot be modified because the AEP is a fixed input and it is not re-evaluated by modifying number of years.
39	Performance & Accuracy	Economic inputs	Lock input of project lifetime in case AEP is introduced? Otherwise request avg. AEP?
40	Performance & Accuracy	External inputs	Allow user to edit/update individual external files after having left the External input page
41	Performance & Accuracy	External inputs	If I don't input the files, I get an error message that disappears quite quickly 'problem computing results', this needs to be more descriptive of what went wrong and needs to be fixed, and not disappear.

ID	Feature	Subject	Comments
42	Performance & Accuracy	Results page	The result pages need a bit more formatting, the top headers should be frozen when scrolling down the page.
43	Performance & Accuracy	Results page	Group results as they look disjointed, joint them? Presenting results in tabs instead of in different pages (like LMO)
44	Performance & Accuracy	Results page	In the report page, it is worth also displaying the complexity level, below the Name of the study & description
45	Performance & Accuracy	Results page	I am not sure the results need to be split up on 4 pages, having a separate page for the 4 financial metrics particularly.
46	Performance & Accuracy	Results page	It would be good if some way to visualise the financial metrics, and comparison to the benchmarks, but maybe this is still to be added
47	Performance & Accuracy	All results	Represent results graphically (e.g. payback time, cashflows, ...)
48	Performance & Accuracy	All results	Introduce contextual messages (Negative NPV, means that project is not profitable)
49	Performance & Accuracy	All results	Provide guidance on how to interpret the results and the 'What next question'.
50	Performance & Accuracy	All results	Present results (economic and financial) as tables instead of text.
51	Performance & Accuracy	All results	Output readability: separation between the thousands separator but not the million (e.g. unit costs)
52	Performance & Accuracy	Economic results	Provide feedback/guidance about what next? How could these values be improved?
53	Performance & Accuracy	Bill of Materials	Introduce sub-totals and grand totals in the Bill of Materials
54	Performance & Accuracy	Bill of Materials	The tables should look neater, data formatted, title text not truncated
55	Performance & Accuracy	Bill of Materials	Frozen top row (for visibility when scrolling)
56	Performance & Accuracy	Bill of Materials	Unit of Measurement column doesn't seem correct (device total cost- N/A?)
57	Performance & Accuracy	Bill of Materials	Formatting of larger number- use of 1000 separators might be useful
58	Performance & Accuracy	Bill of Materials	Omit parameters that will not be shown at CPX1
59	Performance & Accuracy	Bill of Materials	Option to export BOM
60	Performance & Accuracy	Bill of Materials	Consistency needed using CAPEX or CapEx, same for OPEX
61	Performance & Accuracy	Bill of Materials	Remove "bouncing animation" in BOM outputs as it moves buttons
62	Performance & Accuracy	Bill of Materials	The format of top header with the title of each result (e.g ID, Name, Quantity, etc) does not seem to maintain a size of the text. An example is "category" in the shown screenshot
63	Performance & Accuracy	Bill of Materials	The combined Project Bill of Materials has entries for total ET system etc, I think this should be spelt

ID	Feature	Subject	Comments
			out in full. I would also expect there to be a column to give a value for this rather than just n/a.
64	Performance & Accuracy	Bill of Materials	The bill of materials is missing sub and grand totals
65	Performance & Accuracy	Financial results	Do not allow payback periods to have negative values (in case of an extreme grant)
66	Performance & Accuracy	Financial results	At some point the thousands also become harder to read. Change units depending on how large the value is?
67	Performance & Accuracy	Financial results	Presenting outputs in table format might be neater
68	Performance & Accuracy	Financial results	Contextual help might be useful here. (e.g. NPV - 80.8million, so what does that tell the user….) so guidance into the 'So what" or "What to do next"
69	Performance & Accuracy	Financial results	Remove decimals when showing millions
70	Performance & Accuracy	Financial results	Present graph of cashflows (income vs. Expenses) with payback times
71	Performance & Accuracy	Benchmarking	Project stage option disabled
72	Performance & Accuracy	Benchmarking	Cost over LCOE do not sum to 100% (99.9%) (due to rounding errors)
73	Performance & Accuracy	Benchmarking	Introduce cake charts for composition of costs over LCOE
74	Performance & Accuracy	Benchmarking	could really benefit from some formatting to make results clearer, at moment very hard to follow as just text on white background
75	Performance & Accuracy	Input spreadsheet	The Spreadsheet provided could use the same terminology as the tool to avoid confusion
76	Performance & Accuracy	Input spreadsheet	Where some of the data are uploaded as files (e.g. BOM of ED), it's also worth making clear in the Spreadsheet that the data provided as just for reference as already inputted in the files.

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

SCORES

TABLE 9.11: USABILITY OF RAMS

ID	Statement	Response 1	Response 2	Response 3	Response 4	Response 5	Response 6
1.1	The software is intuitive and easy to use in general	5	4	5	4	4	4
1.2	It is easy to create and delete a Study	5	4	5	5	5	5
1.3	It is easy to edit, save and export a Study	4	3	5	4	4	5
1.4	The process of inputting data is clear and efficient	3	3	5	4	2	4
1.5	Results are meaningful, easy to interpret and use	4	3	3	4	3	4
1.6	I could complete the process without errors	5	4	5	4	4	5
1.7	I am satisfied with the overall speed of computation	5	4	5	4	3	5
1.8	The software can be run from my computer without any issue	5	4	5	4	4	5
1.9	The training sessions and documentation are useful for learning how to use the software	5	4	5	4	4	4

TABLE 9.12: USER-FRIENDLINESS OF RAMS

ID	Statement	Response 1	Response 2	Response 3	Response 4	Response 5	Response 6
2.1	The user interface is simple, easy to navigate and well-organised	5	4	5	4	4	4
2.2	The user interface looks professional	3	3	5	3	2	4
2.3	It responds promptly to user actions (inputs, selections, clicks, …)	5	4	5	3	3	5
2.4	It provides the user with enough help, indications and/or guidance throughout each process	4	2	5	2	2	4
2.5	The meaning of each data input/user selection is clear	4	3	4	2	2	4
2.6	The meaning of each data output is clear	4	3	4	2	4	4
2.7	Visualisation of results is clear and informative	4	3	5	4	2	4
2.8	The user can add further information to the Study through the interface	3	3	4	3	3	4

TABLE 9.13: PERFORMANCE AND ACCURACY OF RAMS

ID	Statement	Response 1	Response 2	Response 3	Response 4	Response 5	Response 6
3.1	Results are robust and not sensitive to small changes of inputs	4	4	5	3	4	4
3.2	Results are credible and trustworthy for the audience	4	4	3	3	3	4
3.3	The accuracy of results is acceptable considering the granularity/complexity of data inputs used	4	4	4	4	4	4
3.4	The accuracy of results corresponds to the user expectation for the stage of technology maturity	4	4	3	3	4	3
3.5	The computational time is adequate for the level of accuracy provided	5	4	5	4	4	5
3.6	The software did not suffer from any sort of data shortage/lack of memory during the test	5	4	5	4	3	5
3.7	The software can handle errors without crashing	5	4	5	4	4	5

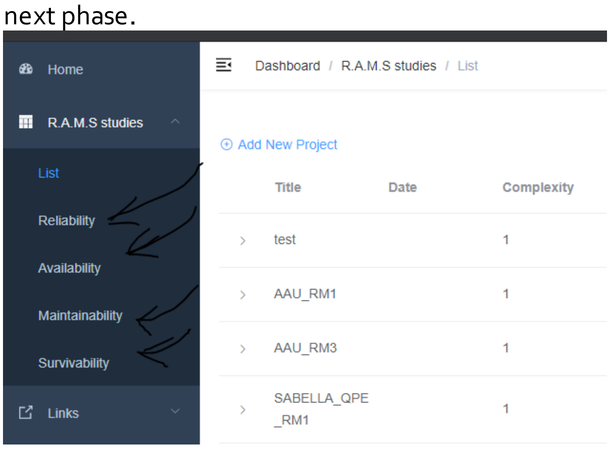
Fully aggregated results have been analysed without differentiating scores between VSs and functionalities. In all cases the average value per statement has been considered.

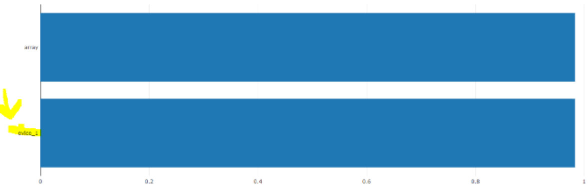
TABLE 9.14: VALUE OF RAMS

ID	Statement	Response 1	Response 2	Response 3	Response 4	Response 5	Response 6
4.1	The software allows the user full control of the design process	4	2	**4**	3	2	4
4.2	It produces results that allow easy comparisons	3	3	**5**	4	4	1
4.3	It provides a large range of alternatives to create/assess technologies	4	2	**4**	3	3	3
4.4	The user is informed about the internal processing (e.g. remaining time, log) and warned about potential inconsistencies	5	3	**5**	4	2	4
4.5	The software meets my expectations in terms of results, graphical options, interaction, and functionality	5	3	**3**	4	3	3
4.6	I would recommend the use of this software	5	4	**5**	4	3	4

COMMENTS

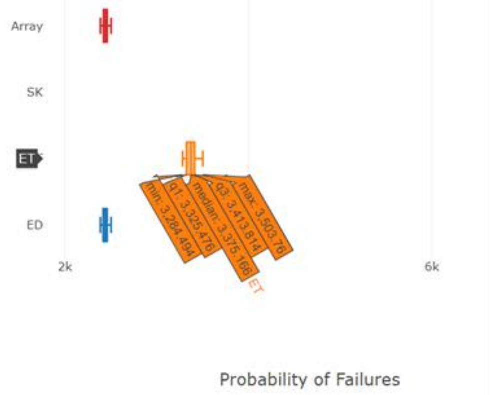
TABLE 9.15: COMMENTS FOR RAMS

ID	Feature	Subject	Comments
1	Usability	Creating/editing a new study	Possibly change the "installation lifespan" term to something like project lifetime? Also I was surprised that this was asked so early (immediately when creating the study).
2	Usability	Creating/editing a new study	The line breaks in this window are a bit weird. Can everything be place in the same line, by reducing the size of the input boxes?
3	Usability	Project list view	There is a "Date" column which does not have any entries.
4	Usability	Project list view	I'm not sure what the Status column means.
5	Usability	Project list view	I'm not sure this is a problem but I'm not sure if you are aware of this. Right now the user is allowed to click on one of the metrics on the left panel and randomly enter a study. I can see this possibly causing problems, such as editing studies unintentionally because they were not required to click the correct study name to move to the next phase. 
6	Usability	Reliability section	I really like the file inputting experience (side bar). However, I did not understand how a file can be deleted.
7	Usability	Reliability section	Error message when introducing the wrong hierarchy in the wrong place (e.g. ET instead of ED) is a really nice to have, but would be great if it could be more explicative (wrong file format?)
8	Usability	Reliability section	Tried to introduce two files at once and it gave an explicative error message. Nice.
9	Usability	Reliability section	When introducing a file that I had previously introduced, is the module replacing from the database one file for the other? If so, a message saying this should be produced.
10	Usability	Reliability section	A persistence message (that the user must click ok) could be shown to the user after running the calculations, because it's not clear when they are done (maybe a message was temporarily shown but I was looking elsewhere and did not notice).
11	Usability	Reliability section	The "help"/information buttons are a really nice feature. Good job.

ID	Feature	Subject	Comments
12	Usability	Reliability section	I'm assuming the array category includes the failures of all components? Maybe mention this somewhere in the help buttons?
13	Usability	Reliability section	You mention that the number of simulations should be around 5 for testing purposes. Do you have an idea of how many it would be expected in normal running conditions? 100? 1000?
14	Usability	Reliability section	One of the PTOs (RM1 cpx1, DEV_0_PTO_1_0_Mech/Elec/Grid) does not have data entries? Why is that? Why is the max_ttf "-1"? I would expect it to be -1 in case of no failure occurring.
15	Usability	Reliability section	Number of Simulations. Also, in that "i button" it's written Montecarlo instead of Monte Carlo
16	Usability	Reliability section	I really enjoyed how you're presenting the Time to Failure plot. Please add horizontal axis label (Time to failure in hours).
17	Usability	Availability	Name of device is partially hidden? 
18	Usability	Maintainability section	I was surprised that the Available Time is requested from the user. I thought this would only happen for cpx1 but for cpx3 it also does. Shouldn't it use the LMO maintenance outputs (which include operation durations)?
19	Usability	Maintainability section	Will reference values/suggestions be shown to the user? It's hard to understand whether inputs of available time, probability distribution and standard dev are realistic.
20	Usability	Survivability	The warning message about the expected duration is a nice addon.
21	Usability	Survivability	Progress bar of computation would be nice
22	Usability	Survivability	Normalise capitalization of variable description (Inside FLS inputs)
23	Usability	Survivability	I suggest also writing the full names instead of just the acronyms ULS and FLS
24	Usability	Survivability	The "expert inputs" look very expert.
25	Usability	Survivability	Write covariance instead of COV? Provide assistance towards this parameter?
26	Usability	Survivability	System survivability (FLS) did not show a critical component id ever
27	Usability	General	It was not clear to me what changes from CPX1 to CPX3 in RAMS. Maybe I would suggest hiding the "expert inputs" in the maintainability section of the survivability page, as it will probably be too complex for a simple user in cpx1?

ID	Feature	Subject	Comments
28	Usability	General	Is the project duration affecting anything else other than the Maintainability parameter? What happens if the user introduces an input file from LMO with 20 years but when creating a new study, he introduced a different number of years?
29	Usability	-	Generally, the software is intuitive, however it would also be more intuitive if the input and output displays are distinguished via colour coded or separated panel.
30	Usability	-	I did not find the functionality to export the study.
31	Usability	-	In the standalone mode, the json format is very hard to use for newcomers. Ways to make the step of inputting data easier could be: move from json to Excel files, add a feature in the GUI to create a Fault Tree with simple buttons to add levels, choose the OR or AND gate, add the properties for components, etc… that would make this task easy for people who won't read D6.3. The same could be done about survivability inputs for the system.
32	Usability	-	The underlying assumption about reliability is a design life of 20 years, which should be reminded to the user so that the Probability of Failure is explained or change the title for the Figure to "Probability of Failures at 20 years". It could be useful to add the curve of PoF of failure against time (Figure 5.1 to 5.3 in D6.3). For the graphical representation of the result, it would be helpful if the unit of time to failure is displayed. Other graphics also need to display the unit. For the component reliability, the decimal value can be rounded up to reasonable decimal value.
33	Usability	-	One of the users encountered few errors, but mostly due to misunderstanding about the data input.
34	Usability	-	The software is usable in its current form, given inputs it produces results.
35	Usability	-	The user-friendliness of the interface needs some work.
36	Usability	-	The software is very easy and straightforward to use.
37	Usability	-	The process of inputting data is not very clear because I didn't have much knowledge on the input data and on the expected results using those data.
38	Usability	-	Great having an estimation of calculation time (less than a minute even when asks for 2-5 minutes)
39	Usability	-	No graphical results on Reliability (even going out and re-entering)
40	User-Friendliness	-	Introducing data would be easier if it was more obvious that a file was previously uploaded (maybe make the input buttons turn green when it's ok?).
41	User-Friendliness	-	Maybe it was just me, but I was surprised it is not considering LMO operation durations for calculating the maintainability.
42	User-Friendliness	-	Minor changes of formatting, writing words in full etc., will give a professional look.

ID	Feature	Subject	Comments
43	User-Friendliness	-	Persistent warning message when computations have been calculated is important, especially for tools with long computation times.
44	User-Friendliness	-	Help button is a nice decision, but some inputs are not obvious.
45	User-Friendliness	-	Maybe buttons to directly access the previous or next section could be useful.
46	User-Friendliness	-	I liked to have an input summary, but the format could be made more readable (trees, figures, charts?). In particular: 
47	User-Friendliness	-	The processing indication in the top right corner stays rolling even if new case already uploaded.
48	User-Friendliness	-	D6.3 was essential to understand how to provide inputs, "how-to"s with mentions to precise sections in this report would be valuable, in particular to §5. Examples and Annexes.
49	User-Friendliness	-	A help panel could be useful for each tool to sum up the major step and calculations led in each section
50	User-Friendliness	-	Guidance on how many runs (or rule of thumbs to estimate it) for the Monte-Carlo simulations would be great
51	User-Friendliness	-	Assumptions relative to default values should be clearly expressed in the GUI to the user (assumed design life, repair periods…)

ID	Feature	Subject	Comments
52	User-Friendliness	-	In the Maintainability section, maybe adding a single sentence with "the probability that the component would be replaced in Available Time hours is …" could help, as I found Maintainability expressed in a probability format not really clear (maybe change for e.g. probability of success for maintenance operation). Maybe showing how this value is used in subsequent calculation to the user (whether it is used as input for availability to get the values for downtime) could be great.
53	User-Friendliness	-	In the Maintainability section, displaying the formula for the probability distribution function adjusted with data provided by the user could be helpful.
54	User-Friendliness	-	In the Survivability section, adding reference to formula in D6.3 could be great. A figure showing values
55	User-Friendliness	-	I did not find clear why average waiting time is required for the reliability calculations, as the only reference to it in D6.3 is related to availability (for downtime calculations) and maintainability, as included in Time To Repair. I found this confusing.
56	User-Friendliness	-	Survivability expressed as a number is not really clear to me.
57	User-Friendliness	-	Results for Availability are not friendly to access 
58	User-Friendliness	-	System availability could be presented under another format, I found bars not really informative, as there were only two - identical - values to show.
59	User-Friendliness	-	Lack of information displayed online to be able to run the software without a guide.
60	User-Friendliness	-	The user inputs reset between changing tabs, can lead to mistakes.
61	User-Friendliness	-	Display the current status in the page (waiting inputs, computing step/evolution, finished), the brief popups are easy to miss.
62	User-Friendliness	-	The plots are nice, but there is no way to visualise and export the numerical results.
63	User-Friendliness	-	Need more detail in the meaning of the output variables.
64	User-Friendliness	-	The user interface could look more professional, but it is very user-friendly.

ID	Feature	Subject	Comments
65	User-Friendliness	-	Some descriptive examples of the input data would be better to illustrate what is looked for and required. Some indication of how inputs are likely to affect the outputs would also be useful to show how sensitive the outputs are to inputs.
66	User-Friendliness	-	Input data are difficult to be opened and accessed: difficulty to change input values.
67	User-Friendliness	-	Sometimes, the information is the lower part of the page (you have to go to look it). No big issue.
68	User-Friendliness	-	Some difficulties to read results. The axes of graphs have no title nor unit of measures (e.g. reliability graph abscissa). An explanation of acronyms (SK,ED..) should be provided for sake of everybody usability.
69	User-Friendliness	-	Tables collecting the results would be useful.
70	Performance & Accuracy	Reliability assessment	Given that the user has not tried the simulation with significant number of cycles, at the moment it is not possible to evaluate the accuracy of the simulation, and a real time to compute the results via a Monte-Carlo analysis.
71	Performance & Accuracy	Reliability assessment	The computation times and responsiveness are adequate.
72	Performance & Accuracy	Reliability assessment	We are not experts enough in the domain to evaluate the accuracy of the results.
73	Performance & Accuracy	Outputs	The outputs should be presented having a limit of decimal places, that could be 2. Components Reliability Energy Delivery Energy Transformation Station Keeping id mttf 0 1952.462258625032 1 1615.5088852988692
74	Performance & Accuracy	Reliability assessment	Too many decimals in the results.
75	Performance & Accuracy	Survivability assessment	Please add an explanation about results: 1=survive, 0=do not survive?
76	Performance & Accuracy	Outputs	Identifiers should be explained in some way: DEV_0_PTO_0_0_MechT what the zero stand for? Energy transformation: max_ttf=-1 what is the meaning of this?
77	Performance & Accuracy	Outputs	Add Unit of measures to numbers and graph axis
78	Value	-	Not easy to compare different studies.
79	Value	-	Would expect to use LMO operation duration outputs for availability.
80	Value	-	The design life is assumed to be 20 years for reliability, 10 for availability, which designers would like to adapt to their needs, eventually having multiple design lives if multiple technologies are used in a single farm

ID	Feature	Subject	Comments
81	Value	-	Parameters in the Survivability section are referring to moored systems, which may sound confusing when designing fixed tidal turbines
82	Value	-	Maybe adding the possibility to add a reliability target (0.001 as given in IEC 62600-2, or other values), and displaying to the user if the constraint is respected for the project
83	Value	-	In D6.3, relative to maintainability, it is written that "it is assumed that the design lifetime is 10 years, because the input of downtime only represents 10 years". It would be great to have design life as an input parameter in GUI, and to allow the user to provide a table under an Excel file (with guidance shown to the user about the format to adopt) with the number of columns equal to the design life.
84	Value	-	Indications on how much of the calculation has been done (for reliability, as the status of calculations is not displayed, and the user is still allowed to manipulate inputs, manipulation which may be prevented so that the user keeps control on inputs and avoid wrong manipulations).
85	Value	-	With regards to value of the tool, the Monte Carlo simulation is used only for reliability estimation. It is not enough for RAMS evaluation. In the context of evaluating tidal turbine, where maintenance access is difficult and costly (i.e. it is one of the most important factors in decision making), it will be more useful if the Monte Carlo simulation is also run for availability estimation (which seems not to be the case, but as the interactions with LMO are complex, maybe we did not understand what calculations are led in integrated mode, adding guidance about it could be great). A complete availability Monte Carlo simulation will be able to provide us with: • Availability both in terms of time and production level, considering the weather windows impact, marine current cycle, failure rate, and time to repair. • Total expected numbers of failure for the simulated project duration. This information is important for design evaluation and project economics estimation. We were expecting the various RAMS tools to interact with each other, for example use a Monte-Carlo simulation to figure out downtime in Availability. Indeed, in some other commercial tools, values provided as inputs to Availability are results from Monte-Carlo simulations, thus we found it surprising to provide it as inputs.
86	Value	-	Useful tool for the DTOceanPLUS suite but need some work in the interface.

ID	Feature	Subject	Comments
87	Value	-	The comparison between studies didn't look direct, the user must collect the results independently and then compare them.
88	Value	-	Increase the text information, mainly on results: which is the meaning of the number we see and some reference values to compare results.
89	General Remarks	-	The comments in this form are made with respect to the standalone inputs, outputs, functionalities, etc... and average marks would be higher regarding inputs formatting, and guidance for the integrated software, as there would be far less inputs coming from the user, and more coming from the other tools. We understand that investing time in the standalone version to make it more user-friendly would not have been the best thing to do for developers at the time of release. Nonetheless, we considered ourselves as users for the standalone version of RAMS, willing to lead our own study, and marks are given accordingly.
90	General Remarks	-	The software looks very consistent and robust.

9.4 ENVIRONMENTAL AND SOCIAL ACCEPTANCE (ESA)

SCORES

TABLE 9.16: USABILITY OF ESA

ID	Statement	Response 1	Response 2	Response 3	Response 4	Response 5	Response 6
1.1	The software is intuitive and easy to use in general	4	4	5	3	4	-
1.2	It is easy to create and delete a Study	3	3	4	5	4	-
1.3	It is easy to edit, save and export a Study	3	4	5	5	4	-
1.4	The process of inputting data is clear and efficient	4	4	4	3	4	-
1.5	Results are meaningful, easy to interpret and use	4	3	4	5	4	-
1.6	I could complete the process without errors	4	5	5	4	4	-
1.7	I am satisfied with the overall speed of computation	4	5	5	5	5	-
1.8	The software can be run from my computer without any issue	4	2	5	5	5	-
1.9	The training sessions and documentation are useful for learning how to use the software	2	5	5	5	3	-

TABLE 9.17: USER-FRIENDLINESS OF ESA

ID	Statement	Response 1	Response 2	Response 3	Response 4	Response 5	Response 6
2.1	The user interface is simple, easy to navigate and well-organised	4	4	5	5	5	5
2.2	The user interface looks professional	2	3	5	4	5	5
2.3	It responds promptly to user actions (inputs, selections, clicks, …)	4	2	5	5	4	5
2.4	It provides the user with enough help, indications and/or guidance throughout each process	2	3	2	2	3	5
2.5	The meaning of each data input/user selection is clear	3	3	2	3	3	5
2.6	The meaning of each data output is clear	3	4	2	3	4	5
2.7	Visualisation of results is clear and informative	4	4	5	4	4	5
2.8	The user can add further information to the Study through the interface	3	3	5	3	3	3

TABLE 9.18: PERFORMANCE AND ACCURACY OF ESA

ID	Statement	Response 1	Response 2	Response 3	Response 4	Response 5	Response 6
3.1	Results are robust and not sensitive to small changes of inputs	3	4	5	4	4	5
3.2	Results are credible and trustworthy for the audience	4	4	5	5	5	4
3.3	The accuracy of results is acceptable considering the granularity/complexity of data inputs used	4	5	5	5	5	5
3.4	The accuracy of results corresponds to the user expectation for the stage of technology maturity	4	4	5	5	5	5
3.5	The computational time is adequate for the level of accuracy provided	5	5	5	5	4	5
3.6	The software did not suffer from any sort of data shortage/lack of memory during the test	5	5	5	5	5	5
3.7	The software can handle errors without crashing	3	5	5	5	5	3

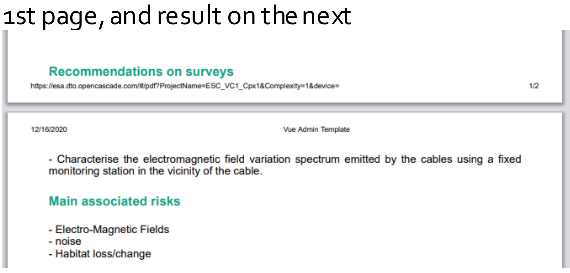
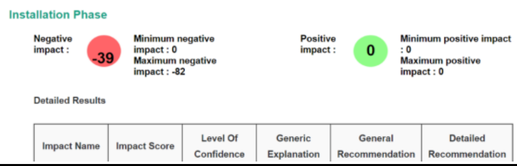
Fully aggregated results have been analysed without differentiating scores between VSs and functionalities. In all cases the average value per statement has been considered.

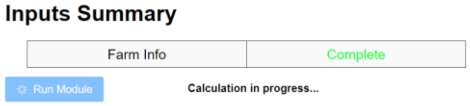
TABLE 9.19: VALUE OF ESA

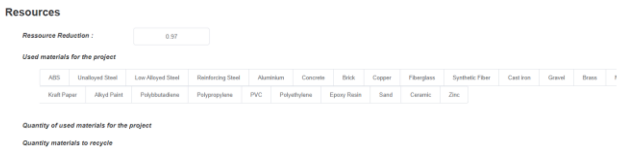
ID	Statement	Response 1	Response 2	Response 3	Response 4	Response 5	Response 6
4.1	The software allows the user full control of the design process	3	3	5	3	4	5
4.2	It produces results that allow easy comparisons	4	5	5	5	5	5
4.3	It provides a large range of alternatives to create/assess technologies	3	4	5	3	4	4
4.4	The user is informed about the internal processing (e.g. remaining time, log) and warned about potential inconsistencies	3	2	5	3	3	3
4.5	The software meets my expectations in terms of results, graphical options, interaction, and functionality	4	4	5	4	4	5
4.6	I would recommend the use of this software	4	4	5	5	4	5

COMMENTS

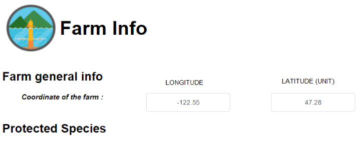
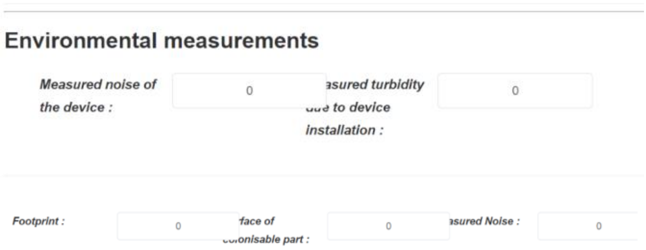
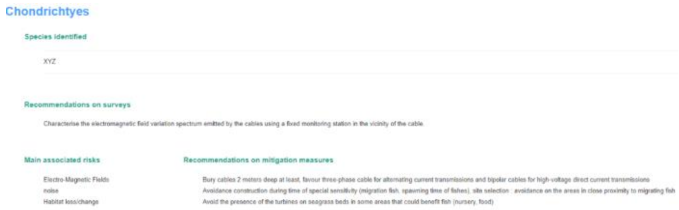
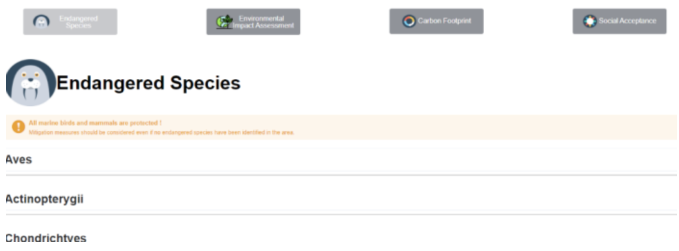
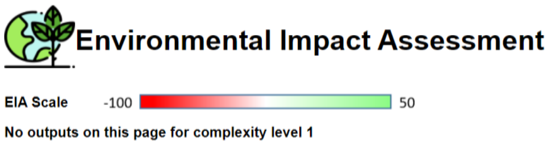
TABLE 9.20: COMMENTS FOR ESA

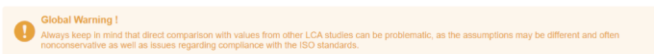
ID	Feature	Subject	Comments
1	General comments	Welcome Page	Looks clean and professional. Could you remove the text in the picture since there is already a title to the page "Welcome to the Environmental and Social Acceptance module"? Could you also remove the exclamation mark (!)? Not sure what it adds
2	General comments	ESA Home Page	The icons look a bit blurry (the create new project and load project) A contextual description will be needed here in my opinion: What is the tool about and what should they expect as outputs.  The exported report could possibly include the inputs of the user – Longitude/latitude/ site data, etc… Is there a way to ensure that the title of the section is on the next page of the report here? Like providing section breaks in MS Word? Refer example provided below- title of section on 1st page, and result on the next  Is it worth having the DTOcean+ in the header of the exported report as well?
3	General comments	Autosave option	I see the tool has a save/save as option top-right, but are the data autosaved as the user clicks "Next"? Or will they lose the data if they close the page? Formatting (Font style/ size) could be reduced to fit in 1 line. In the example below, Min negative impact: or could be on one line, same as the rest 
4	General comments	Formatting of numbers	worth reviewing this to only show 2 decimals after the 0 where relevant
5	General comments	-	The side nav bar has a hover option for 'Run Module' but there is no icon. There is just an empty space.
6	General comments	Export results to PDF	Export results to PDF: The PDF looks very clear and professional

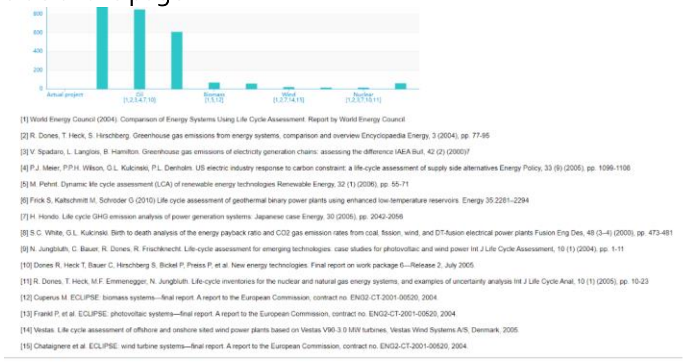
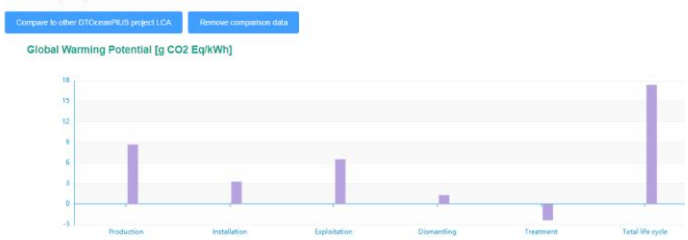
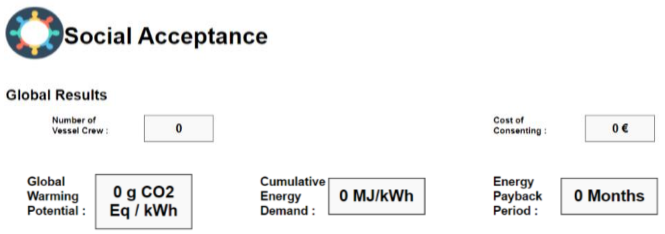
ID	Feature	Subject	Comments
7	Usability	Inputs: Collection	Fairly intuitive, I would suggest letting the user enter the name of the study when they are defining the complexity level and standalone/integrated mode Once the site data have been entered, it is not very intuitive what the user has to do- the next page is the input summary page like the one below. This page could use some contextual guidance to let the user know to go to the device info tab next on the left-hand side pane.  Note- I am not sure if the server is down or not, but this screen was loading for over a minute. I was able to click on 'Device info' tab while this was still loading
8	Usability	Inputs: Collection	Easy to create/delete or view (input/results).
9	Usability	Inputs: Collection	Easy to edit and export study. In the Load project section- I really like how well presented the existing projects are and the clear "Modify input", "View results".
10	Usability	Inputs: Collection	For VC1-cpx1 it was not as obvious to know if the lat/long were the only data required to run the ESA. I had to check on the Left-hand side tabs to see that the other input data were not required at cpx1. It might be worth having a prompt on the main screen (central page).
11	Usability	Inputs: Collection	The results are clear and easy to interpret.
12	Usability	Inputs: Collection	Error/ Continuous loading page kept loading after I selected 'Run Module', probably a glitch with the server, because once I refreshed the page, I lost the study and restarted.
13	Usability	-	The overall usability is good, but it could be worthwhile adding some help functionality to make the walkthrough easier.
14	Usability	-	Could also add the 'Previous page' button on the same line as the 'Next page' button just to make navigation faster.
15	Usability	-	Once the user has reached the Inputs Summary page, there doesn't seem to be a way to go back and change inputs. Does the user then have to restart the whole procedure?
16	Usability	-	I sometimes had issues to have to correct home page:  Maybe this was due to an issue with the server? Maybe asking for confirmation before deleting a study could be good.
19	Usability	-	Create Project: When a project is created, there should be a 'Name' option straight away, instead of having to click on 'Save as' to name it which isn't intuitive
20	Usability	-	It's very good that data is saved when you click between pages and you don't lose the data

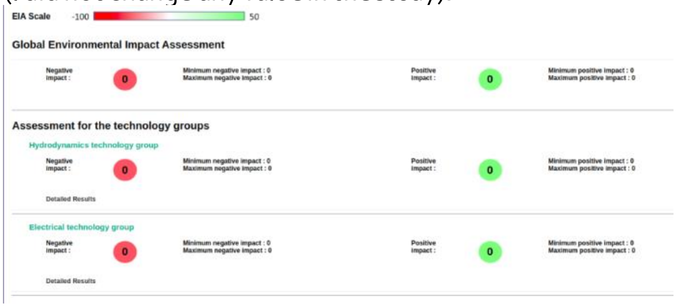
ID	Feature	Subject	Comments
21	Usability	-	Some more explanation of what the parameters mean in the GUI would be useful
22	Usability	-	The EIA results are not explained until you click "Detailed Results' which is not an easy button to find – it would be good to have more explanation of the numbers in the actual GUI
23	Usability	-	Software was pretty straight forward to use, relatively intuitive to fill out. There was no guidance as to what the level of complexity would refer to, and also able to proceed to next stage with not fully filling out the forms. The training session was good and informative but there was a lack of description in the documentation, it was also formatted such that not very easy to follow. Would have been helpful to have had notes saying that there is no data to input for certain options and explaining the ramifications or what the difference in output would be if no data put in.
24	User-Friendliness	-	Neat, simple and easy to navigate
25	User-Friendliness	-	User guidance/ help is missing. Although the tool is clear, it does not give much help or contextual description if required. Although the units are provided as you hover over the cells. I wonder if this will be obvious to all the users.
26	User-Friendliness	-	Input are clear mostly, in VC2 (RM3 loaded project) this 'resource' section where the quantity of used materials for the project and Quantity materials to recycle is blank. Is that mean there are none? Not so sure if none or sub section missing? 
27	User-Friendliness	-	Results are clear and well-presented especially in VC2 where the top bar shows the 4 tabs referring to each output section. This was not available in VC1 (complexity 1)
28	User-Friendliness	-	The user is only able to add information to the relevant text/data field but no additional comments. No commentary boxes available.
29	User-Friendliness	-	The software is easy to move through. It is very user friendly and the results are well thought out. There could maybe be a bit more information as the user is inputting the data.
30	User-Friendliness	-	It took many minutes for the Next Page button to let me access the "Electrical Info" page. Maybe this was due to an issue in the server.

ID	Feature	Subject	Comments
31	User-Friendliness	-	Maybe information on how the Zone type (open water, sea loch entrance or sounds) is used in analysis could be useful, as well as device dimensions (as it is set to 0 for the RM1_ESA case, but the module is able to run). I did not find clear why footprint, colonisable part and measured noise were not to be provided for the substation. Maybe information on how the fuel consumption is used in analysis could be useful, as I would expect to provide some more information on the vessel type for marine operations (it is likely that large variations occurs in greenhouse emissions between the various vessel technologies, though fuel consumption provides a reasonable rough estimate).
32	User-Friendliness	-	Distinction between highly toxic antifouling and moderate antifouling was not very clear to me, maybe some more guidance could be great, and more generally, how this data is supposed to be processed in the analysis, maybe simply by referring to a section in a deliverable or training material.
33	User-Friendliness	-	The EIA scale is probably the best solution to present such qualitative data and compare studies, but the scores are not very easy to understand for someone who did not took time reading training materials and deliverables, and it may require further guidance. I would say the same about Minimum negative/positive impact, and the Level of Confidence, how it is calculated. It could be useful to give the user the ability to define his own ranking between criteria with various weight. Maybe the following titles could be changed to more precise ones: Assessment of the pressure, Hydrodynamics, Electrical and Station Keeping "technology groups" "Collision Risk" and "Collision Risk Vessel" could be further detailed and distinguished. To give recommendations in the EIA section is a good idea and adds value, but the two columns "General recommendations" and "Detailed recommendations" are giving the same information, a column may be removed.
34	User-Friendliness	-	More guidance and explanations required for the user to understand the language used within the tool. e.g. Farm Info: Hover over info buttons are OK – but [DD] meaning decimal degrees isn't intuitive. Labelling the boxes with permanent labels would work better.
35	User-Friendliness	-	More explanation of outputs in the GUI would be helpful
36	User-Friendliness	-	There is a certain clunkiness to the interface, could do with some better formatting to make look more professional. There could do with some more description as to what the expected inputs might be.

ID	Feature	Subject	Comments
37	Performance and Accuracy	Inputs: Collection	Farm general Info: Coordinate of the farm: not intuitive what these are until, I hovered over the cells. Might be worth adding on top of the Longitude/latitude field the 'title' like shown below: 
38	Performance and Accuracy	Inputs: Collection	VC3- RM1 (loaded project): There are typos to correct in the Used materials section: Polybutadiene When I display this section on my big screen - no issue with resolution but on the laptop screen the text seem to overlap (screenshot below) 
39	Performance and Accuracy	Outputs: Endangered species	Where the results are clear and well displayed, I wonder if the formatting of a table like this can be amended to ensure texts is within the same cell size as the tile column 
40	Performance and Accuracy	Outputs: Endangered species	VC2-RM3: The top bar with the tab for each output section is now visible in this example but was not visible in VC1 at complexity 1. Please check for consistency. 
41	Performance and Accuracy	Outputs: Environmental Impact Assessment	VC1- Low complexity: Clear and straightforward. Might be worth adding an explanation if say EIA Scale is say -15 or -25 what does that mean? 

ID	Feature	Subject	Comments
42	Performance and Accuracy	Outputs: Environmental Impact Assessment	VC2 - RM3 - It is hard for me to interpret the results of the EIA assessment. So, I am told that: Global EIA is -30 Negative impact, and +5 positive impact, what does that tells me? And are there actions/ suggestions that should be provided to the user. No details provided so really hard to know what to do next. Hydrodynamic tech group: clearer with the detailed results table explaining what this the score means. One comment on the Detailed results table- the Level of confidence is it out of 10? Or 5? A legend is needed to clarify. I like how you can expand/collapse each sub section and results table. Electrical technology group: Is an impact score of 0 good? Or should the developer still aim to increase it? Worth adding contextual guidance to support user. Underwater noise section general/specific recommendation: "Use specific technical XXX to reduce imperatively the noise..." is a word missing there? Technical what? EMF should a glossary be provided for abbreviations? Station Keeping group: I think there is an issue with the formatting of the score here (check figure below), also the maximum impact have over 10 decimal values 10.011937908 
43	Performance and Accuracy	Outputs: Carbon Footprint	VC1 - Low complexity: No output as expected at complexity 1
44	Performance and Accuracy	Outputs: Carbon Footprint	VC2 - RM3 project: Really neat display of GWP, CED, and Payback value. I feel this tile Compare with other technologies/energies should be amended to maybe other energy sources/ WEC technologies. If you are going to use abbreviation GWP/EPP, are you able to add them in brackets first.
45	Performance and Accuracy	Outputs: Carbon Footprint	VC2 - RM3 project: Warnings: great to have this warning for the user. Worth explaining what LCA stand for and the ISO standards and assumptions made in this study - maybe directing the user to the help guide. 

ID	Feature	Subject	Comments
46	Performance and Accuracy	Outputs: Carbon Footprint	VC2 - RM3 project: The references are taking a big chunk of the page. I think they should definitely be moved to a pop-up window or add a help section that can be expanded/collapsed on the Right-hand side of the page. 
47	Performance and Accuracy	Outputs: Carbon Footprint	VC2 - RM3 project: Is the comparison doing what it's meant to do? It seems only the other study is displayed and nothing about the current study. Is it because the current study has 0 GWP for everything? Some indication is needed to know that. 
48	Performance and Accuracy	Outputs: Social Acceptance	VC1- Low complexity: No output as expected at complexity 1
49	Performance and Accuracy	Outputs: Social Acceptance	VC2-RM3 Are these values zero because the inputs were not provided or because this are the correct results of the analysis? Seem strange to have 0 cost of consenting and 0 number of vessel crew. A contextual guidance could explain to the user what the results mean 
50	Performance and Accuracy	Inputs Collection	It is very easy inputting data but they may be some room for adding a small help function or example pop up so a user can understand what they are putting in. There was also a nice hover over function showing units. May be worthwhile looking into having a small box.

ID	Feature	Subject	Comments
51	Performance and Accuracy	Outputs: Endangered species	The results for the endangered species are good and clear. There could be a change in the message colour that appears (use success variable in bootstrap) instead to highlight to the user that everything is clear.
52	Performance and Accuracy	Outputs: Environmental Impact Assessment	I like the range of images and positive space to highlight information as this avoids the user being bombarded with loads of text and numbers.
53	Performance and Accuracy	Outputs: Carbon Footprint	The carbon footprint tab is very clean and sophisticated. I like the space between the graphs so the user can fully analyse the data without an overload. There is also the nice hover over effect to give exact figures.
54	Performance and Accuracy	Outputs: Social Acceptance	Design is very clean.
55	Performance and Accuracy	Outputs: Environmental Impact Assessment	I could not obtain the same results as the reference case RM1_ESA for this section, though I had all sections completed (I did not change any value in the study):  Scores could be rounded to unity (Minimum positive impact: 10.01428576481154).
56	Performance and Accuracy	Outputs: Carbon Footprint	I could not visualize the results for the RM3 case. Maybe the results for the various sources/stages of emissions/energy consumption could be presented in a pie chart. I would find interesting to find a way to show sensitivity of results to a single parameter (e.g. in the results page for carbon footprint, being allowed to select installation emissions due to fuel consumption, and being given the information that changing the current value for fuel consumption to a new one will modify total greenhouse emissions for the project by X %). The graph with the Energy Payback Period is not really useful as it only displays a single value.
57	Performance and Accuracy	Outputs: Social Acceptance	The two informations provided in this section were not relevant, I was expecting the number of jobs created by the project to include many others aspects than the only marine operations, and the cost of consenting (56 euros) was not really representing what I was expecting to find.
58	Performance and Accuracy	Study Management	An indication along the top banner which project you're in would be helpful. The ability to make new versions of a study when running the module is very useful. The fact that complexity 1 has less inputs is great.

ID	Feature	Subject	Comments
59	Performance and Accuracy	Inputs Collection	Zone type: 'Sea loch entrance' and 'sounds' were unexpected as the descriptions as they are colloquial – this naming could be better. We would have expected to see 'Open water' or 'At shore' for example. Initial State: There should be definitions for each parameter e.g. 'Turbidity' – explanation of what these terms mean. Fishing Regulation: There could be an explanation of what the terms 'complete prohibition' etc mean – maybe a hover over button? Receptors: 'Particular Habitat' – not clear if the months selected are the times that the habitat is in danger? Does blue mean it's selected? Device Info: The Device locations are in units of UTM here but they were in DD at the beginning – mismatch in units. Resource Reduction: This could use more explanation There is a typo in "Ressource". Used materials for the project: It's good that as you add more materials, the info appears below. Very clear and intuitive to use. Materials for foundations: More hover over explanation of the materials here. Electrical Info: Colonisable surface area of the electrical components – added explanation needed. Logistics Info: The 'Mean Size of Vessels' would be better to have types of vessels like Tug Boat etc rather than exact length in meters. Typo: Comsumption should be Consumption. 'Exploitations' should be 'Maintenance' instead. Inputs Summary: Should be "Incomplete' rather than "Uncomplete".
60	Performance and Accuracy	Outputs: Endangered species	Endangered species: This is laid out very well and is nice and clear – also good pictures. Probability of presence was 999 – not clear what units this is?
61	Performance and Accuracy	Outputs: Environmental Impact Assessment	Environmental Impact Assessment: The ranges of minimum and maximum impact don't explain where this came from. The results are not explained until you click "Detailed Results' which is not an easy button to find – it would be good to have more explanation of the numbers in the actual GUI
62	Performance and Accuracy	Outputs: Carbon Footprint	Carbon footprint: 'Actual project' is a confusing label – it should be 'current project' or have the actual name of the project as the user named it. The references could be hidden behind a "Show references" button in order to not take away from the main outputs. The graphs and benchmarking are great and very clear, good to have the ability to compare projects.
63	Performance and Accuracy	Outputs: Social Acceptance	Social Acceptance: This page is not as detailed as the other pages.

ID	Feature	Subject	Comments
64	Performance and Accuracy	Outputs: Environmental Impact Assessment	The presence of harmful or toxic substances contained in the wec such as: lube oil, hydraulic oil or other and relevant risk of leakage or spill. This aspect could be linked to FMEA and evaluated environmental risk.
65	Performance and Accuracy	Outputs: Social Acceptance	The visual impact could be an important matter in those sites where the skyline changes would raise problems for local communities and tourism attraction.
66	Value	-	Help/guidance might be helpful.
67	Value	-	The user is given the choice to run the tool at different levels of complexity and the user is able to run the tool without having to specify all the different materials required.
68	Value	-	The user is not informed about the internal processing however, there is a clear indication of list of input sections and output sections.
69	Value	-	The software should have more contextual description and help/ glossary, etc.
70	Value	-	There is a lot to be gained from this software. It is very clean which adds to the user value and produces results in a sophisticated manner, so the user is not overloaded. The use of images and icons presents a much more easy on the eye feel and it is quicker to interpret the data.
71	Value	-	Regarding resource used and associated environmental impact, I would appreciate to be given the possibility to add materials, and their characteristics, or edit current characteristics, in case I can provide more accurate values for the specific material/process.
72	Value	-	In general, the tool is very useful and easy to use – the complexity levels have been defined with different inputs which is great. The ability to compare benchmark results is a great feature.

CONTACT DETAILS

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